

4.2
Edition

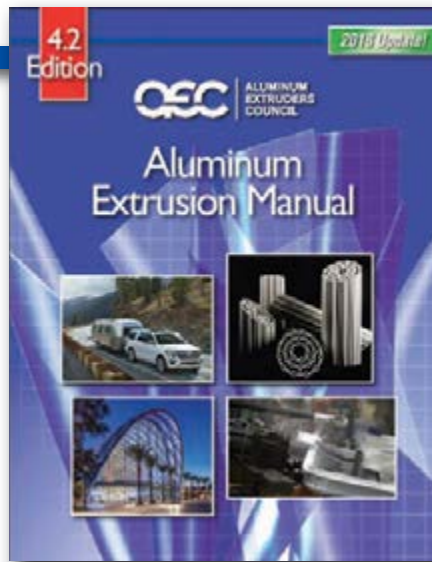
2018 Update!



ALUMINUM
EXTRUDERS
COUNCIL

Aluminum Extrusion Manual





This Manual presents aluminum as the material of choice, and extrusion as the process of choice, for countless product applications. Further enhanced by the many value-added services provided by extruders, aluminum profiles offer unique freedom in product design.

To make the Manual more valuable, many of the most used tables, charts, and other industry references are included, or web links to these resources are provided. Source publications are cited where applicable and, of course, retain their authoritative characteristics.

ACKNOWLEDGEMENT

The Aluminum Extrusion Manual, 4.2 edition, is produced by the Aluminum Extruders Council with the direction and assistance of dedicated volunteers. The work of many devoted individuals and the support of their respective companies led to the development and update of this Manual. Without their dedicated efforts this undertaking could not have been realized.

ABOUT AEC

The Aluminum Extruders Council (AEC) is an international trade association dedicated to advancing the effective use of aluminum extrusion in North America. AEC is committed to bringing comprehensive information about extrusion's characteristics, applications, environmental benefits, design and technology to users, product designers, engineers and the academic community.

Further, AEC is focused on enhancing the ability of its members to meet the emerging demands of the market through sharing knowledge and best practices. Specialized educational conferences, seminars, workshops, webinars and meetings throughout the year provide an outlet where AEC members can confront and solve today's challenges.

More than 100 member companies represent aluminum extruders operating hundreds of extrusion presses in hundreds of plants worldwide, along with primary aluminum producers and other industry suppliers.

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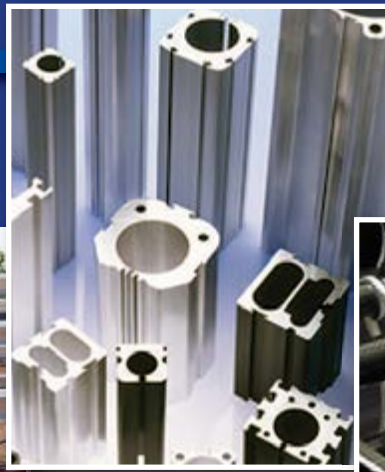


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Aluminum Extrusion Manual

The *Aluminum Extrusion Manual* presents aluminum as the Green Material of Choice. Aluminum's inherent "green" features of recyclability and sustainability, coupled with its other unique attributes, makes aluminum a versatile material for many applications. But the exciting story of aluminum doesn't stop there. The ability to extrude aluminum into complex shapes (profiles) gives designers creative freedom. Where the environment, time, cost and process repeatability are the important parameters, aluminum extrusions offer a material and process choice that is literally second to none for countless product applications.

The sections of this Manual are laid out in a manner that makes the *Aluminum Extrusion Manual* the "go to" reference guide for users and producers of aluminum extrusions alike. The *Aluminum Extrusion Manual* begins with an in-depth discussion of aluminum extrusion's material and process advantages as compared to other materials and other forming processes. For many end-use applications the ability to extrude a net shape meets the end-use application, but where further fabrication and/or finishing may prove beneficial, aluminum extrusions offer clear advantages. Able to be finished by mechanical treatment, by coating or by anodizing, the range of finishes that extrusions can achieve is extraordinary.

The *Aluminum Extrusion Manual* has been prepared by the Aluminum Extruders Council as a reference guide to stimulate the design imagination and offer designers the technical information needed to assist them in their efforts. Many of the industry's most-used Tables, Charts, and Standard References are included in the Extrusion Manual.

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Section

I

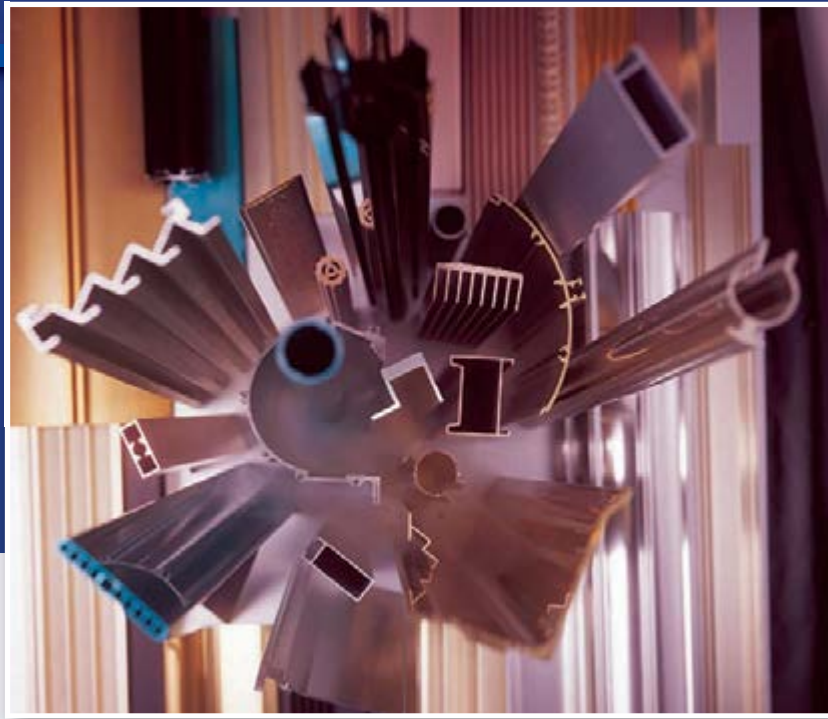
Advantages of Aluminum Extrusions



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Aluminum Extrusion
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Section I



Advantages of Aluminum Extrusions

Aluminum extrusions (or profiles) have continuously demonstrated to be as superior in performance, reliability, and efficiency for a variety of markets—from consumer durables to transportation and from electronics to building and construction. Where time, cost, and process repeatability are important parameters to the designer, aluminum extrusions offer advantages unmatched by other materials and processes.

Today's designers are able to work with an abundance of materials including aluminum, steel, copper, plastic resins, and composites, as well as an abundance of processes including roll forming, stampings, castings, powdered metal, injection molding, and plastic resin extrusion. Each material and process offers distinctive performance criteria for the designer. For many applications, aluminum—and specifically the aluminum extrusion process—offers performance criteria exceeding those of alternative materials and processes.

Advantages for Designers

The ability of the designer to utilize a near-net shape process to close tolerances, coupled with a list of superior physical characteristics, aluminum extrusion offers unsurpassed advantages. Aluminum's inherent advantages, including light weight, high strength-to-weight ratio, formability, finishability and machinability, together with the process advantages of extrusion, offer freedom and versatility to designers.

In terms of form, fit, function, appearance, and cost, aluminum extrusions are second to none. Aluminum profiles offer a long list of advantages: first, those inherent in aluminum and second, those gained from the extrusion process.



Photo courtesy of Naturalite Skylight Systems by The Vistawall Group. Photographer: Wes Thompson.

ALUMINUM'S MATERIAL ADVANTAGES:

- Recyclable
- Lightweight
- Strong
- High Strength-to-Weight Ratio
- Resilient
- Corrosion-Resistant
- Thermally Conductive
- Non-Toxic
- Reflective
- Electrically Conductive
- Nonmagnetic
- Nonsparking
- Noncombustible
- Cryogenically Strong

ALUMINUM EXTRUSION'S PROCESS ADVANTAGES:

- Attractive
- Wide Range of Finishes
- Virtually Seamless
- Complex Integral Shapes
- Fastening and Assembly
- Joinable
- Fabrication
- Tolerancing
- Cost-Effective
- Short Lead Times

Material Advantages of Aluminum

Aluminum has numerous design advantages, both in terms of physical and chemical characteristics.

Aluminum Is Recyclable

Aluminum is fully, and repeatedly, recyclable. Aluminum can be recycled over and over without any degradation or loss of its innate characteristics. This well known and documented feature maximizes efficiency. For many products, where product life has a limitation (such as applications in the transportation and consumer durables markets), aluminum's recyclability—along with its other attributes—can make it a superior material choice compared with other materials. Aluminum has significant scrap value, making it not only environmentally friendly because of recyclability, but cost effective as well. Recycled aluminum takes only five percent of the energy necessary to produce virgin aluminum. Aluminum need not be a part of landfills.



Photo courtesy of Fisker Automotive.

This aluminum space frame for the extended-range electric Fisker Karma sedan helps the vehicle to surpass the 2025 fuel economy target under the Corporate Average Fuel Economy standards (CAFE) set by the U.S. government.

It has been estimated that 70 to 75 percent of all aluminum ever produced is still in use today.



For more on aluminum recycling and sustainability, go to the Sustainability section in this manual.

Aluminum is Lightweight

Weighing approximately one-third as much as steel, iron, brass, or copper, aluminum's lightweight characteristic has made it desirable within such markets as transportation and consumer durables. Aluminum profiles' light weight advantage translates into fuel efficiency, product portability, and economical shipping costs.



Truck trailers (above) and rail transit cars (below) made of aluminum save fuel costs by reducing weight.



Lightweight aluminum is ideal for use in sporting equipment to help with portability and hold down freight costs.

Lightweight aluminum power tools are durable, but easy to handle.



Aluminum is Strong

Appropriately alloyed, aluminum's ultimate tensiles can reach as high as 90,000 PSI, approaching those of steel. As a result, there are many structural applications of aluminum. Where formability is more important than strength, aluminum can be alloyed for much lower ultimate tensile. Low, medium or high strength, aluminum offers design flexibility.



This aluminum walkway system, designed to be cantilevered from the existing bridge structure, provides suitable walkway/bicycle paths. Aluminum's high strength is just one of the reasons extruded aluminum was used for this structural application.

Photo courtesy of MAADI Group.



This profile represents the cross-section of an all-aluminum highway median barrier. Designed for use on narrow roadways, the multi-piece assembly can be split and used as a bridge parapet. A comparable steel structure would weigh more than twice as much; a traditional concrete barrier is five times as heavy, yet this aluminum barrier is strong enough to do the job.

MATERIAL	Modulus, E P.S.I.
Mild Steel	29.0
Aluminum	10.0
Brass	13.0
Zinc	13.0
Plastics:	
PS	0.51
PET	0.29
Nylon	0.42
Peek	0.56

Aluminum Offers a High Strength-to-Weight Ratio

Combining aluminum's characteristics of light weight and strength produces a ratio (ultimate tensile divided by density) unmatched by any other economical material. Applications such as fitness and sports equipment, appliances, and the transportation market utilize aluminum for this very beneficial feature.



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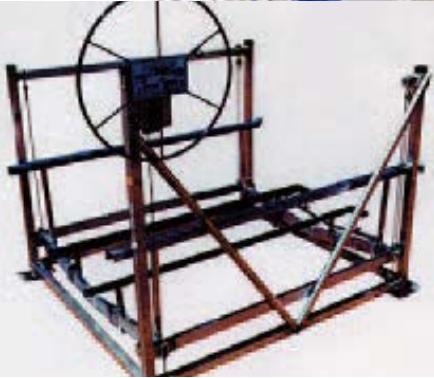


Corrosion-resistant stadium seating may be exposed to the elements year-round and easily withstand periodic cleaning.



Aluminum is Resilient

Where strength must be flexible, aluminum can deflect under loads and then spring back. Whether sailboat masts or modern streetlight poles, where resiliency is critical to design, aluminum can meet the specifications.

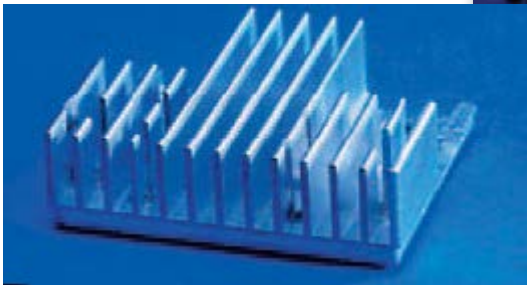
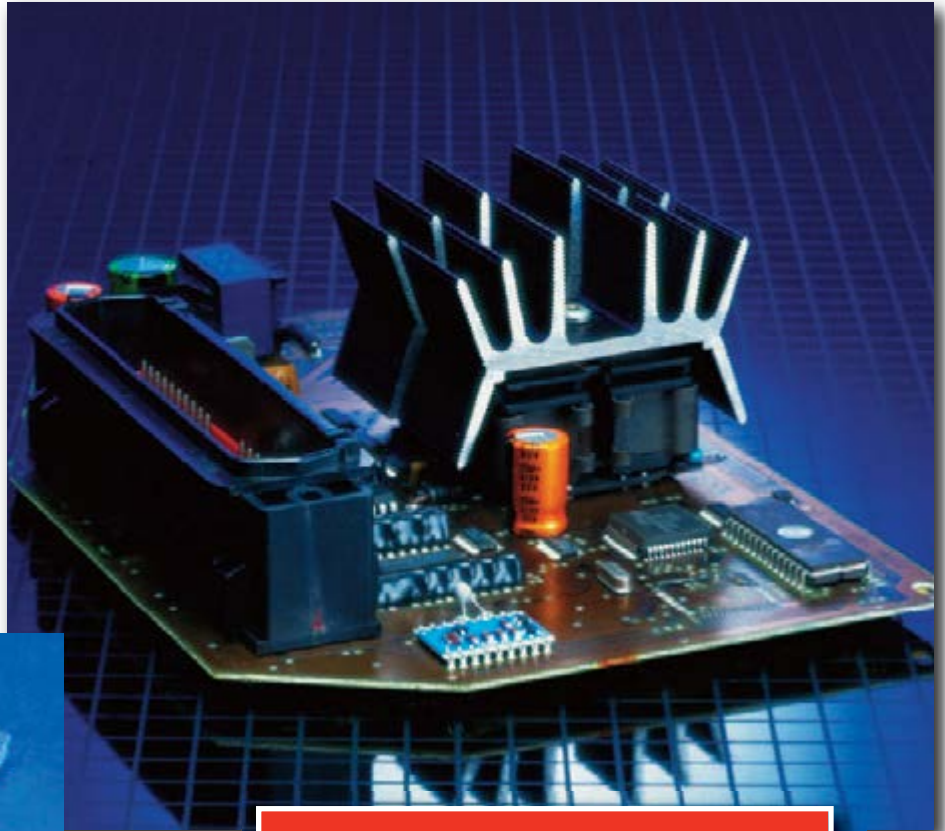


Aluminum is Corrosion-Resistant

Aluminum does not rust. When exposed to air, aluminum reacts with the oxygen to form a thin oxide layer that is both durable and corrosion-resistant. Scratch through the protective oxide layer, and it reforms a new layer. Properly alloyed and finished, aluminum can resist corrosion by salt water and various other chemicals and materials.

Aluminum is Thermally Conductive

Aluminum is widely used to transfer heat for both cooling and heating applications. On a weight-to-cost basis, no other material conducts heat better.



Extruded aluminum heatsinks are used to dissipate heat in applications such as electronics.



Aluminum is Nontoxic

Aluminum is nontoxic in solid form, making it an excellent material for products from food preparation and packaging to chemical handling and processing. The smooth nonporous surface is easily cleaned and does not absorb bacteria-sustaining food particles.

Aluminum is Reflective

In its natural finish, aluminum is more than 80 percent reflective. Aluminum reflects not only light, but also radio waves and infrared radiation, making aluminum extrusions ideal for radio frequency (R.F.) shielding in electronic applications, as well as for more aesthetic applications such as household appliances.

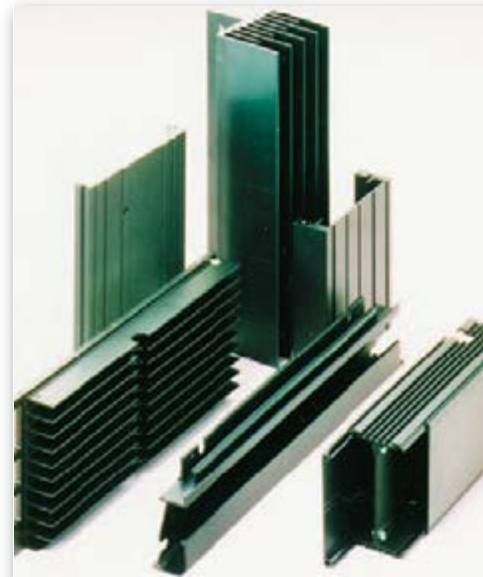
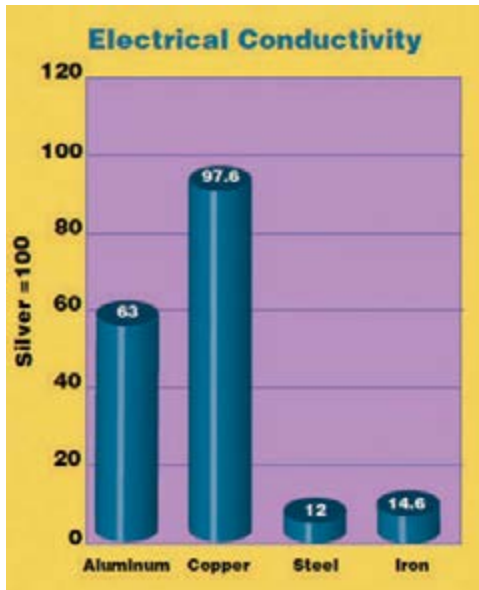
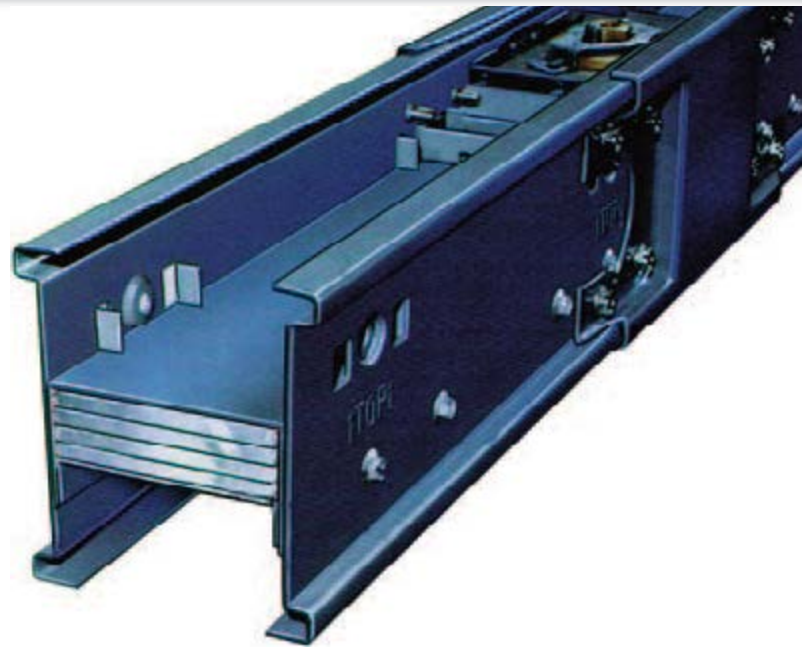


Aluminum extruded components are used in copy machines because of aluminum's highly reflective nature.



Aluminum is Electrically Conductive

As an efficient and cost-effective conductor, aluminum is an ideal material for electrical system components and bulk power transmission. Volume for volume, aluminum is about 62 percent as efficient an electrical conductor as copper; on an equal-weight basis, aluminum exceeds copper as a conductor.



Aluminum Is Nonmagnetic

Aluminum's nonmagnetic character makes it useful for high-voltage hardware, and for equipment used in magnetic fields. Aluminum profiles enjoy extensive use in much of today's electronic equipment.

Extruded aluminum components are often used in and around MRI (magnetic resonance imaging) machines because of aluminum's nonmagnetic properties.



Aluminum has Cryogenic Strength

Aluminum gains strength when temperatures are reduced, making it a preferred metal for cryogenic applications. Aluminum profiles are well suited to withstand the extreme low temperatures of deep space.



The extruded aluminum handrails on the International Space Station serve as tether anchors for equipment and lifelines for the crew. Aluminum provides the excellent mechanical properties for this mission-critical application.



This fuel tank heating element must be nonsparking to protect volatile fumes from unintended ignition.

Aluminum Is Nonsparking and Noncombustible

Aluminum's nonsparking characteristics make it an excellent material for applications in flammable or explosive situations. Not only is it noncombustible, aluminum generates no hazardous emissions when exposed to high heat, a favorable feature which is not shared by many synthetic substances, including plastic resins.





Aluminum Profiles are Attractive

The natural metallic surface of an aluminum profile is aesthetically pleasing and corrosion-resistant, even without additional finishing. Aluminum's natural protective oxide coating is transparent and can be enhanced by anodizing for extra protection, without affecting the metal's appearance.

Aluminum extrusions are used extensively in exhibit displays because of aluminum's attractive natural finish.





Aluminum Profiles Accept a Wide Range of Finishes

Mechanical finishing can create surface textures: from rough, to matte, to mirror-like. The metallic hue can be colored by appropriate chemical or anodizing processes. Surface coatings such as chromate, paint, powder coating, electroplating, or laminates may be applied. The nearly unlimited variations in appearance enhance designers' choices.



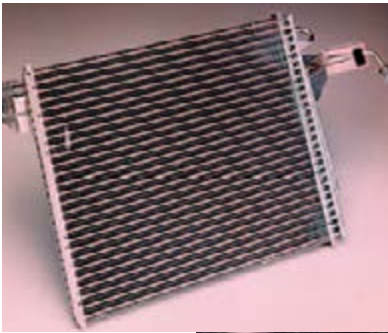
Picture frames, such as these, can be coated in a wide array of handsome finishes.



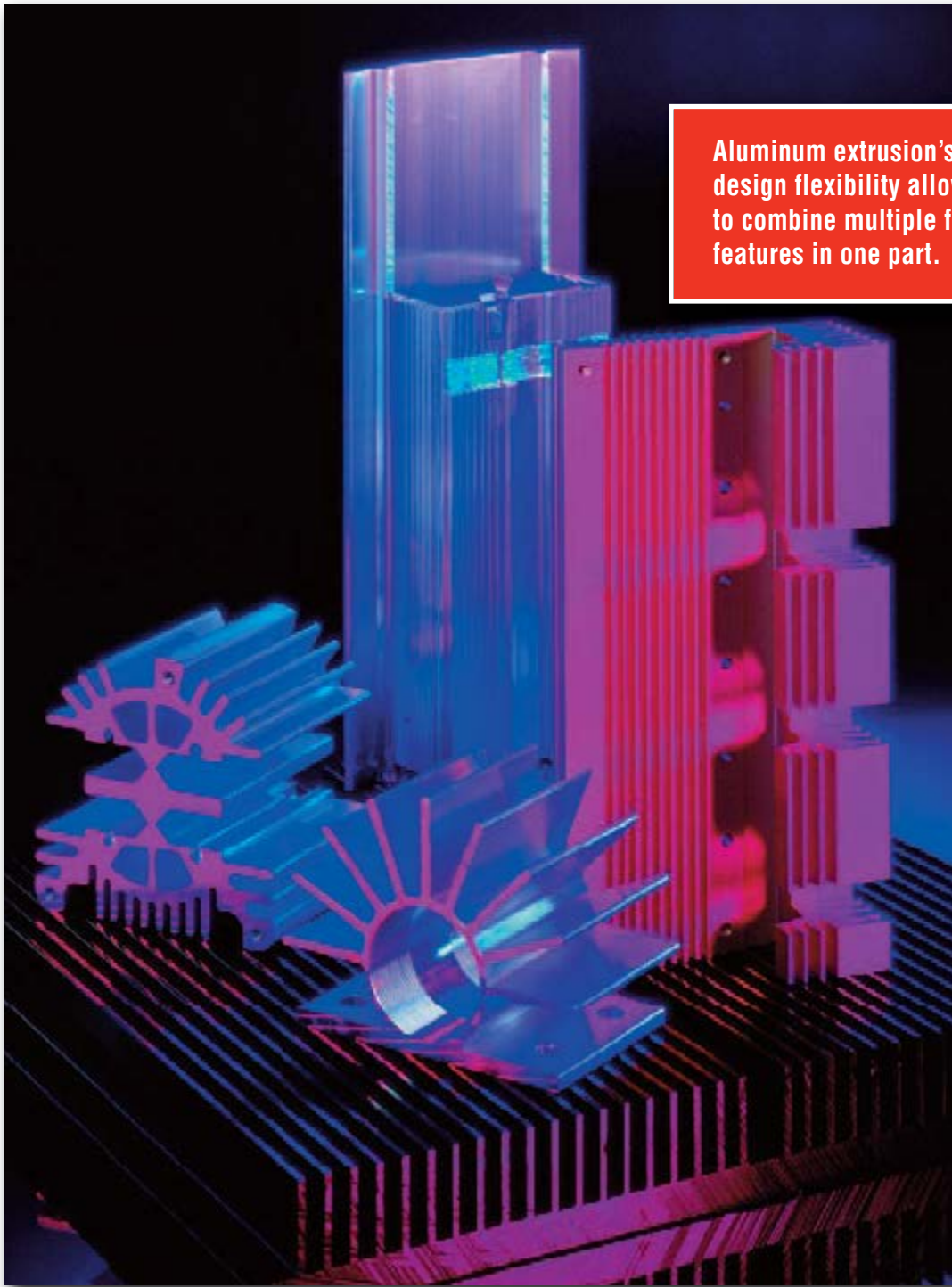


Aluminum Profiles are Virtually Seamless

Aluminum can be extruded to form hollow shapes without mechanical joints or seams that could loosen, weaken, or leak (especially compared to rolled and stamped products). This is especially important for products that require R.F. (radio frequency) shielding.



Aluminum's noncorrosive properties and the extrusion process' ability to produce seamless profiles are essential for air conditioning condenser units used in automotive applications.



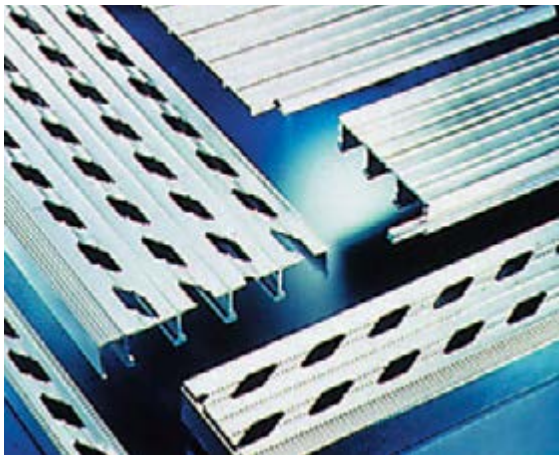
Aluminum extrusion's incredible design flexibility allows the designer to combine multiple functions and features in one part.

Aluminum Extrusion can Yield Complex Integral Shapes

No other process allows the designer more flexibility in combining form and function through complex integral shapes. Aluminum extrusions can deliver economical—and highly precise—shapes that would be difficult, if not impossible, to produce satisfactorily in any other way.

Profiles can be Designed to Facilitate Fastening and Assembly

Extruded features such as lap joints, dove tails, screw slots, etc., offer excellent methods of assembly to other extrusions or other parts. As an integral part of cross-section design, such features can be used to reduce manufacturing steps, scrap, and material cost.

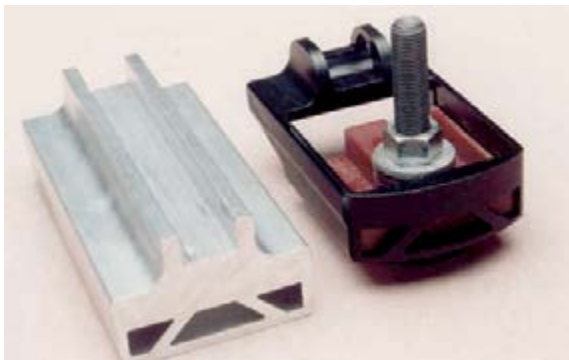
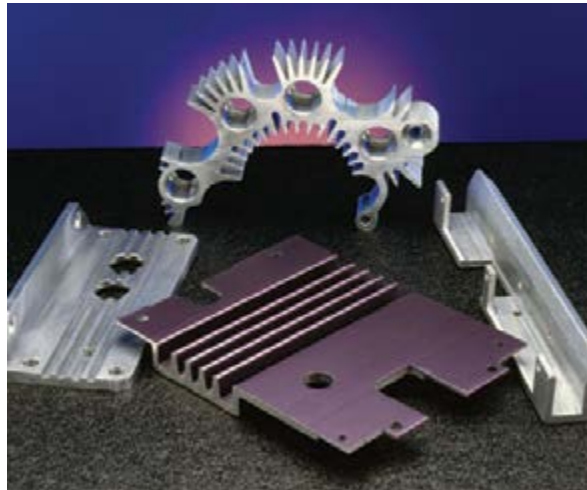
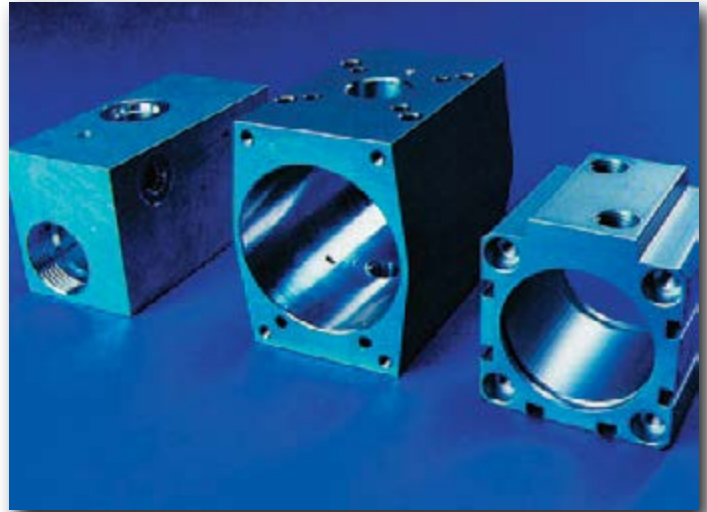


Profiles are Readily Joinable

Welding, soldering, brazing, adhesives, and mechanical fastening . . . all are suited to joining aluminum extrusions to other aluminum products or to different materials.

Profiles can Reduce Steps in Fabrication

Secondary operations can be minimized because of aluminum profiles' feature of near net shape coupled with the incorporation of holes, slots, or screw bosses into the shape. Extrusions can be further fabricated by cutting, drilling, punching, machining, and bending. The fabrication cutouts are recyclable, further adding to the extrusion's cost effectiveness.



Aluminum can be Extruded to Tight Tolerances

Every process has its deviation from nominal. For castings, for example, it's shrinkage and draft. For the aluminum extrusion process, tolerances are more an evolution than they are fixed. Improvements in die construction and press practices may provide for even tighter tolerances than standard on aluminum profiles. For many applications, standard aluminum extrusion tolerances have proven to be more precise than those for most competing processes.

See section 8, page 1 for information on standard dimensional tolerances.

Aluminum Profiles are Cost-Effective

Tooling costs for aluminum extrusions are often expressed in hundreds of dollars, while other material processes are much higher.

The savings from utilizing aluminum profiles go beyond initial tooling costs. Coupled with the previously discussed product advantages, aluminum extrusions' net shape design to exacting tolerances, ease of fabrication and finishing offer designers a cost-effective process to produce products to precise standards.

Typical Tolerances for Competing Materials

Roll Forming (includes Aluminum, Brass, Bronze, Copper, and Steel [carbon, stainless, galvanized] in thickness from .005" to .375")

Decimal Dimensions	+/- .010
Angular Dimensions	+/- 1 degree
Max. Bow (up, down, side)	.015 per ft. X length
Max. Twist	1/2 degree per ft. X length
Length Tolerances	12.0" to 36.0" +/- .062
	>36.0" to 144.0" +/- .094
	>144" +/- .125

Stamping (includes Aluminum, Brass, Bronze/Copper, and Steel Alloys)

	+/- .002 on centers
	+/- .001 on hole diameters
	.005 radius on bends
	+ .002 on hole distortion
	+ .002 between hole centers
	.001 radius on outside corners
Flatness	.005" /in TIR

Casting (includes Aluminum, Bronze, Iron, and Steel)

Linear tolerances	+/- .010 for first inch and +/- .0015 for each additional inch up to 12"
Walls	.020 - .025 on small castings
	.040 - .050 min. on larger castings

Powdered Metal (Includes Aluminum, Bronze, Copper, Iron, Steel [carbon, stainless], and Titanium)

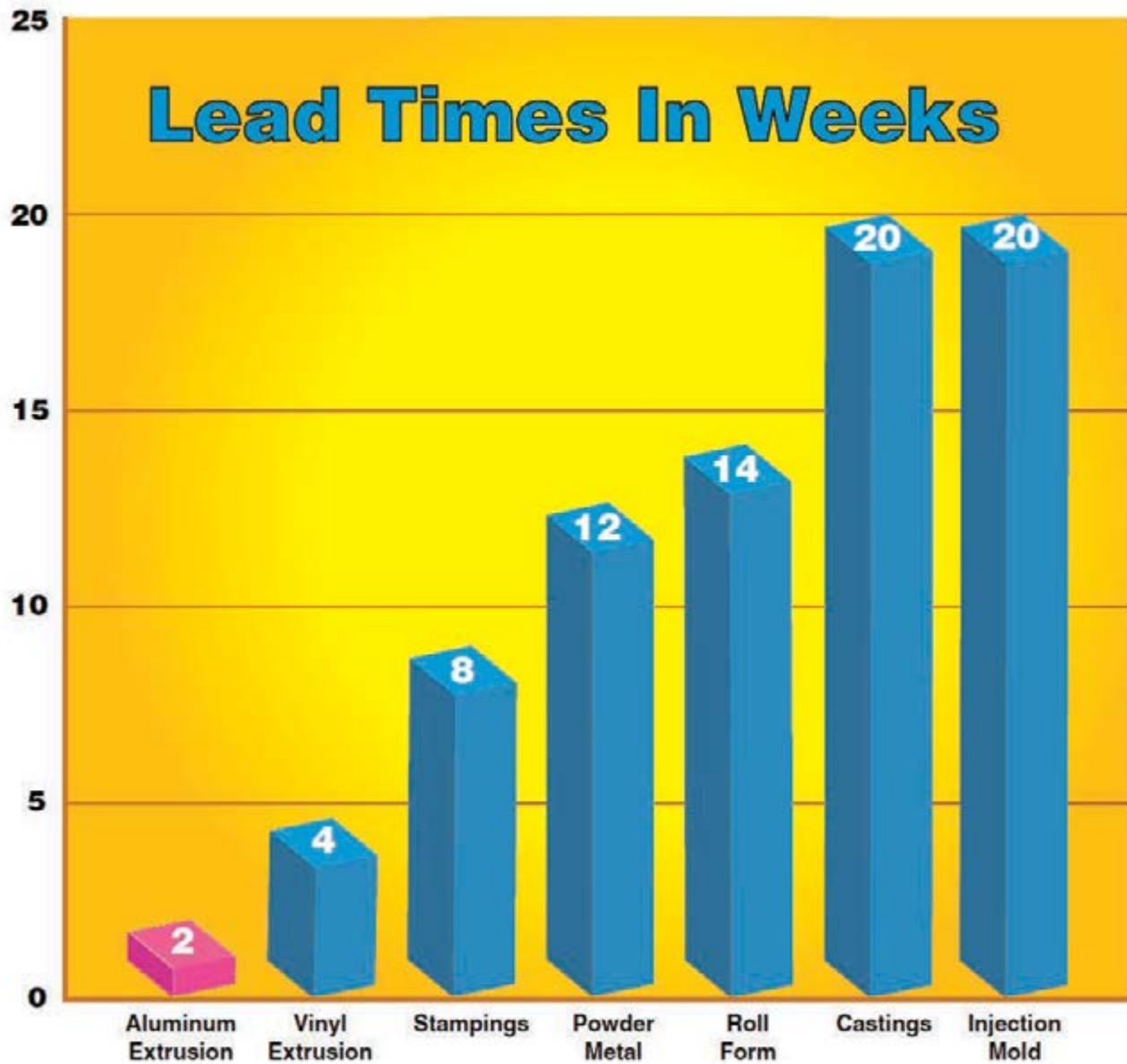
Typical Dimensions	+/- .003
Critical Dimensions	+/- .001

Process	Typical Tooling \$
Vinyl Extrusion	1,500 and up
Injection Molding	25,000 and up
Die Castings	25,000 and up
Roll Forming.....	30,000 and up
Stampings:	
(short run)	minimum \$
(long run)	5,000 and up
Aluminum Extrusions	500 to 5,000 ¹

¹ Typical tooling for aluminum extrusion falls between \$750 and \$2,000.

Aluminum Profiles Have Short Lead-Times

From prototyping to full production, no other process offers the designer faster turn-around from actual production tooling. While dies can be made in as little as a week or two, other processes—such as roll form, injection mold, and die casting—may require 20 weeks. Only machined parts may exceed aluminum extrusion turnaround time.





Section

1.1

Sustainability



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Sustainability

While the production of primary aluminum is an energy intensive process, aluminum's recyclability – combined with other inherent properties – make aluminum an important element in sustainability.

This section will review the value – and reality – of aluminum recycling, outline the findings from a recent assessment of extrusion's environmental footprint, recap some of the ways that the use of extruded components is reducing the environmental impact of buildings and autos, and suggest actions that you, as an extrusion user, can take to further reduce the environmental impact of your products.

Aluminum's fundamental properties **do not change** with mechanical processing. Thus, aluminum can be recycled time and time again with no degradation of properties. And producing aluminum via recycling requires only **8% of the energy** compared to producing it from virgin materials. Each ton of aluminum recycled, rather than produced from ore, saves:

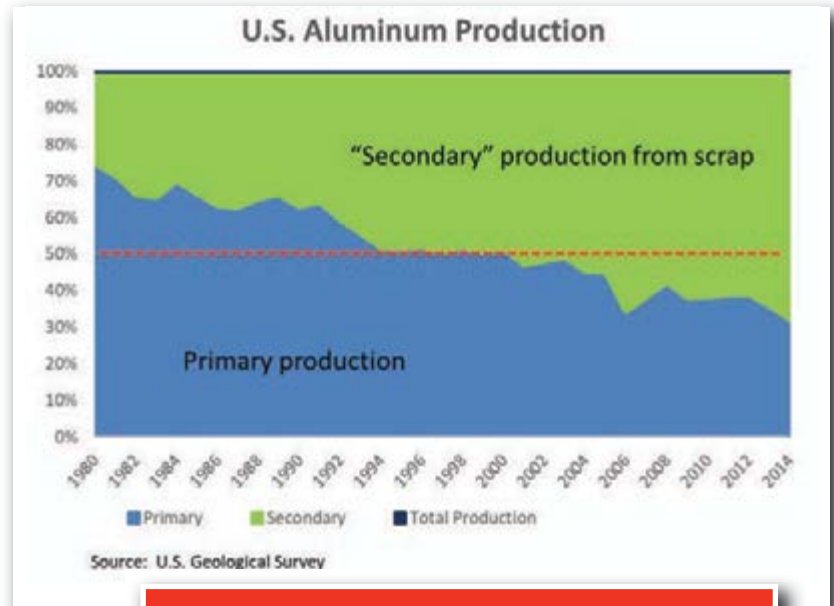
- 24 barrels of crude oil equivalents
- Over 15 tons of fresh or sea water
- More than 9 tons of CO₂ equivalents

Aluminum's infinite recyclability, combined with its light weight, high strength-to-weight ratio, corrosion resistance and formability, make aluminum extrusions an important element in many sustainable solutions. Whether by helping to light-weight vehicles to improve fuel efficiency and reduce emissions, reducing the energy requirements of commercial buildings, or facilitating installation of solar energy farms, aluminum extrusions both enhance sustainability and reflect sustainable practices.

Recycling: Not just theory, but reality

Many materials claim to be easily recycled, or to have recycled content, but the recycling of aluminum extrusion is more than theory, it's reality. A few facts:

- Over half of U.S. aluminum production has been “Secondary” – from reprocessing aluminum scrap – for over 15 years. Virtually all cans and castings are produced from recycled metal.
- In 2015, roughly 55% of the metal used in aluminum extrusion produced in North America was recycled aluminum.
- Individual extruders are frequently producing extrusions, even for demanding structural or aesthetic applications, with recycled content substantially greater than the 55% average for the North American industry.
- Recent studies have shown that roughly 95% of the aluminum in commercial buildings being demolished ends up in the recycling process.
- Similar studies (Worcester Polytechnic Institute - 2016) have documented that over 90% of the aluminum content in autos being dismantled goes into recycling.
- In developing the aluminum-intensive F-150 pick-up, Ford incorporated an extensive closed loop aluminum recycling system in the body plant. Currently, Ford recycles enough aluminum sheet to produce the equivalent of 30,000 F-150 bodies each month.
- An extensive infrastructure for collecting, processing, and recycling aluminum has existed for years in North America. Currently, AEC members operate over 30 remelt facilities (for processing aluminum scrap into billet – the raw material to the extrusion process) across the continent.



For more than 15 years, over half of all aluminum production in the U.S. has been “secondary” aluminum reprocessed from scrap.



Recycling can produce extrusion billet sufficient for the most demanding extrusion applications. However, it's not just throwing any scrap aluminum in the melt furnace.



This is not the first step in producing extrusion billet with recycled content. Nor are used cans, gutters, and engine blocks used. Rather, the recycling process starts with post-industrial and select post-consumer scrap (e.g. wheels, door frames) that is carefully characterized, segregated by alloy, and tested, with subsequent addition of needed alloying elements.

Extrusion's Environmental Footprint

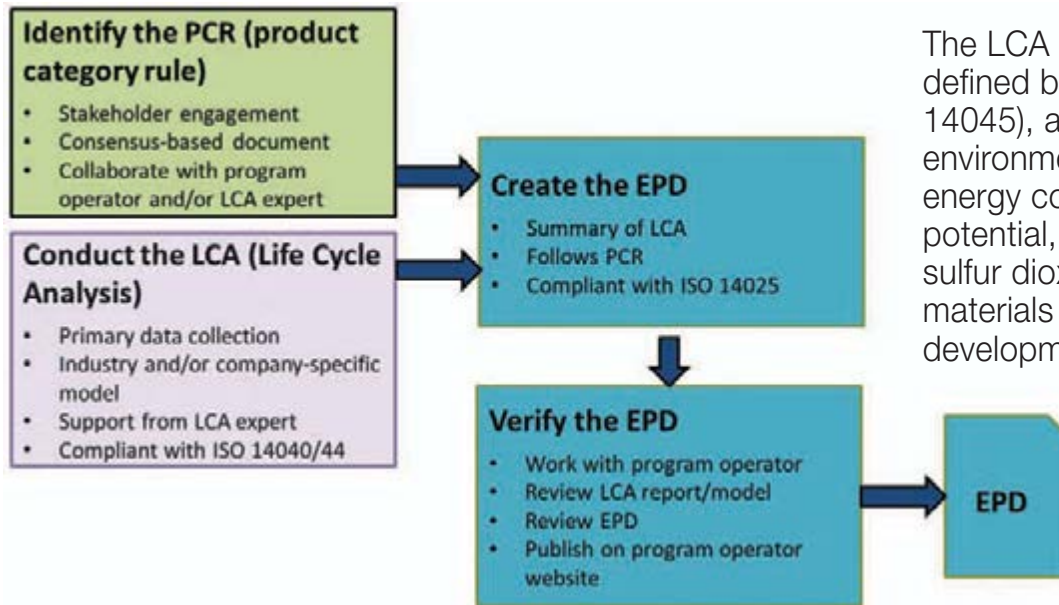
To document the environmental impact of the extrusion process, and to set a benchmark for industry improvements, in 2016 the Aluminum Extruders Council conducted an industry Life Cycle Analysis (LCA) and published two Environmental Product Declarations or EPDs, frequently described as “environmental nutrition labels” for products. One AEC EPD covers mill finish, painted, and anodized extrusions; the other covers thermally improved extrusions, with the same finish options.



Environmental Facts	
Declared unit: 1 metric ton of extruded aluminum	
Primary Energy Demand [GJ]	102.44
Global Warming Potential [kg CO ₂ -eq]	6570
Acidification Potential [kg SO ₂ -eq]	38
Eutrophication Potential [kg N ₂ -eq]	0.77
Smog Potential [kg O ₃ -eq]	327
Water Consumption [kg]	3130
Boundaries: Cradle-to-Gate	
Company: XYZ Extruders	
Recycled content: 29%	

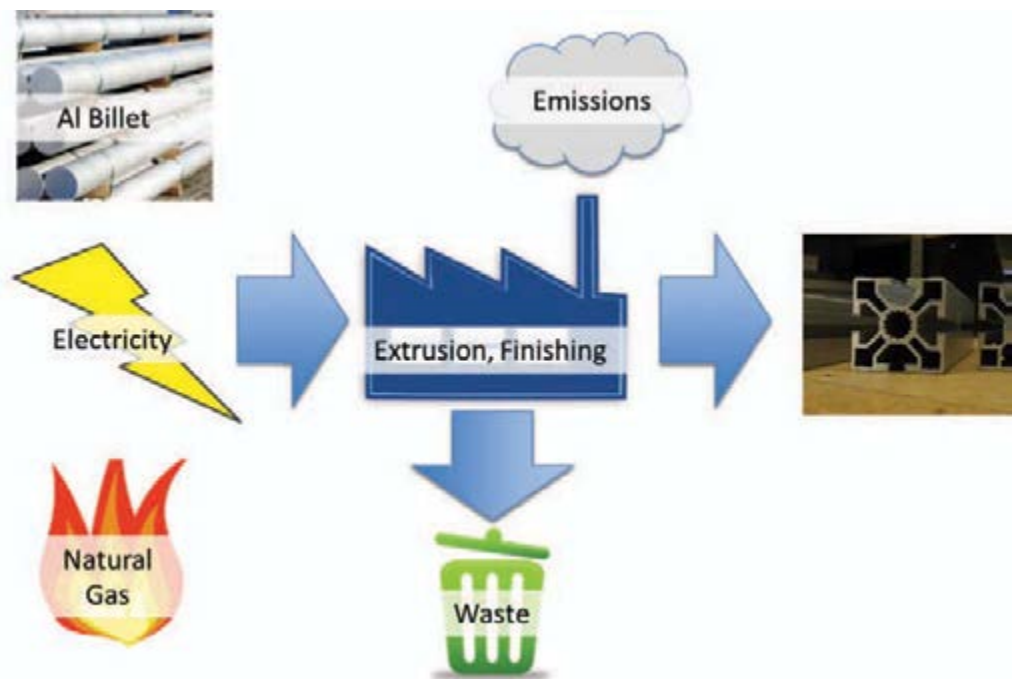
The Process

The LCA and EPD processes are strictly defined by ISO standards (14040/44 & 14045), and are widely used to report the environmental impact, such as primary energy consumption, global warming potential, acidification potential (e.g. sulfur dioxide emissions) of various materials and end products. The development process is shown to the left.



Note that all EPDs must be certified by a qualified, independent third party; in addition, most LCAs are conducted with the assistance of a sustainability/environmental specialist. For its extrusion industry EPD project, the AEC worked with *thinkstep*, a global sustainability software and consulting company based in Stuttgart, Germany. The “program operator”, or third-party certifier, was UL Environmental. Both are recognized leaders in sustainability reporting.

Creating the LCA requires documenting all inputs and outputs related to the subject process for a year. For this project, 11 North American extruders provided data on 30 facilities, with over 85 presses, 22 paint or anodizing lines, 4 thermal break operations and 12 remelt/casthouse facilities, providing data for calendar year 2015. Up to 300 discrete data points were obtained for each facility, depending on the scope of its operations.



Where primary data was not available from participating extruders, secondary data was used from recognized data bases on regional power grids, aluminum billet environmental impact (depending on region of origin), etc.

In aggregate, the 11 participating extruders provided data covering 1.7 billion pounds of extrusion production, or about one-third of the total North American output for subject year 2015.

The Results

Complete results for both EPDs (extrusions and thermally improved extrusions), as well as the complete LCA/EPD Background report can be downloaded on the AEC website as detailed later.

The following is illustrative of the detailed results provided for the various forms of extrusion covered in the study (i.e. mill finished extrusion, painted extrusion, anodized extrusion, and thermally-improved extrusion with the same finish options).

Impact assessment: mill finished extrusion, per metric ton

Impact Category	Unit	A1-A3	C4	D
<i>CML 2001 (v4.1)</i>				
Global warming potential	kg CO ₂ eq	7,510	2.24	-4,910
Ozone depletion potential	kg CFC-11 eq	8.27E-07	4.29E-11	-2.08E-07
Acidification potential	kg SO ₂ eq	49.2	0.00970	-35.1
Eutrophication potential	kg PO ₄ ³⁻ eq	2.74	0.00124	-1.45
Photochemical ozone creation potential	kg C ₂ H ₄ eq	2.71	9.84E-04	-1.76
Abiotic depletion potential for non-fossil resources	kg Sb eq	0.00494	8.59E-07	-0.00263
Abiotic depletion potential for fossil resources	MJ	78,400	33.9	-45,200
		manufacturing	disposal	credit for recycling potential*

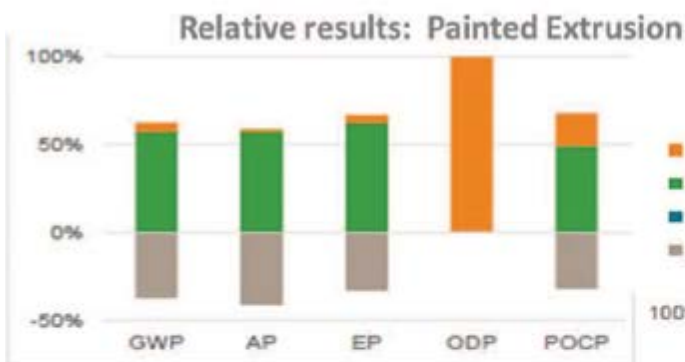
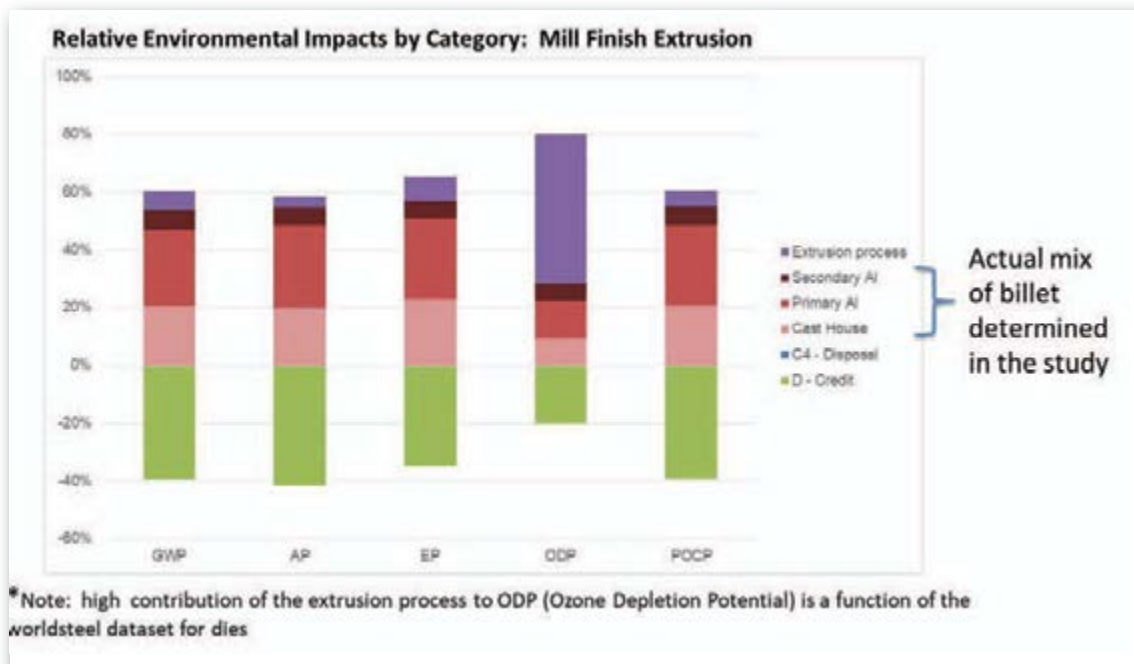
The chart to the right reports the environmental impacts for various impact categories (e.g. global warming potential, acidification potential) of the identified product by production stage. Production stage A1-A3 represents manufacturing (raw material, inbound transport, conversion), C4 represents disposal at end-of-life, and D represents reuse and recycling potential and is therefore shown as a negative, or an offset to the impact of the prior stages.

*Based on the difference between actual recycled content – as reflected in the manufacturing stage – and a 95% recycling rate as demonstrated in several studies.

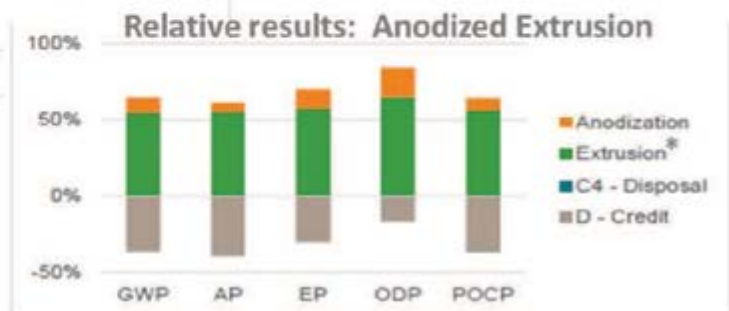
Note: Some EPDs also present data on the product transformation and use stages (A4-C3). Such an approach may be appropriate for a discrete finished product, like a window, but not for a product input like aluminum extrusions which can be incorporated into a vast array of finished products.

Reviewing the detailed EPD data leads to some important conclusions about the environmental impact of extrusions:

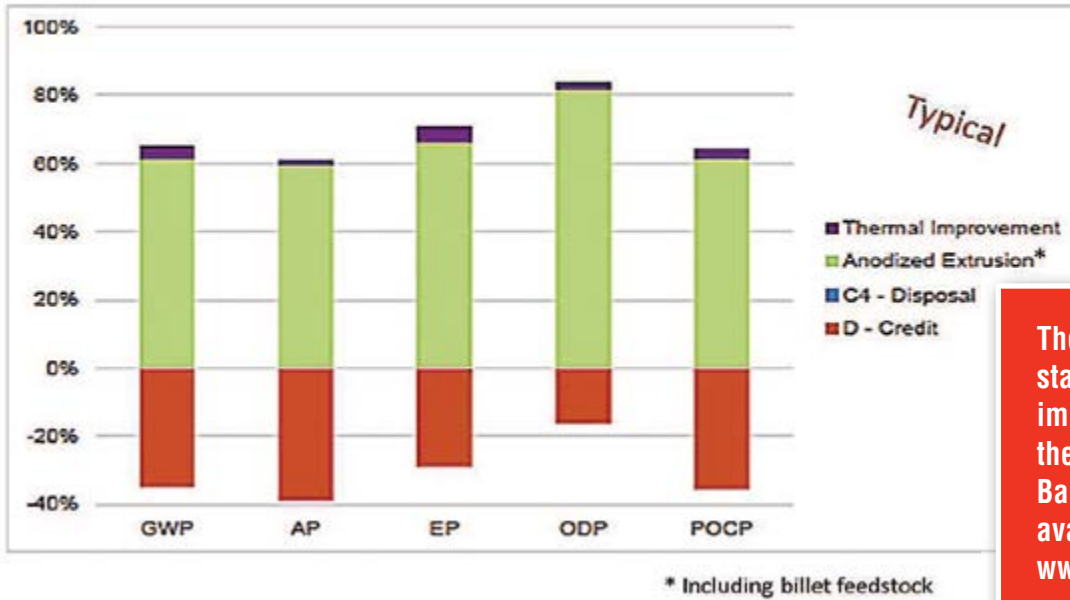
- The extrusion process itself has a relatively low environmental impact. By far, the largest contribution to extrusion's impact is the source (hence energy employed) and the composition (i.e. recycled content) of the billet.
- Similarly, painting or anodizing extrusion adds only minor environmental impact.
- Thermally improving extrusion also adds only minor environmental impact, and is certainly more than offset by the benefit of reduced building energy consumption as a result of the thermal improvement.



* Including billet feedstock



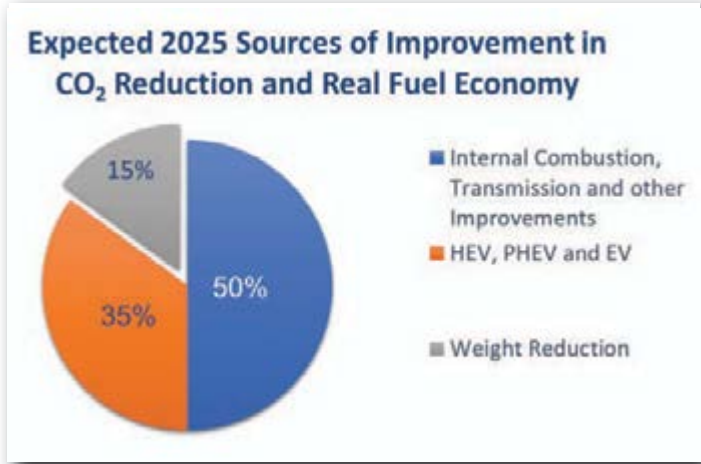
Relative results: Thermally Improved Anodized Extrusion



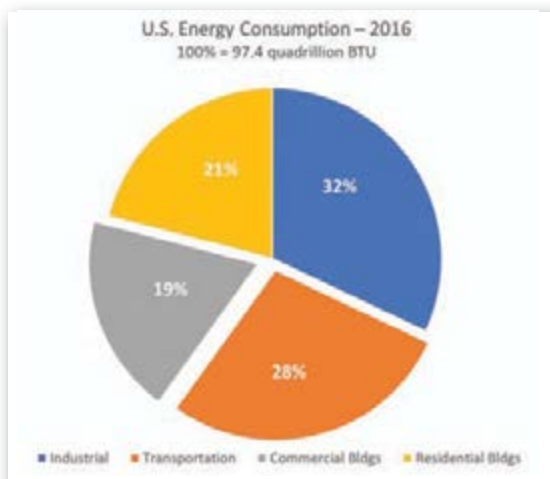
The complete EPDs, for both standard and thermally improved extrusion, as well as the underlying LCA/EPD Background Report, are available at www.AEC.org/EDP.

In-Use Benefits for Sustainability

While the environmental impact of aluminum extrusion production is not inconsequential, and ongoing efforts to reduce extrusion’s environmental footprint are important, the contribution of extrusions in reducing the environmental impact of the products in which they are used is much more significant. This is particularly a current focus in transportation and in buildings, which collectively represent over 47% of U.S. energy consumption.



Source: Ducker Worldwide



Source: U.S. Energy Information Administration

In the chart at left, of transportation energy consumption, nearly 59% is represented by light vehicles (cars, light trucks, SUVs), with the remainder rail, aircraft, truck and bus. In commercial buildings, 34% of energy consumption is for heating and cooling; another 10% is for lighting.

Transportation

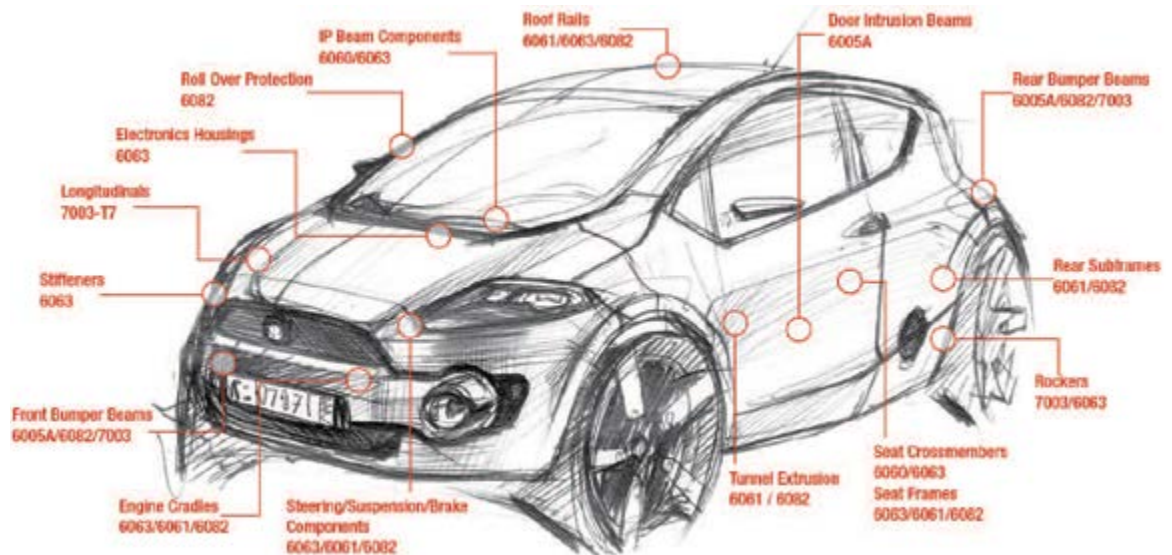
Extrusion use in light vehicles increased nearly 50% from 2012 to 2016 as automakers focused on increasing fuel efficiency to meet a 2025 target of 54.5 miles per gallon. As shown below, it is expected that lightweighting, in which aluminum is playing a key role, will represent a significant portion of the advances needed to achieve the 2025 target.

The per-vehicle gains came not only from the introduction of new aluminum-intensive vehicles like the Ford F-150 and Cadillac's CT6, but also from the replacement of a host of steel-based components in other vehicles. Today, extrusion-based components are found in a wide range of applications as illustrated below.

In total, the use of aluminum extrusions, in combination with other changes to vehicle architecture, is yielding major decreases in vehicle weight.

- Ford F-150's cab and bed weigh as much as 400 pounds less than competitive vehicles
- Tesla's Model S body-in-white comes in at 205 pounds less than segment competitors
- The Audi A8 body similarly weighs over 225 pounds less than competitors

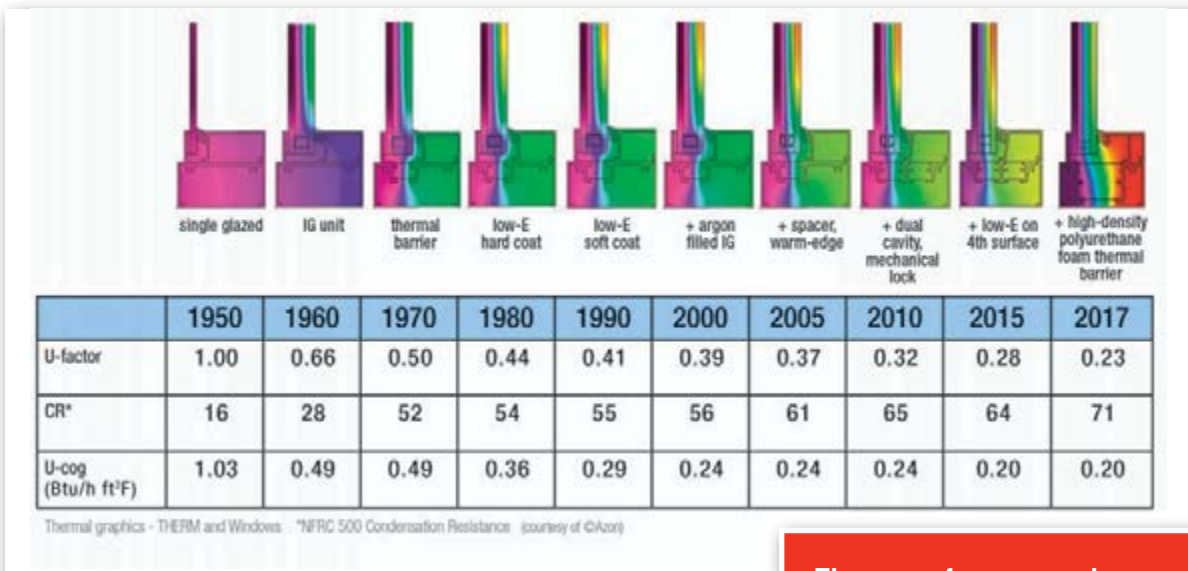
These weight reductions lead to improved fuel efficiency and reduced carbon emissions, and in the case of zero-emission electric vehicles, greater range and performance. As a result, aluminum extrusion intensity is expected to continue to grow in light vehicles, with an additional 50% increase in extrusion per vehicle by 2025. In addition, as heavy vehicle (i.e. truck, bus) producers strive for increased efficiency and reduced emissions, extrusion usage is growing rapidly in those markets.



Building

Extrusions are also playing a significant role in reducing the 44% of commercial building energy dedicated to heating, air conditioning, and lighting. Extruded components are used for:

- Light shelves, which bounce exterior light into the building interior thereby reducing lighting demands
- Sun shades, externally mounted, to reduce solar heat gain (and air conditioning load)
- Window framing; extrusion's strength facilitates the larger glass lites that are preferred in today's buildings, increasing the use of natural light and providing productivity-enhancing views for occupants.



Courtesy of Azon

Unfortunately, aluminum's thermal conductivity also creates a challenge to keeping the cold out in winter and the heat out in summer. Typically, extruders and window/door producers utilize polymer thermal breaks to minimize thermal convection across a frame. As shown in the industry EPD, such thermal improvement does add to the environmental footprint of extrusions; however, that slight addition is more than offset by the resulting reduction in energy needed for heating and cooling.

The move from a non-improved aluminum frame to one with a thermal barrier can reduce the U-factor of the frame alone by 0.5 BTU/ft²- hr-°F. A 6'x5' commercial window with a 2" frame and a 40-degree inside-outside temperature differential yields a saving of 130+ BTU/hr.

Since thermal barriers were introduced in the 1970's, the combination of advances in thermal barrier technology and window/glass technology has yielded a 75% reduction in U-factor, the measure of thermal transmittance, through conduction, convection, and radiation.

Mitigating Environmental Impact

Note that the data presented is representative of various points in time and reflects industry-wide performance. Individual extruders, the extrusion industry, and the aluminum industry as a whole, are constantly investing to lessen their environmental impact. For example:

- The power requirement to produce a ton of bauxite has been reduced roughly 15% from 2010 to 2015.
- Similarly, the power requirement for the smelting of a ton of aluminum has been reduced roughly 5% over the same period. Note that some billet data in the AEC EPDs is based on 2010 aluminum production datasets, as more recent data is only now becoming available.
- Recycling of bauxite waste has increased by orders of magnitude over the same period as previously waste materials have been diverted into commercial applications such as cement production.
- Use of recycled material for extrusion in North America increased from 51% in 2011 to 55% in 2015.
- North American extruders have invested in over 20 new state-of-the-art presses since 2015; these presses are typically substantially more energy efficient.

What You Can Do

Extrusion users can reduce the environmental impact from their own extrusion use by using extruded components with significant recycled content, and by specifying that primary aluminum in their products come from “clean power” smelters; i.e. those that use hydro power rather than coal. The 2015 World Aluminum data indicates while only 30% of global aluminum production is hydro based, 100% of aluminum from Canada, nearly 100% from Russia and roughly 75% from the U.S. is produced with hydro power. In contrast, roughly 90% of aluminum from China is produced with coal.

(Source: World Aluminum: Life Cycle Inventory Data and Environmental Metrics for the Primary Aluminum Industry, 2015 Data)

Section
2

Applications



ALUMINUM
EXTRUDERS
COUNCIL

Aluminum Extrusion
Manual
4.2 Edition

Section 2



Aluminum Extrusion Achieves Sustainable Innovation

Designers and engineers constantly redefine innovation by creating lighter, stronger, environmentally sound products using extruded aluminum components. Our featured applications demonstrate how aluminum extrusions:

- lower production costs
- increase energy efficiency
- create more eco-friendly and recyclable products, and
- enable green technologies to succeed and flourish.

Global markets—from green building and transportation to renewable energy and engineered products—count on aluminum extrusions to achieve results: cost-effective, high-performance products.

Explore aluminum extrusion's limitless design possibilities, and turn your ideas into reality.

Photo credits appear at the end of the section.



ALUMINUM
EXTRUDERS
COUNCIL



Sunshades & Light Shelves

The Heifer International World Headquarters in Little Rock, Arkansas, a U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Platinum-certified building, has a curved shape that maximizes sun exposure with its east/west orientation. Integrated passive sunshades, comprised of extruded aluminum components on the building's exterior, block excess sunlight to reduce solar heat gain. Light shelves made from extruded aluminum were installed inside the outer walls to bounce light up, redirecting natural light to reflect it further into the building. Importantly, 97 percent of the project's aluminum building materials contain recycled content.

The extruded aluminum solar shading products combine with a narrow floor plate, aluminum curtain wall system and strategic interior glazing to allow natural light to penetrate floors for brighter open work spaces. Aluminum's strength-to-weight ratio allows deep shading extensions, and extrusion allows creation of various textures and shapes. Such extruded aluminum solar control systems are the favored choice for sustainable design, saving energy and money.



Atriums

The Henry Doorly Zoo in Omaha, Nebraska, features two new pavilions that utilize extruded aluminum tubes and I-beams for the overhead skylights and vertical walls, providing efficient structural framing that complement the internal environments. The Butterfly Pavilion uses extended vertical glass walls to allow maximum light to enter, and the neighboring Insect Pavilion uses reduced glass walls to minimize solar heat in the carefully managed environments. The sloped aluminum and vertical walls combine to provide a single-system solution for the zoo project.

Aluminum extrusions allow for custom components that match the desired width and depth specified by the architect. Each aluminum extrusion's final shape is custom engineered as required by the design loads, and each component fits the final overall aesthetic.

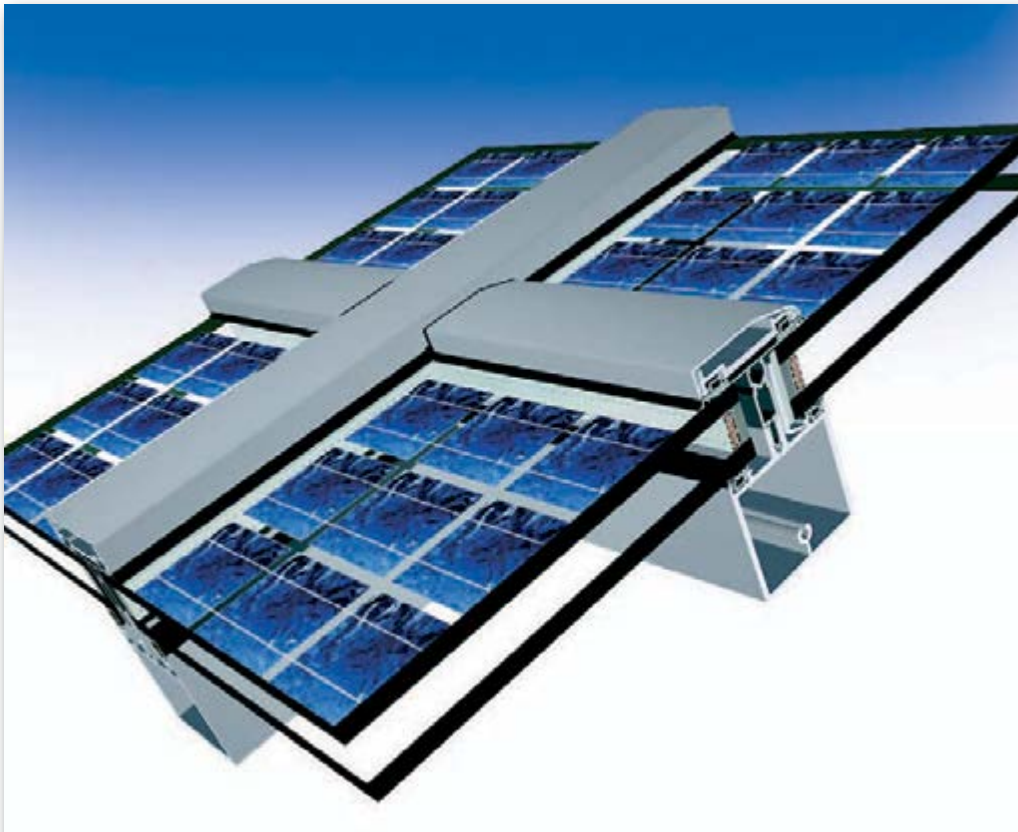


Photovoltaic (PV) Panel Framing and Skylights

The IPS Building in Meckenheim, Germany, uses building-integrated photovoltaic (BIPV) insulating glass modules framed in extruded aluminum as a multifunctional insert in its skylight system. The complex geometric skylight panel configuration is a semitransparent canopy that serves many functions:

- protecting occupants from solar heat and glare
- targeting natural daylight
- and generating high solar power levels.

Large PV panel surface areas with optimal tilt angles ensure the highest power yield, making BIPV technology exceptionally energy efficient.

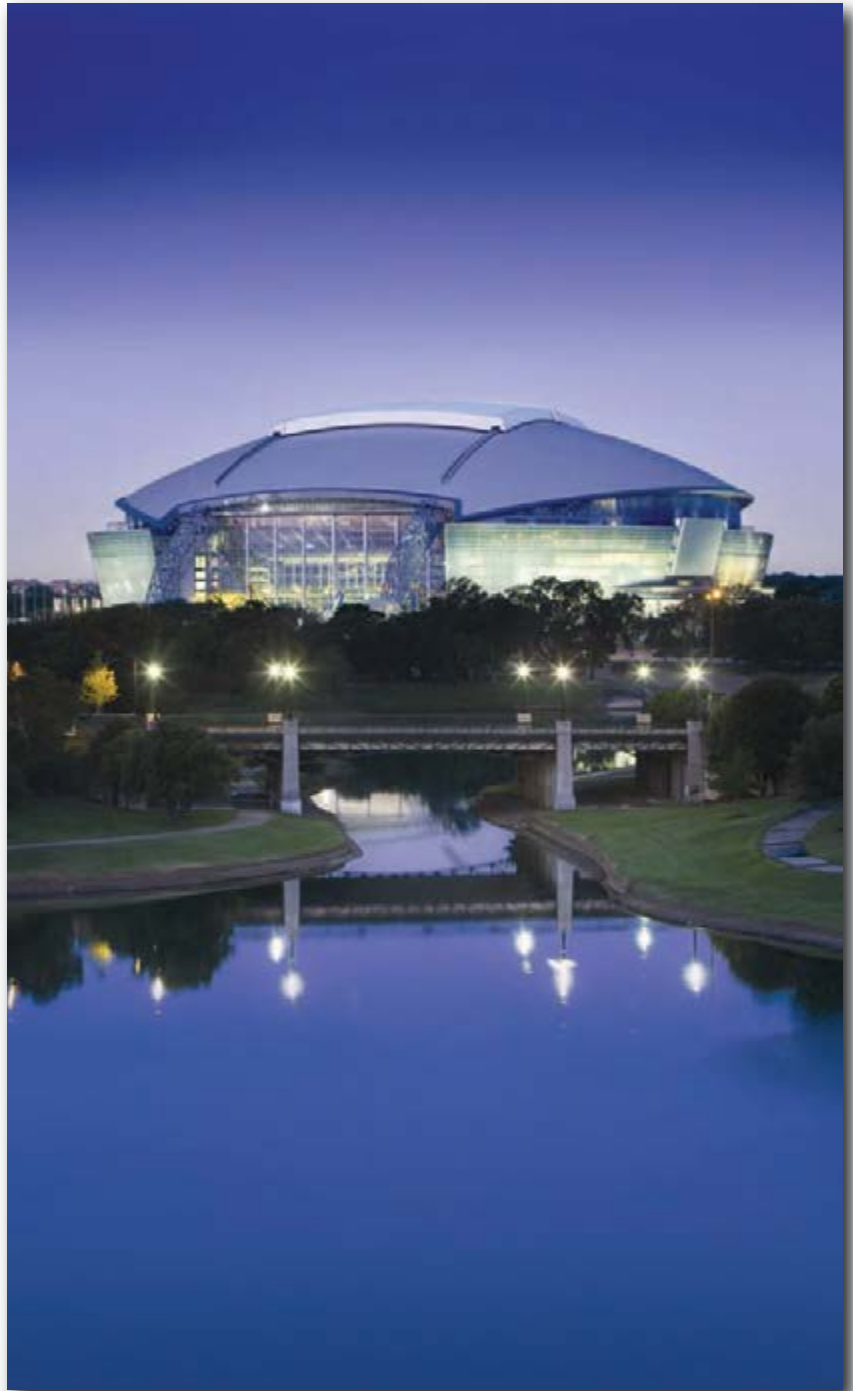


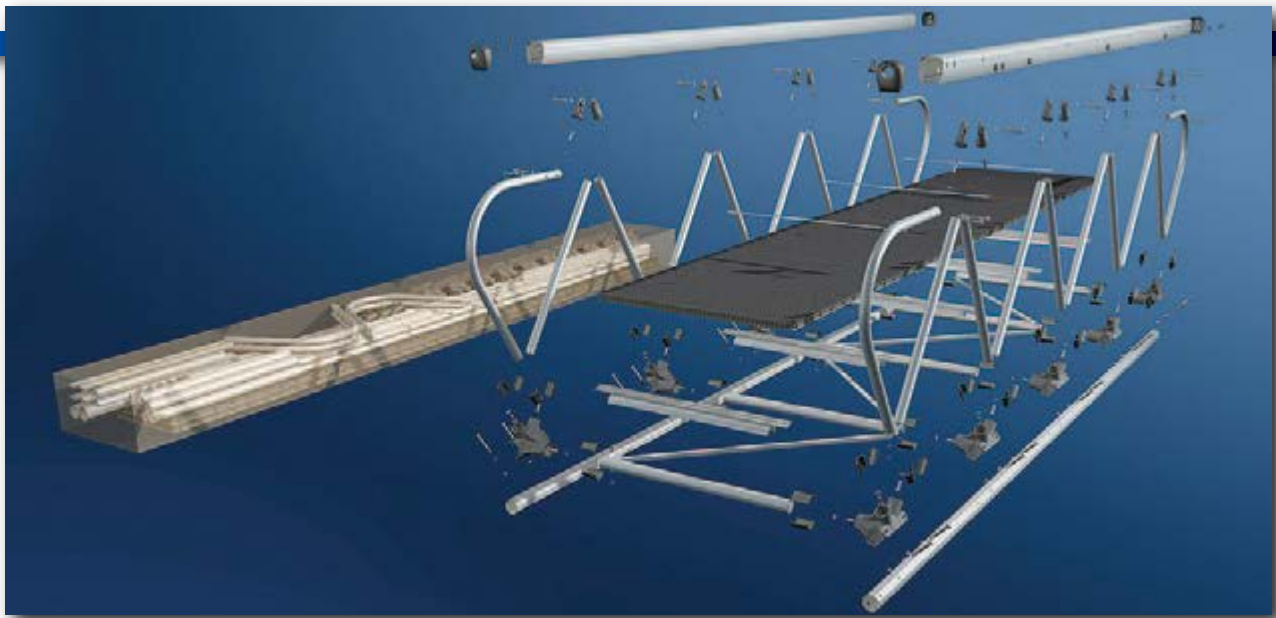
The IPS building also uses an extruded aluminum vertical facade for the skylight system. The BIPV technology integrates seamlessly with the facade system, framed and structurally supported by aluminum extrusions in a breathtaking design configuration. The fully-integrated system uses strong, load-bearing aluminum extrusions to construct a skylight/atrium envelope that saves and generates energy, while enhancing building design.

Dallas Cowboys Stadium

The Dallas Cowboys football stadium in Arlington, Texas, incorporates more than 1.2 million pounds of aluminum extrusions into the glass curtain wall and movable end zone door systems. This one-billion-dollar stadium seats 80,000 fans and features a quarter-mile-long retractable roof. The glass curtain wall and end zone doors are framed in custom aluminum extrusions, forming complex assemblies. A total of 61 new extrusion dies were used to create the extruded aluminum framing, using aluminum alloy 6063-T6.

The 86-foot-high exterior stadium walls slope outward at a 14-degree angle, containing 5,070 glass panels that graduate from blue to silver in color. Exterior aluminum extrusions have a two-coat silver Kynar painted finish. Each end zone features a five-leaf clear glass retractable door. These custom-designed and engineered end zone doors are the world's largest movable glass doors, at 120 feet high and 180 feet long, incorporating 250,000 pounds of custom extruded aluminum curtain wall into their design.





Pedestrian Bridge

The multi-purpose Make-A-Bridge™ system uses interlocking aluminum extrusion members to build a structurally strong pedestrian bridge that attaches easily to new or existing structures. The patented no-weld design increases aluminum's yield strength and eliminates thermally affected zones on the walkway structure. The extruded aluminum members have a lighter unit weight, at one-third that of steel. Make-A-Bridge is a safe, dedicated span that handles pedestrian, bicycle and light vehicle traffic for cantilevered walkways on existing bridges, skywalks, or overpasses; bike path, park, trail, and golf course bridges; and light vehicle access bridges, gangways, and footbridges of all types.

Off-the-shelf bundled extruded components assemble into load-bearing spans up to 60 feet long, designed to save time and fuel by loading/unloading quickly on standard semi-trailers. Easy assembly and installation are achievable without specialized labor. With extrusion, computerized fabrication and a pre-engineered system incorporate features with speed and accuracy, adding value at reduced overall cost. Attractive anodized or baked paint finishes, integrated handrails and kick plates, built-in LED lighting, overhead canopies, and non-slip decking options are available. This innovative design is an Extrusion Technology Foundation (ETF) Design Competition winner.

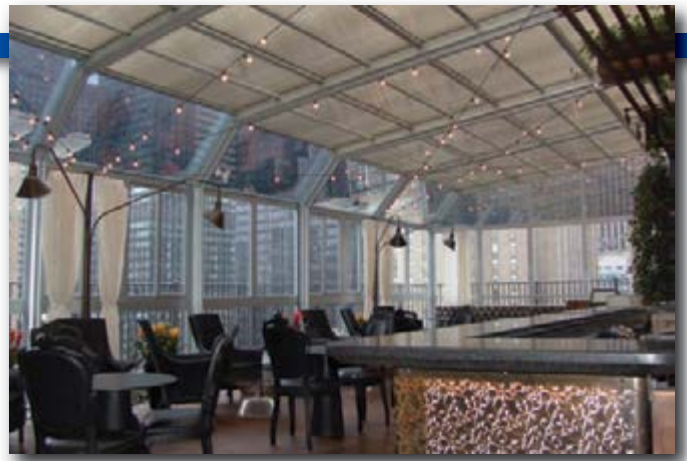


See www.etfdesign.org for more information on Design Competition winners.



Moveable Enclosures

When management of The Kimberly Hotel in New York City wanted to transform previously unusable rooftop space into a thriving, profitable dining and entertainment venue, they envisioned a restaurant lounge where patrons could dine and mingle while taking in world-famous Midtown Manhattan views. Their dilemma: how to create an idyllic setting without being limited by weather and draw visitors to this high-rise hotel's new roof-top bar/lounge with penthouse-level views of the New York City skyline.



Thanks to an innovative extruded aluminum motorized retractable enclosure, manufactured by Roll-A-Cover International, Bethany, CT, guests can now enjoy the space, known as Upstairs at the Kimberly Hotel featuring an al fresco experience year round, regardless of the weather.



See www.etfdesign.org for more information on Design Competition winners.

The Roll-A-Cover team custom designed the moveable enclosure, which opens and closes easily in just moments with the push of a button. The ambient space is climate-controlled with radiant heat in the floor and a forced air heating and cooling system for year-round comfort.



The project utilizes more than 20 different profile shapes that are comprised of hollow, semi-hollow and solid custom-designed aluminum extrusions that are exclusive to the company. Roll-A-Cover President and CEO Michael Morris notes, "Aluminum extrusions are highly structural and lightweight compared to steel, if the shapes are designed properly. Aluminum extrusions have allowed us to have flexibility with our product designs, colors, and... ease of use during fabrication versus steel."

Pre-assembled in-house and delivered directly to the job site, the enclosure consists of the extruded panel wall and roof sections. Due to aluminum's light weight, the six-man crew was able to quickly assemble the enclosure's roof and walls on the job site using standard tools so that minimal time was required; the system took approximately 24 to 35 hours over two to three days to assemble.

The enclosure system's configuration can be customized for many types of outdoor spaces at venues ranging from restaurants and convention centers to universities and museums. Residential applications also allow for year-round use of pools, hot tubs, and patios. Aluminum extrusions make this innovative enclosure a most creative and cost-effective solution for transforming spaces.

Operable Glass Door/Wall Systems

Architects are increasingly looking to bring the outside in ... or move the inside out. Whether for a mountain home with a stunning view, or an urban restaurant seeking to connect diners with the street scene, architects are creating walls of windows that can be moved out of the way to blend interior and exterior.



The builder of this home in Park City, UT chose the aluminum Lift & Slide door system for its structural strength and ability to support the massive expanse of glass used for the 26-foot-wide by 12-foot-high opening.

Aluminum extrusions allow for great design flexibility and accommodate more natural daylight while reducing utility costs and focusing attention on the scenic view.



Panda Windows & Doors Lift & Slide door system was specified for the Aspen Art Museum's rooftop area to extend the useable space onto the outdoor terrace. Extruded aluminum profiles frame each of the 6-foot-wide by 8-foot-high sections of this "moving" multi-panel wall system that shelters visitors against the elements and provides optimal thermal insulation.

The panel doors open around a 90-degree zero-post opening with a pair of 42-foot-wide panel systems spanning a massive 84 feet.



Energy Management in Commercial Buildings

Commercial buildings account for nearly 20% of all energy consumed in the United States. Extrusions are making a major contribution to reducing the energy consumption – for both new buildings and major renovations – and leading toward “net zero” buildings.

Salt Lake City's Public Safety Building sets a new standard in creating a functional, energy efficient government structure in stunning Modern architecture. It is the first public safety building in the nation to be designed as a net-zero

energy building, generating as much energy as it uses. It also is one of the first public safety buildings designed to meet the U.S. Green Building Council's LEED® Platinum certification criteria. Aluminum extrusions are an integral part of the building's design and helped the architects reach those sustainability goals. Wausau Window and Wall Systems supplied the extruded aluminum thermal unitized curtainwall, windows, light shelves and sun shades for the project.

"A complete daylighting system provides shading from direct sunlight, glare protection and daylight redirection," explains Wausau's government/military market manager, Tom Mifflin, LEED Green Associate. "Lighting accounts for 40% of the energy used in a typical commercial building. Properly executed, daylighting can reduce HVAC peak loads with corresponding reductions in mechanical equipment capacity and carbon footprint."



The campus also includes photovoltaic panels within a glass awning framed by aluminum extrusions that extends from the main entrance onto a newly created outdoor plaza, generating energy to power electrical outlets that are available for public use. In addition, a rooftop photovoltaic panel system produces power for the building.

Extrusions are playing a major role in improving the efficiency of renovated structures as well. Transforming an existing building into a sustainable design requires careful analysis of how materials such as extruded aluminum work with technology to achieve high efficiency and dramatically reduce carbon emissions.

The Edith Green-Wendell Wyatt Federal Building in Portland, Oregon is a good example of how transforming an old building can reap energy savings and provide sustainable benefits. And, aluminum extrusions are contributing to that goal. The structure includes several features that utilize aluminum extrusion:

- Unique, custom “reed-like” aluminum extrusions were used as shading devices on the south, west and east facades designed to respond to the sun conditions, maximize daylight and minimize solar heat gain during the summer; the extrusions also provide a “trellis” to support vegetation for additional shading
- East and south facade light shelves were installed to provide daylighting 16 feet inward
- Extruded aluminum piping was utilized for a solar thermal hot water system
- A roof mount canopy was incorporated for photovoltaic and rainwater collection, generating 200,000 kWh/yr. and providing water for toilets, irrigation and mechanical makeup.





Solar Energy

Nevada Solar One, in Boulder City, Nevada, is the third-largest solar power plant in the world, generating electricity to power 40,000 homes in the Las Vegas area. Seven million pounds of extruded aluminum tubing and components are used in this parabolic trough solar collector system, forming 9,120 space frames over a 400-acre expanse.

Each space frame is produced to be warp-free, critical to supporting the system's 184,000 reflective mirrors, which affect the solar collectors' accuracy and efficiency. The framing

support design, featuring space frame technology called the Organic Connector, allows the mirrors to be 34-percent more accurate, translating to increased energy production.

Framing elements underwent punching, multihole drilling, and CNC fabrication. Efficient transport of 40,000 pounds of aluminum components per day to the power plant site was possible due to consistently high production volume and quality.

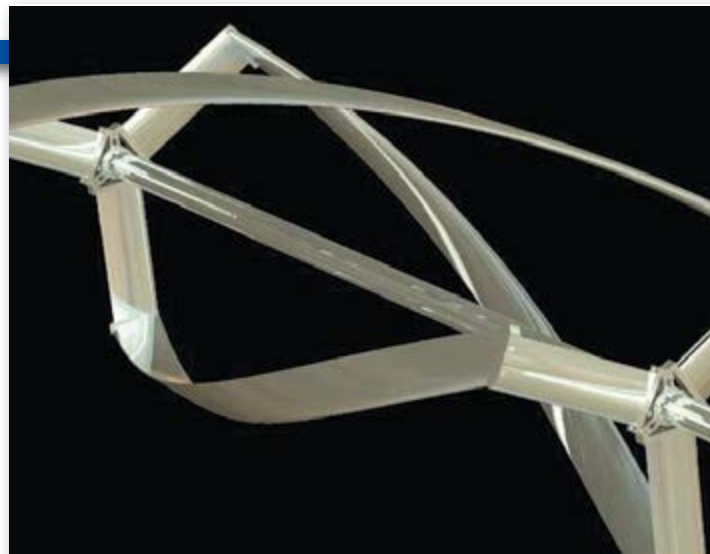


See www.etfdesign.org for more information on Design Competition winners.

Water & Wind Turbine

The Gorlov Helical Turbine (GHT), with its extruded aluminum blades, has proven a practical way to harness both hydropower and wind energy to generate clean electrical power. The GHT, an ET Foundation 2008 Design Competition Winner, features extruded aluminum blades and spokes that spin freely, regardless of water or wind direction.

The GHT's hydrokinetic technology for clean power generation is scalable, and ranges from a single unit to modular systems. The GHT functions anywhere there is moving water regardless of depth or direction. The extruded aluminum blade design generates smooth, vibration-free rotation that creates renewable energy without massive infrastructure or high cost, preserving water ecosystems without disrupting plants or animals. A single GHT module output provides up to 20kW, operating efficiently and accommodating off-grid sites. The 100-percent aluminum construction is self-starting, offering a lightweight, corrosion-free and recyclable energy solution that meets any system size requirements.



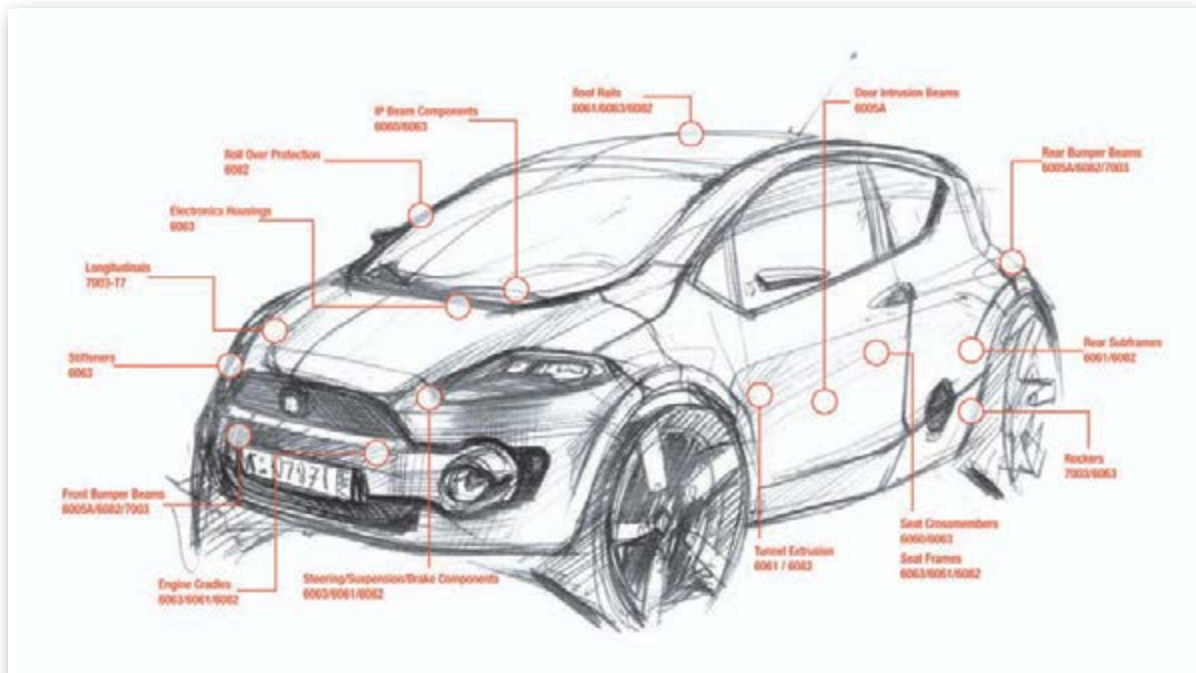
The vertical-axis GHT wind turbine system utilizes a gravity-based, rooftop mounting structure that is ideally suited for harsh wind conditions such as those on large flat roofs of industrial buildings. The 3.5kW rooftop system uses an airfoil-shaped helical twist design, generating lift throughout its rotation, capturing wind from any direction. The mobile and impermanent structure allows the system to be relocated to optimize power production. Single or multiple configurations harness wind power in urban environments and remote areas, alike.



See www.etfdesign.org for more information on Design Competition winners.

Improving Vehicle Efficiency and Environmental Performance

As auto builders, both in North America and around the world, strive to develop the fuel efficient and environmentally friendly cars and trucks that governments are mandating – and consumers are demanding – aluminum extrusion is playing a major role. Between 2012 and 2017, the weight of extruded shapes (not including extruded pipe & tube or rod & bar) per North American car, SUV or light truck increased by nearly 70%, to about 27 pounds per vehicle. And projections suggest a further increase of another 50% by approximately 2022.



The reason for this dramatic growth is clear: reducing the weight of vehicles – or lightweighting as the industry calls it – is a key strategy in improving fuel efficiency and reducing vehicle emissions. Ducker Worldwide estimates that lightweighting will produce at least 15% of the efficiency improvements needed to meet future demands; improved aerodynamics, multi-speed transmissions and improved – or alternate – powertrains will provide the balance of the improvement.

So where are aluminum extrusions being used? Throughout the vehicle, with applications that range from exterior trim to “crush cans” for crash management, to the vehicle structure and more!

Perhaps the first contemporary North American volume vehicle to make extensive use of aluminum extrusions was Tesla’s Model S, introduced in 2012 with more than 25 extrusions in its aluminum-intensive body. But the landmark was the redesign of Ford’s F-150 pick-up truck, the company’s (and North America’s) best-selling vehicle in 2014. The F-150, with its all-aluminum cab and bed, hit the streets with a body-in-white weight roughly 400 pounds less than a key segment competitor; a weight saving that Ford turned into improved towing, performance and efficiency. The F-150 makes extensive use of extrusion in the cab structure (shown above), with over 40 pounds of extrusion per vehicle.



The basic F-150 architecture has subsequently been incorporated in Ford’s Expedition model and is slated for the 2020 redesign of the Explorer, bringing the benefits of aluminum (and extrusions) to these popular SUVs.

General Motors hasn’t been letting Ford pursue aluminum all alone, however. GM’s 7th generation Corvette, launched in 2014, features an all-aluminum chassis, with plenty of extruded components; the Corvette was followed by a new Cadillac flagship, the CT6, introduced in 2016 with a body-in-white of 60% aluminum.



Cadillac CT6; © General Motors

Aluminum extrusions appear throughout the CT6 structure, with multi-void hollows utilized for the rocker and engine cradle assemblies, and contribute to a weight reduction of about 220 pounds as compared to a similar steel-intensive vehicle. Cadillac engineers also point to improved stiffness, handling, and comfort.

Electrification - The Next Vehicle Chapter

While ongoing lightweighting of today's "conventional" vehicles will lead to more and more extrusion content, there is another change coming that will further extrusion's contribution. That change is the move away from internal combustion engines and towards electric vehicles. In response to increasing demands for reduced carbon emissions and future mandates banning Industrial combustion vehicles in a number of major cities and countries, almost every auto builder has announced aggressive programs to roll out electric vehicles. For example, Volvo has announced that every vehicle launched from 2019 forward will offer either: a gasoline engine with a 48-Volt mild-hybrid system, a plug-in hybrid (PIH) system with both gasoline and electric motors or a full battery-electric (BEV) system. General Motors will build on its experience with the electric vehicle (EV) Chevy Bolt, and launch 20 new all-electric vehicles by 2023.

In such an environment, the lightweighting provided by today's extrusion applications translates into additional battery range, a key to customer acceptance. But extrusion will also end up in new applications specific to EVs. Battery cases will be one such application, where extrusion's thermal properties will be utilized to keep batteries at reasonable operating temperature. Similarly, extrusions will be utilized to house and cool the electronics for battery/drive system management. And, we will find extrusions as housings for the electric drive motors, such as this housing currently in use for a heavy truck application.



See www.etfdesign.org for more information on Design Competition winners.

This complex extrusion houses a 100 horsepower (continuous duty rating) electric motor located at each rear drive wheel of a heavy duty truck. Each of the multiple orifices located circumferentially around the actual motor housing is serrated to increase surface area and the efficiency of the cooling fluid which flows through the orifice.

Whether your future vehicle will be a fairly straightforward evolution of today's design, will be powered by batteries or hydrogen, or is fully autonomous so you can just sit back and enjoy the trip, the one certainty is that there will be a substantial volume of aluminum extrusions incorporated in the vehicle.

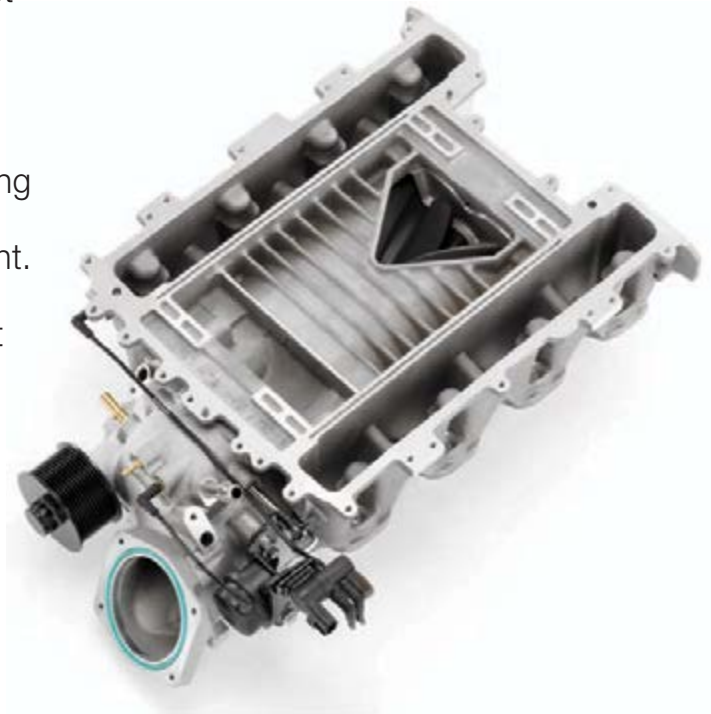


Aluminum Impeller

The extruded aluminum impeller for this revved-up Twin Vortices Series (TVS) supercharger means improved efficiency at half the previous size for a given volume of airflow. The new four-lobe design handles airflow with a unit pressure ratio of 2.6:1, rather than the previous 2.0:1, with a maximum speed of 24,000 revolutions per minute (rpm) rather than 18,000 rpm. The manufacturer used computer modeling to examine airflow dynamics and perfect the extruded four-lobe design to yield vastly improved airflow.

This engine-driven supercharger is as efficient as competing exhaust-driven turbochargers, achieving reduced parasitic losses by 35 percent, and making the unit 13-percent more thermally efficient. The rotors now have four lobes each, which twist 160 degrees about the rotor's axis, matching inlet air velocity to the rotor mesh's velocity as it progresses forward. With a matched velocity inside the supercharger, its improved efficiency makes for a quieter and more powerful supercharged engine.

For more information, visit AEC.org and click on Extrusion Applications, and "What is it?"



Mass Transit Bus

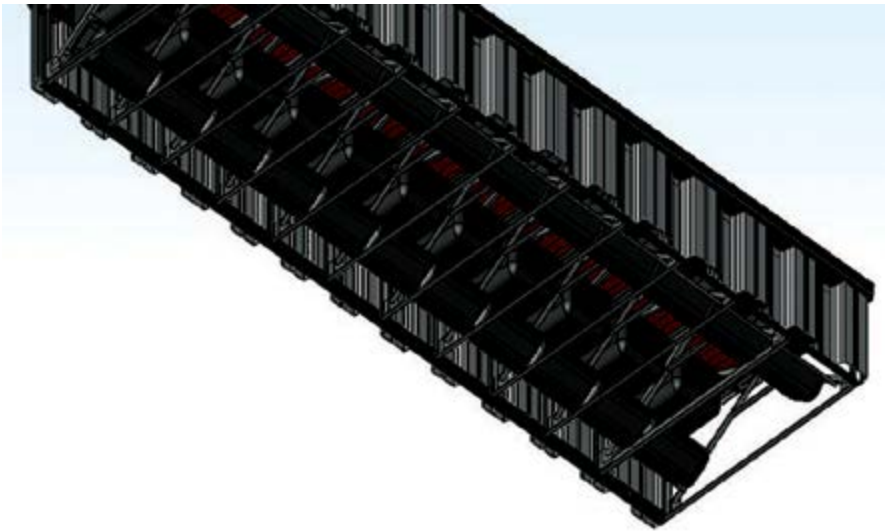
Mass transit buses with aluminum space-frame technology, which debuted in service at the 2008 Beijing Olympic Games, offer an advanced generation of energy-efficient, environmentally friendly buses for ever-growing throngs of commuters. Choosing aluminum to reduce bus weight and save fuel while maintaining structural safety is essential to achieving sustainable transportation.

The lighter bus features an extruded aluminum space frame and door frames, helping to reduce bus body weight by 46 percent, compared to traditional steel bus bodies. A study by the Institute for Energy and Environmental Research in Heidelberg, Germany, shows that a weight reduction of 220 pounds in a diesel-powered city bus saves 674 gallons of fuel over its lifetime, significantly reducing carbon dioxide (CO₂) emissions and maintenance costs over its lifetime. This new lightweight family of “green” buses will continue to achieve greater fuel economy and improve air quality worldwide.



Floating Breakwaters

This eco-friendly aluminum floating breakwater (FB) system's extruded aluminum modules are designed for wave attenuation to save eroding coastlines and protect marinas and harbors from extensive wave damage. The aluminum FB system resists harsh marine corrosion, and alleviates foundation and erosion problems that can occur with other types of breakwaters. Aluminum extrusions form the main structural elements in the FB, chosen for their low modulus of elasticity, high strength, energy absorption, and ability to bend slightly to dissipate waves.



Custom hollow aluminum extrusions improve torsional rigidity for efficient performance and reliability in winds up to 74 miles per hour. Heavy-duty tracks, integrated into the design's exposed edges, allow easy attachment of ladders, cleats, bollards, and pedestals. The modular system's flexible joints between 40-foot sections enable the floating breakwater to withstand the peculiar stresses of this challenging marine environment. The high-performance FB system at Old Port Cove Marina in North Palm Beach, Florida, a "clean marina" renovation, protects vessels and supports pilings.

Trailer/Camper

The innovative multiconfigurable GO Trailer uses 13 unique aluminum extrusions in its frame structure and converts from a low-profile travel trailer to a comfortable camper in just minutes. The rugged aluminum frame structure handles on- and off-road terrain, and is light enough for most vehicles to tow. The framework's high-performance requirements of tight-radius curves and intricate connection points are met by extruded aluminum, which offers high-quality, attractive components that are strong, durable, and corrosion resistant.



The GO trailer's design optimizes aluminum extrusion's ability to form complex shapes, incorporating multifunctional aluminum components and reducing the overall part count. Aluminum keeps the trailer's weight to just 700 pounds (325 kilograms), yet hauls home-improvement materials, bikes, boats or ATVs with ease. The GO sport trailer/camper is a Grand Prize winner of the ET Foundation's Design Competition for its innovative and versatile framework design.



See www.etfdesign.org for more information on Design Competition winners.



Bicycle Wheel Rims

Offering a smooth, responsive ride for racing or triathlon training this aerodynamic bicycle wheel rim is the lightest deep-section clincher rim in the world. The aluminum rim's profile, low spoke count, and bladed spokes slice the wind to hold high cruising speeds. Aluminum has enough ductility to be rolled into a consistent curving bend, yet achieves the strength and stiffness needed to avoid shattering in a crash. A patented process is used to roll large sections of aluminum extrusions into very thin-walled wheel rims without buckling. Rims are then heat-treated and anodized in preparation for powdercoat painting and baked-on transfer decals.



Aluminum's toughness and corrosion resistance give the rims a deep profile that sheds mud. Choosing aluminum extrusions for bicycle rims allows for ease of production and fabrication at the lowest cost using the highest-strength alloy to achieve consistent bend and thickness for the best racing bike wheel possible.

Volleyball Uprights

Used for major national and international high school and college events, this aluminum upright volleyball system uses high-strength extruded aluminum for light weight and easy set up. The aluminum extrusion tubing adjusts easily for men's or women's regulation net height. Each upright is fabricated from 0.266-inch extruded aluminum tubing, with the upright pair weighing 35 pounds. Uprights are 88-inches long, have a powder-coat finish, and extruded aluminum tube pistons telescope into the uprights, held in place by a spin-lock mechanism. Strength and precision, made possible by hollow extruded aluminum tubing, allow continuous fine adjustments to achieve correct net height for any situation to meet established specifications.



New Wave Truss

Aluminum extrusions provide the versatility and variety needed for this next generation in truss design used for eye-popping displays for the trade show, retail, corporate, and entertainment markets. The unique extruded aluminum truss structures in 6-inch by 6-inch cross-sections feature profiles cut on an angle with perpendicular end frames formed from extruded profiles. The attention-grabbing trusses use these perforated plates bonded to the main chords that pass through them, rather than using traditional welded assemblies. The OMNI connector system provides many 2-D and 3-D assembly possibilities without custom fabrication. Anodizing produces a range of colors and textures that goes beyond the typical polished silver and powder-coated finishes.

This award-winning extrusion design combines color, lighting and electrical discharge machining (EDM) to incorporate logo branding, names or messages directly into the truss.



See www.etfdesign.org for more information on Design Competition winners.



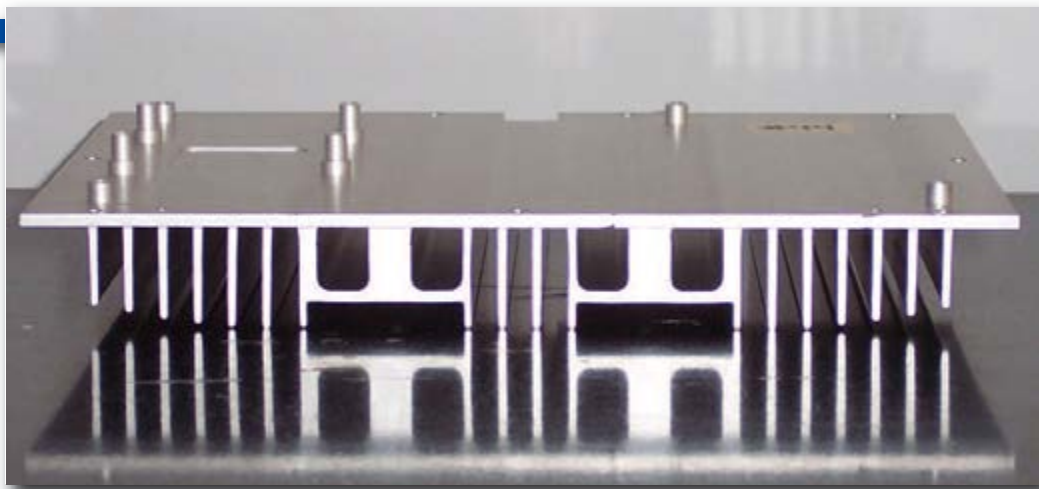
Trade Show Booth Structures

This trade show booth is constructed exclusively from aluminum extrusions, making it easy to install, dismantle, and transport to any exposition site. Such exhibit displays are light, yet strong, and support signs, lighting, and attachments in almost any size and configuration imaginable. Round, 1.25-inch extruded aluminum tubing incorporated into such exhibit displays may also be used to support top canopies.

Heatsink

This heatsink, used in a touch-screen kiosk, represents a highly engineered custom part. The original design incorporated standoffs that were to be inserted into milled holes located on the bottom of the heatsink. However, the locations of the standoffs were directly under the fins and/or hollow areas of the profile and could not be altered due to mating components and assembly requirements.

A unique solution was devised to extrude the additional metal on the bottom of the heatsink where the standoffs were to be located and CNC (computer numerically controlled) machine the area to mill away the excess material, thus creating the standoffs as built-in features of the extrusion itself. The extrusion process enabled the manufacturer to create a less costly part without compromising the end product's overall integrity. Made from 6063-T6 aluminum alloy, this award-winning heatsink demonstrates how aluminum extrusion can help designers apply unique and practical solutions to complex problems. And that's just what extrusions are intended to do.



See www.etfdesign.org for more information on Design Competition winners.

Sign Cabinet

This 6-foot by 4-foot sign cabinet uses three extruded aluminum components: a 9-inch frame; a 9-inch frame with retainers, and corner angles used as retainers. The lightweight aluminum extrusions, made from 6063 T5 aluminum alloy, feature corner angles that provide removable retainers on the cabinet's short sides, allowing for easy servicing and cleaning.

Typically used for business signs, the extruded sign cabinet may be attached to a wall by back straps at its top and bottom corners, or pole or swing mounted. Its sturdy design withstands the elements, and has been welded and wired to UL specifications.



With an aging population in developed countries and on-going improvements in medical therapies, it's no surprise that medical devices are a major focus of innovation – and that aluminum extrusions are playing an important role in products that range from low to high tech.

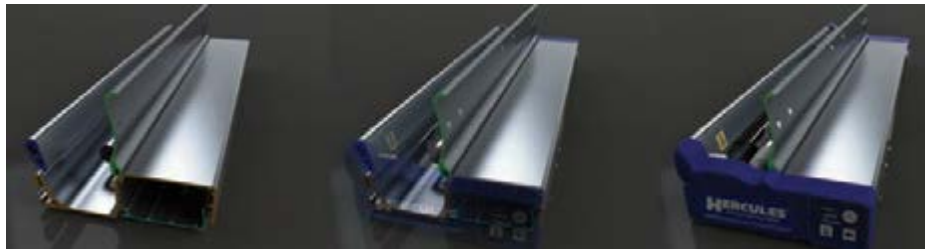
Patient Repositioner

Aluminum Extrusion and the extrusion industry played an integral role in the design, engineering, and eventual success of the Hercules Patient Repositioner, an excellent example of how aluminum extrusion can be utilized in this growing industry.

The repositioner uses a special sheet that rolls into the aluminum housing, pulling the patient back up to the top of the bed. With Hercules, it takes a single caregiver 10 seconds and the push of a button to easily and comfortably reposition a patient in the bed, according to the company.



See www.etfdesign.org for more information on Design Competition winners.



The unit is comprised of several unique aluminum extrusions assembled to act together for smooth operation, including the main

extrusion that separates the sheet tray area from the electronics area that houses the motor, clutch, circuitry, and power supply. "Creating a chassis that can handle the 600 in/lbs. of torque and still be small enough to fit under a cutout in the mattress made aluminum the natural choice," said David Hornbach, Senior Product Designer for The Morel Company in Batesville, Indiana. Other advantages included extruded aluminum's recyclability, strength-to-weight ratio, low tool cost, and the ability to design for reduced part count. Explaining the creative geometry that the extrusion design process affords, Hornbach noted, "The external shapes of some of the components (mainly the waterfall edge) are precise and are integral to the efficiency of the system. This geometry would be difficult to produce with other processes." In addition, using extrusions for this design saved the company money.

"The aluminum extrusion community has done a terrific job making design data accessible for engineers. All tolerances and expectations were known before even meeting with a vendor. This took the 'black art' out of the design process and helped the Morel engineers have the initial designs 'manufacturing ready'. The use of aluminum extrusions allowed us to bring [this product] to market quickly with low overhead and the lowest part total possible."

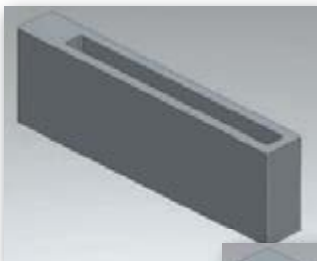
Oncology Radiation Therapy Equipment

Leading radiation oncology equipment company, Accuray, relies on tightly orchestrated relationships with its component suppliers to help design, develop, and integrate components for its TomoTherapy® System. When a failing steel coupling threatened to derail the system's industry-leading reliability, the company looked to aluminum extrusions to provide an immediate solution.

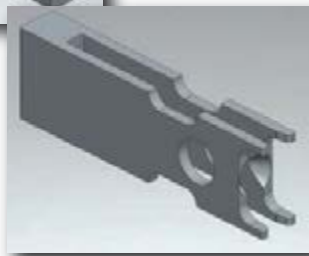
Sixty-four mechanical "leaves" shutter open and closed to deliver the system's prescribed dosage of radiation to diseased cells. But the couplings (initially machined from stock steel using electrical discharge machining) used to connect the leaves with the actuator, would break and prompt a system error causing the machine to safely shut down.



Design engineers with medical market expertise from Alexandria Industries in Alexandria, MN worked closely with Bradley Brunker, a senior sustaining engineer from Accuray's Madison, WI campus, to find a solution for the failing couplings. They identified slight variations from the original design that would improve the part's overall strength and durability and assure repeatability from the extrusion die tooling. Enhancing the aluminum alloy mechanical properties to prevent breakage, the new couplings were extruded, machined and hard-coat anodized, increasing wear resistance and simplifying mating assembly for an intended snap-fit design.



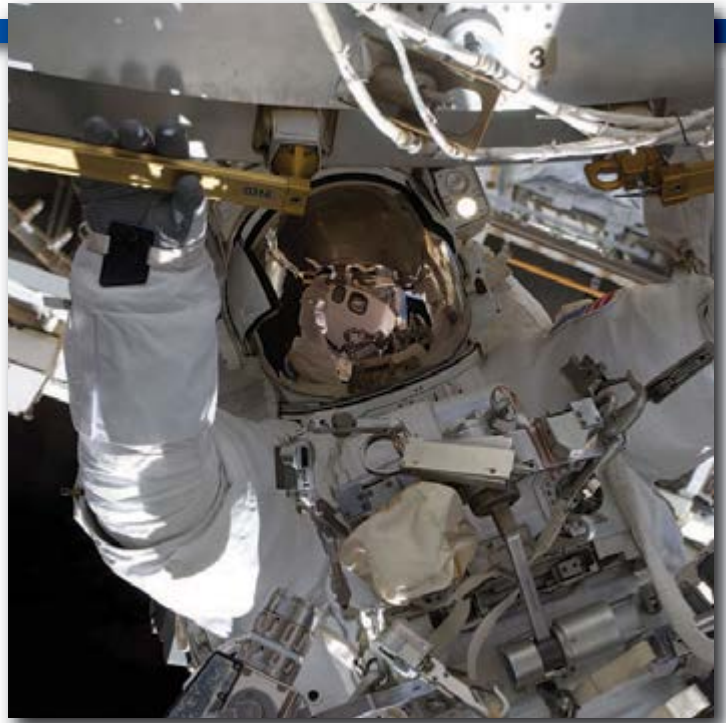
Using aluminum extrusion cut assembly labor by 30 to 60 minutes and cut component manufacturing costs by nearly 90 percent, which took only a quarter of the time to produce. And, because of the couplings' snap-fit geometry, Accuray also was able to eliminate a tool previously used for assembly.



Accuray saved on parts, labor, and cost while increasing the durability of the components and ensuring performance reliability by using aluminum extrusions.

International Space Station

The largest technology-intensive construction project ever undertaken by humankind, the International Space Station (ISS), is the ongoing joint venture of six space agencies: the National Aeronautics and Space Administration; the Canadian, European, Russian, and Italian Space Agencies, and the National Space Development Agency of Japan. The ISS's extruded integrated truss sections span the length of a football field (310 feet). Astronauts are building the extruded aluminum truss structures while anchored by, and tethered to, extruded aluminum handrails. More than 2,100 bright-gold anodized extruded aluminum handrails are attached throughout the space station for dual use as grab handles for the astronauts, and attachment points for lifelines and millions of dollars in scientific and exploration equipment during extra-vehicular activities (EVAs). Astronauts depend on aluminum extrusions for a safe handhold in space on every EVA during more than ten years of missions.



Twelve extruded aluminum truss segments form the structural framework that houses the cooling system and photovoltaic arrays that power the ISS living quarters. Module and node facilities house five experiment labs, airlock and docking compartments, and exploration equipment such as robotic arms. The ISS takes advantage of aluminum extrusion's light weight, corrosion resistance, and critical structural strength in the extreme cold of space to provide reliable service for years to come.

Acknowledgments and Photo Credits

The Aluminum Extruders Council gratefully acknowledges the following companies for their participation, and thanks them for providing information and images for the Applications Section of this Manual (starting on page 1): Kawneer Company, Inc.; CST Covers; Schüco International KG; Dallas Cowboys, Arlington, Texas and Oldcastle BuildingEnvelope™, Santa Monica, California; MAADI Group; Okland Construction; Nik Lehoux Architectural Photography; Roll-A-Cover International; Panda Windows & Doors; Gossamer Space Frames/Acciona Solar Power; Lucid Energy Technologies; Almag Aluminum/Wrightspeed; Hydro Aluminum North America/General Motors Corporation; Alcoa/Zhengzhou Yutong Bus Company; MAADI Group/Technomarine; Sylvan Sport; American Classic; Spalding Equipment; Total Structures Inc.; Classic Exhibits, Inc.; ET Foundation/General Extrusions, Inc.; The Loxscreen Company; The Morel Company; Accuray; Alexandria Industries; NASA/Johnson Space Center.

For more mini-case examples of aluminum extrusion applications, visit AEC.org/ApplicationFeatures

Section
3

The Aluminum Extrusion Process



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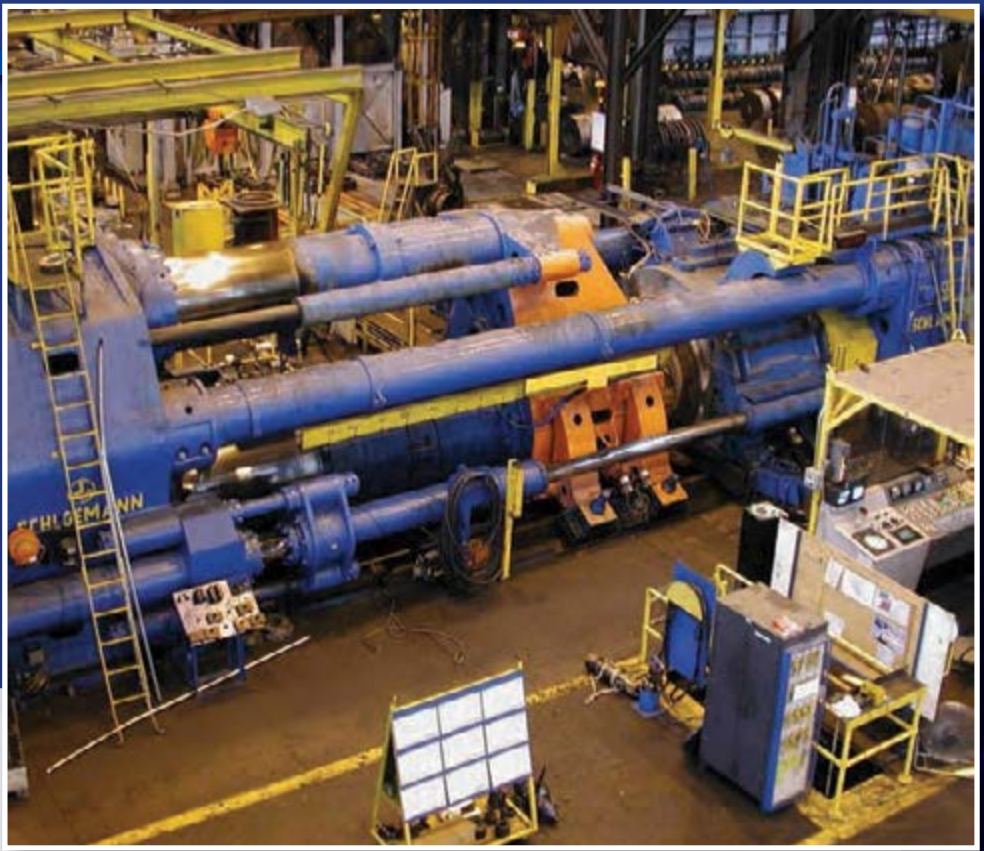


Photo courtesy of Alcoa, Inc.

The Aluminum Extrusion Process

The aluminum extrusion process involves the use of a hydraulic press to force heated (still-solid, but malleable) aluminum alloy through a steel die. The resulting aluminum profile assumes the shape (in cross-section) of the die opening.

The process also involves the use of other equipment before and after the material runs through the press.

The starting material for extrusion, known as billet, is cut to the desired length and heated in a furnace prior to extrusion. After leaving the press, the aluminum profile is quenched (cooled), then subject to a variety of additional handling systems.

The extrusion process follows a few simple steps, but can yield a multitude of shapes and forms.



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The Aluminum Extrusion Process Begins with Aluminum

Aluminum is the most abundant mineral in the earth's crust. In nature, however, it typically does not occur in its pure form, so it must be extracted and refined to be put to use.

Although its use has been traced to 300 B.C., it was not until 1886 that an economically feasible process was developed for commercial production of aluminum. Within days of each other, two inventors--Charles Martin Hall in the U.S. and Paul Heroult in France--working independently and completely unaware of one another's work, each discovered the basic process by which aluminum is still produced today.



The extrusion process allows designers and engineers an almost limitless number of configurations and complex shapes, including this awning bracket (above left) which replaced a three-piece assembly. Aluminum extrusion was also chosen for this modular, demountable interior wall system (above right) because it offers a noncorrosive natural finish, as well as nonmagnetic properties. Aluminum's lightweight strength, durability, and corrosion resistance offer the transportation industry many advantages, as seen in the aluminum body shell (below) for this French next-generation high-speed train, the AGV (Automotrice à Grande Vitesse).

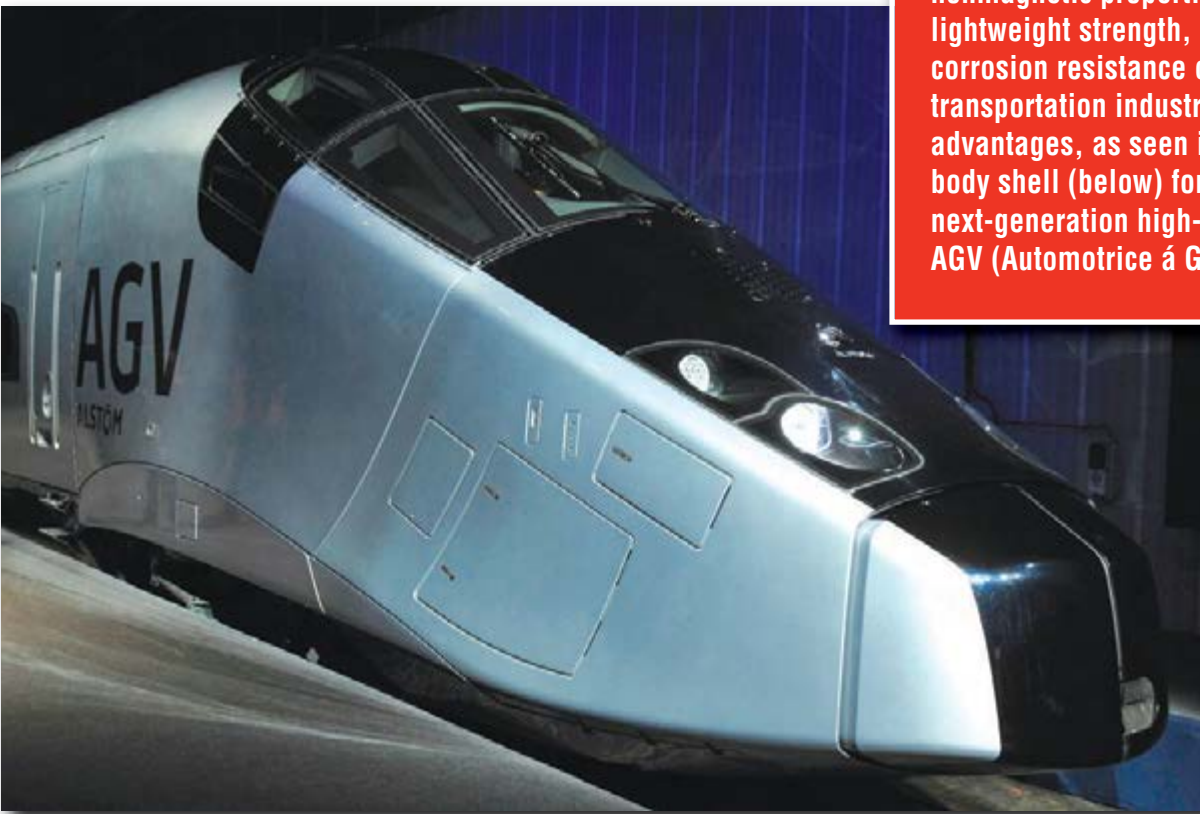
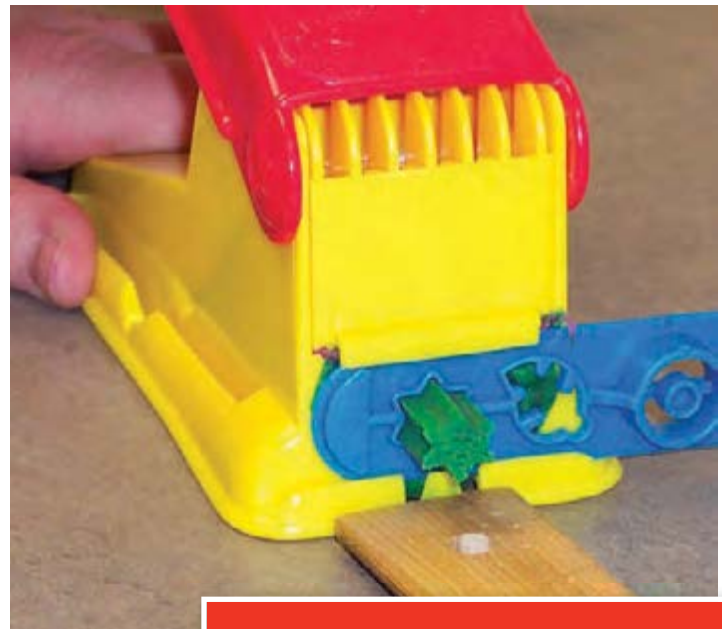


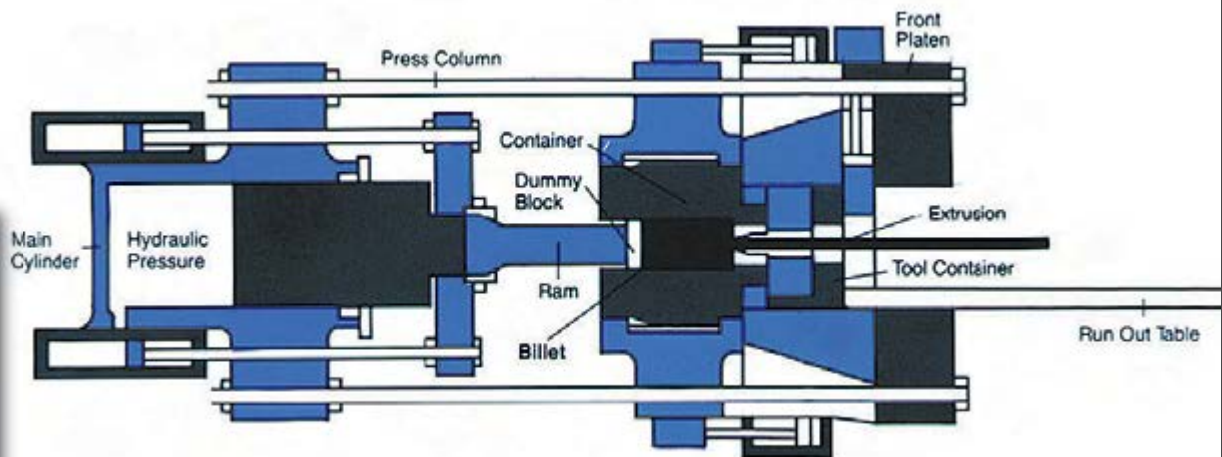
Photo courtesy of Alstom.

Aluminum is the lightweight, high-strength metal of choice for thousands of products. This recyclable, environmentally friendly material is refined from bauxite to produce alumina. It is then “smelted” through an electrolytic and chemical process that generates heat and produces molten aluminum. Other elements are mixed with the aluminum to produce alloys required for most applications. It is then cast into ingot or log form.

Aluminum extrusion is the most innovative forming process for this versatile metal, allowing designers to exercise their creativity and stretch their imaginations to design profiles that meet their exact, specialized needs.



Like modeling clay, the aluminum is not liquid, but rather a malleable solid at the time of extrusion.



Unlike a simple child's toy, an aluminum extrusion press is composed of many different parts that function together.

The Aluminum Extrusion Press

The basic principle of extrusion is as simple--and complex--as forcing modeling clay through a toy press as shown on page 2.

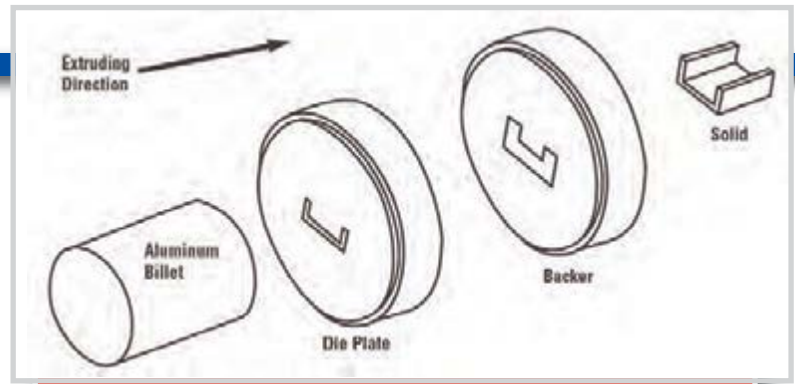
Pressure applied on the lever forces the clay to flow through the open end.

The shape, or profile, of the clay as it emerges reflects the shape of the opening through which it has been forced. Simple openings produce simple shapes; complex openings produce complex shapes.

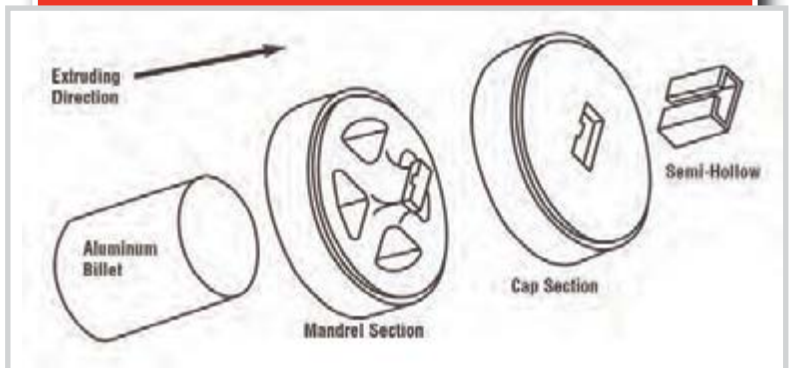
The force in an extrusion press is applied by a hydraulic ram, which uses from 100 tons to 15,000 tons or more of force to push heated aluminum through the container and out the die. The amount of force an extrusion press is able to exert dictates the size of the profiles it is capable of producing. The higher the tonnage of the press, the larger the possible extrusion. The container of the extrusion press is a hollow chamber constructed of steel and generally fitted with a removable liner. The container has an inside diameter just slightly larger than the billet to be extruded, and holds and confines the billet during the cycle.

The die is a steel disk at the end of the container; aluminum is forced through the opening(s) in the die to create the extruded product.

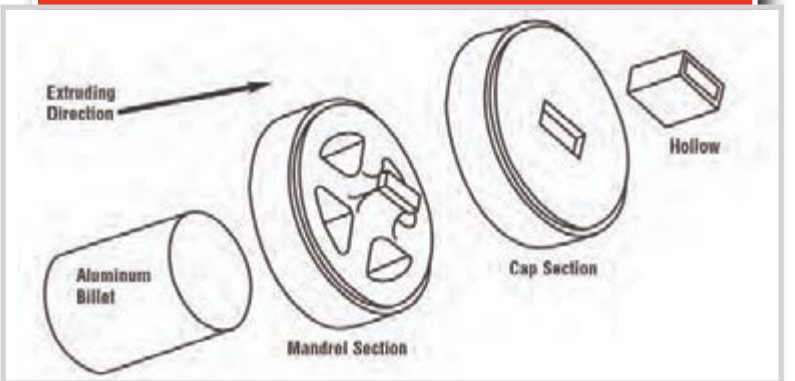
Aluminum extrusion dies are available in three basic categories: solid, semihollow, and hollow. The names describe the shape of the extruded profiles, and each category has specific applications and advantages. (For a more detailed explanation of dies and die categories, refer to Section 5, Extrusion Dies.)



Solid dies have one or more openings, and produce extrusions without any enclosed internal voids. The opening in a solid die has the exact cross-sectional profile of the extruded shape. Solid dies are used primarily in the production of bars, channels and angles, as well as many custom shapes.



Semihollow dies produce shapes that include partially enclosed voids with "open" profiles. The void has an area which is generally in a ratio of three-to-one larger than the tongue of the die. (See Section 5 for a more detailed explanation of semihollow dies.) Semihollow dies are used most often in the production of atypical channels and other custom shapes.



Hollow dies produce shapes that include an entirely enclosed internal void and have "closed" profiles. Hollow dies require two components, a die cap and a mandrel section, in order to produce required shapes. Hollow dies produce tubes and many custom hollow shapes.

The Extrusion Process

Raw aluminum in ingot form is melted and mixed with various combinations of metallic elements (and, sometimes, silicon) to form aluminum alloys. Each alloy has specific characteristics matching application needs. The alloyed material, in ingot form, is then carefully cast into logs. These logs are later cut, to extruder specification, into a form known as billet.

Fahrenheit (approximately 400 to 480 degrees Centigrade), it is loaded into the container of the extrusion press.

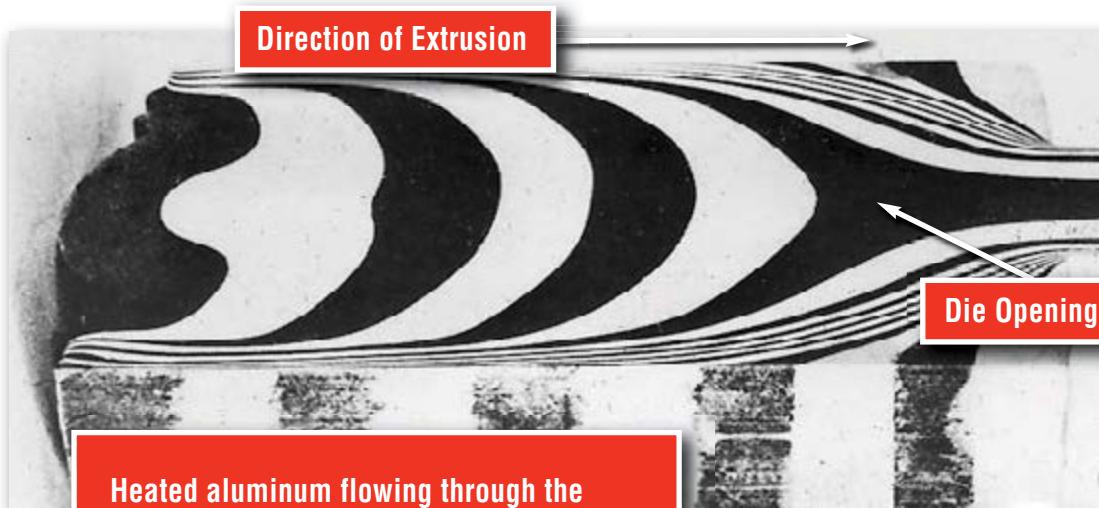
Hydraulic force is applied by a ram, pushing the billet up against the die, and bringing it into full contact with the container wall. Once full contact is established, the pressure increases and the heated metal is

pushed through the die opening to emerge on the other side as a fully shaped profile.

Extrusion presses operate in cycles, with a cycle defined as one thrust of the hydraulic ram. The length of time it takes a press to go through one cycle

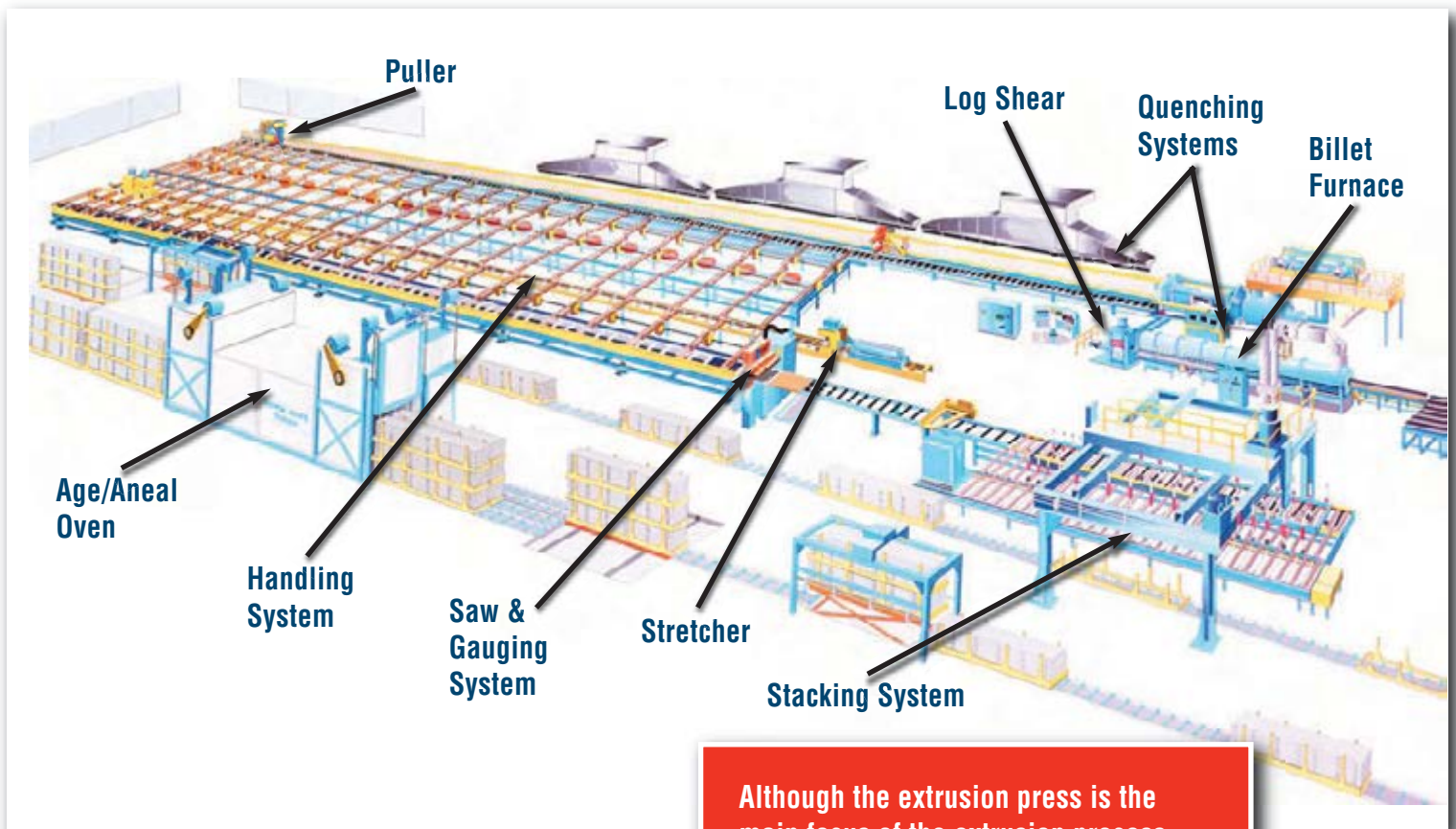
is related to alloy, billet size, number of holes in the die, and the shape of the extrusion.

Depending on the alloy, a complex shape may emerge from the press as slowly as one or two feet per minute; while a simple shape may be extruded at a rate of more than 200 feet per minute. Taking various factors into consideration, a continuous extrusion as long as 300 feet may be produced with each stroke of the press. Pullers are commonly used to facilitate handling the hot and fragile profiles as they emerge from the die.



Heated aluminum flowing through the container and out the die is represented here, with the direction of extrusion from left to right. Note that the center of the billet advances more rapidly than the periphery, causing the surface segregation oxide to cling to the container wall, collecting in back-end residue. (The dark lines are copper bands, placed as markers to illustrate the flow of metal.)

Heating the aluminum for the extrusion process is accomplished either electrically through induction heaters or through the use of gas-fired furnaces. Once the aluminum has reached a specified temperature, generally ranging from 750 to 900 degrees



Although the extrusion press is the main focus of the extrusion process, many other pieces of equipment are required to make an aluminum extrusion. In addition to the press, the illustration depicts a billet furnace, quenching system, log shear, puller, age/anneal ovens, handling equipment, saw and gauging system, stretcher, and stacking system.

Technology Enhances Press Performance

A virtually unlimited array of options, features, and mechanical enhancements greatly affect efficiency and product quality for aluminum extruders today. From the way the aluminum billet is prepared for the press, to the way the raw extrusion is handled once it leaves the press, new technology is transforming the aluminum extrusion industry.

New technologies enhance the way billets are heated, cut, and otherwise prepared for the press. Following the press, technology influences the way extrusions are cooled, cut, moved, handled, and packaged.



Prior to entering the press container, the aluminum billet is heated, bringing it to a malleable state.

The furnace is the start of the extrusion process, and today's highly efficient furnaces include multiple capabilities that enhance the process and help to ensure a quality extrusion. Equipped with programmable logic control (PLC) monitoring systems, all variables of the operation are monitored, including individual temperature zones. In addition, today, many furnaces are interfaced with a log shear. Prior to entering the press container, the heated log can be cut to exacting billet length specifications with a log shear to increase yield and reduce scrap.



The extrusion press is a complex piece of equipment, accurately controlled and monitored to ensure efficiency and safe operation.

Courtesy of Hydro Aluminum

The extrusion press hydraulic system has undergone, and continues to undergo, remarkable technological advances. Today's presses feature stand-alone (self-contained) hydraulic pumps and valve systems. The hydraulic systems are designed to provide precise closed-loop speed control intended to enhance extrusion quality and maximize productivity. Additionally, the system minimizes hydraulic shock and leaks, and the filtration systems maintain clean fluid throughout the system. Computer/PLC systems control and track all variables of the process, including extrusion force, ram displacement, and ram velocity.

Quenching cools the hot extrusion as required to achieve the final mechanical properties.

Various quenching methods are now available to rapidly cool the extrusion once it leaves the press. Among the many methods are air, mist, water spray, and water bath. While each method has its advantages, they all share the goal of quickly and consistently cooling the extrusion. The advancement of

pullers, including the introduction of double pullers, has greatly increased efficiency, saved on labor, and reduced profile twist downstream of the press. Today's pullers are capable of locating and cutting extrusions at the die mark and "on the fly." Run-out tables now feature conveyors as well as belt systems, which move the extrusions to cooling tables and fully automated stretchers, all the while protecting the critical

surfaces of the profiles. Material handling systems today include sophisticated devices that automatically move, batch, load, stack, and destack profiles into staging areas and work centers, without marring the product finish.



Material handling systems are critical to quality extrusions. Automated systems efficiently move cooling extrusions without damage.

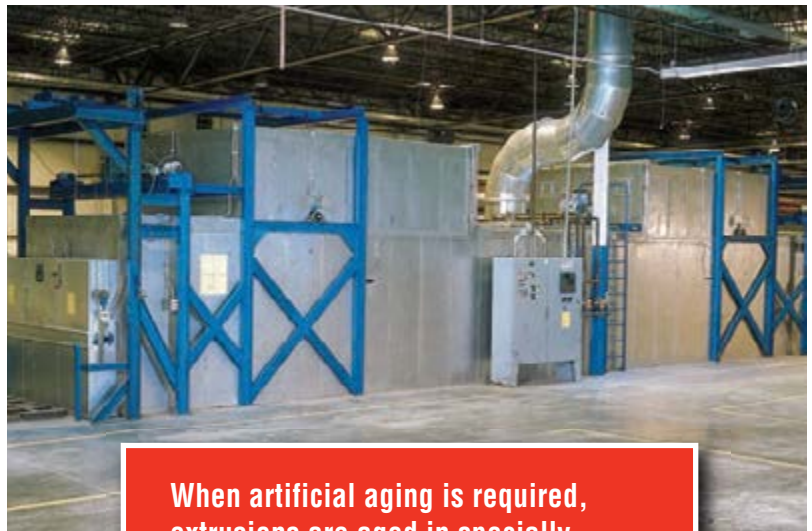
Exit and Quench Temperature Data for Selected 6xxx-Series Alloys

Alloy	Min. Press Exit Temp (deg-F)	Critical Cooling Rate (deg-F/sec)	Critical Cooling Range (deg-F)	Cooling Time (sec) at Minimum Cooling Rate	Cooling Time (sec) at Maximum Cooling Rate
6063	930	2-3	840-480	180 (at 2 deg/sec)	120 (at 3 deg/sec)
6463	930	5	840-480	72 (at 5 deg/sec)	72 (at 5 deg/sec)
6063A	930	3-5	840-480	120 (at 3 deg/sec)	72 (at 5 deg/sec)
6060	930	3-5	840-480	120 (at 3 deg/sec)	72 (at 5 deg/sec)
6101	930	3-5	840-480	120 (at 3 deg/sec)	72 (at 5 deg/sec)
6005A	950	5-15	860-480	76 (at 5 deg/sec)	25 (at 15 deg/sec)
6061	950	10-20	860-480	38 (at 10 deg/sec)	19 (at 20 deg/sec)
6082	950	10-20	860-480	38 (at 10 deg/sec)	19 (at 20 deg/sec)
6351	950	10-20	860-480	38 (at 10 deg/sec)	19 (at 20 deg/sec)

Note: Press exit temperatures refer to the temperature of extrusion at the platen. These are a guide. Actual die exit temperatures are significantly higher.

Extrusion Process Establishes Temper and Mechanical Properties

The completed extrusion, which had achieved temperatures ranging from 900 to 1,100 degrees Fahrenheit or 480 to 595 degrees Centigrade (typical for 6xxx alloys) inside the press, begins to cool immediately after exiting the press. This process of heating and cooling sets up the temper and mechanical properties of the extrusion, including tensile strength, yield, and elongation. Once it has left the press, the profile may be quenched, mechanically adjusted, and aged to meet specifications.



When artificial aging is required, extrusions are aged in specially designed furnaces using appropriate thermal cycles for the alloy and final temper desired.



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Finishing Extruded Aluminum



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Finishing Extruded Aluminum

As soon as mill-finish aluminum is exposed to the atmosphere, an oxide layer begins to form at the surface. For many applications, aluminum profiles require no more protection than this thin, transparent oxide film. However, aluminum profiles can be treated with a wide range of finishes wherever additional protection or an enhanced appearance is desired.

Mechanical Finishes are available in a variety of textures, produced by a variety of mechanical methods such as sanding, polishing, grinding, buffing, or blasting.

Pretreatment refers to specific processes used to prepare the surface of the aluminum profile for subsequent finishing.

Chemical Finishes include etching, which yields a frosted surface appearance, and bright-dipping, which produces a very shiny, specular finish.

Anodizing is an electro-chemical process that allows aluminum profiles to retain their metallic luster while accepting durable and vibrant color.

Liquid Coatings include a broad range of paints—such as polyesters, acrylics, siliconized polyesters, and fluoropolymers—available in a virtually unlimited array of colors.

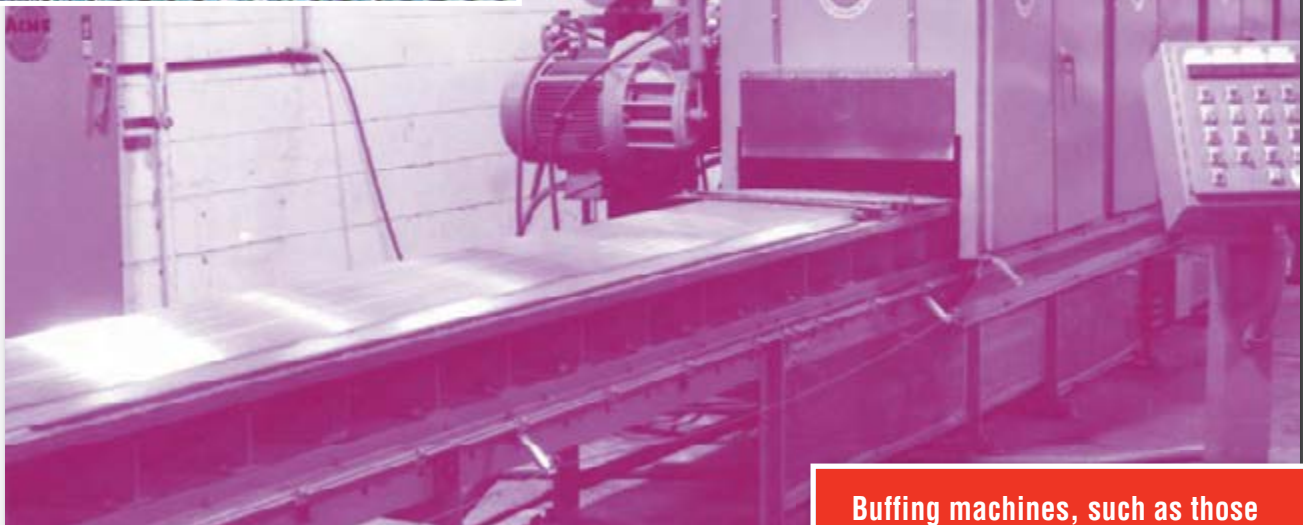
Powder Coatings provide a durable finish with little or no use of solvents; they are gaining use where volatile organic compounds (VOCs) are problematic.



Mechanical Finishes

For many applications in the mill-finished state, aluminum needs no protective coating. When exposed to the air, aluminum develops a thin, transparent oxide film that naturally protects the surface. Wherever additional protection or decoration is desired, aluminum accepts many types of finishes, giving it a versatility unmatched by any other metal.

Aluminum can be given many different types of surface texture—from rough or patterned to a mirror finish—by a variety of mechanical methods: sanding, polishing, buffing, tumbling, burnishing, abrasive blasting, shot blasting, or glass bead blasting. These methods may be applied as a final surface finish, or to improve surface quality, or as preparation for a variety of final cosmetic finishes.



Buffing machines, such as those shown here, can polish aluminum profiles to a bright, mirror-like finish.

Pretreatment

Pretreatment is the preparation of aluminum for subsequent surface finishing. For profiles to be liquid-painted or powder-coated, this process usually includes cleaning/etching of the aluminum and the application of a pretreatment coating. The cleaners may be selected from either alkaline or acidic materials. Some cleaning may be mechanical, such as shot or sand blasting. The pretreatment coatings are applied to the cleaned surface and serve two main functions: to enhance powder or paint adhesion and to provide corrosion resistance.

There are two types of extruded aluminum pretreatment coatings: those containing chromium and those that are chrome-free.

Chrome Conversion Coating Pretreatments

Conversion coatings chemically convert the surface aluminum to an inert form consisting of a thin layer of aluminum and chrome oxides and chrome-chromate or chrome-phosphate. As with anodizing, an oxide layer is formed, although no electrical current is required in the conversion coating process. This finish provides corrosion protection and adhesion as a base for a liquid or powder finish.

Chrome Chromate (Gold/ Hexavalent Chrome). Generally, the chrome chromate process requires 7-10 (or more) stages, consisting of the following:

- ▶ Cleaner/Etchant
- ▶ Rinse
- ▶ Deoxidize
- ▶ Rinse
- ▶ Chrome chromate conversion coating
- ▶ Rinse
- ▶ Final acidulated rinse.

Typically, pretreatment is a 5-7 stage process. These stages clean the metal and properly prepare it for the coating application.



However, more complex processes exist to include deoxidizing, etching, desmutting, and sealing stages.

Chrome Phosphate (Green/ Trivalent Chrome). A typical chrome phosphate process may consist of the following stages:

- ▶ Cleaner/Etchant
- ▶ Rinse
- ▶ Chrome-phosphate conversion coating
- ▶ Rinse
- ▶ Final Acidulated Rinse.

Chrome-Free Pretreatments

Due to environmental and workplace-safety concerns associated with the use of chromium-based substances, particularly hexavalent chromium, the U.S. Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH), along with comparable agencies of other nations, have established regulations on the discharge of chromium waste, permissible exposure limits (PELs), action levels and recommended exposure limits (RELs) for such substances in the workplace.

The extrusion industry therefore began seeking alternatives to chromium-based conversion coatings. Chrome-free technologies are available, offering similar performance to chromium conversion coatings. A typical chrome-free pretreatment process may consist of the following stages:

- ▶ Cleaner/Etchant
- ▶ Rinse
- ▶ Surface Conditioner
- ▶ Rinse
- ▶ Chrome-free coating.

Other processes may be available depending on the end-user requirements of the extruded aluminum.

In order to meet the American Architectural Manufacturers Association 2603, 2604 and 2605 pretreatment qualifications, a multi-stage process must be used. Multi-stage washers usually consist of a spray, cascade and/ or immersion process, followed by a dry-off oven prior to powder or liquid coatings.

Details on coating performance specifications can be found on page 14 of this section.



Multi-stage washers clean the profiles after pretreatment and prior to liquid or powder coatings.

Functions of Pretreatment

Each step of the pretreatment process has an important function:

Alkaline Cleaning: Alkaline cleaners are used to remove surface contaminations (such as grease, oils, and shop dirt). In addition, alkaline cleaners are excellent etchants of aluminum.

Acid Cleaning: Acid cleaners are also used to remove surface contaminants. Acid cleaners are also very good at removing oxide layers from the aluminum.

Etching: Etching of aluminum is a chemical process removing very small amounts of aluminum. The etching of the aluminum surface allows for more surface area to be pretreated. Recent studies have found that proper etching—as part of a complete pretreatment and coating regimen—may help to reduce the risk of filiform corrosion, which is commonly found in aggressive corrosive environments.

Rinses: The removal of any surface contaminants, including any chemicals used in the cleaning/etching of the aluminum and from the water rinse itself, is important. Residual contamination on the aluminum may decrease the field performance of the powder/liquid coating.

Pretreatment: These coatings are applied to the cleaned aluminum surface to enhance powder or liquid paint adhesion and to provide corrosion resistance.



Chemical Finishes

Etching

Etching is the application of a caustic solution to produce a silver-white surface often called *frosted*. The aluminum profile is passed through a hot bath followed by a rinse and a deoxidize–desmut bath to remove undissolved alloy constituents or impurities on the surface. Further rinses complete the process.

Bright Dipping

A special dip solution, often a combination of hot phosphoric and nitric acids, is applied to give the aluminum a *specular* (mirror) finish. In many cases, the aluminum is mechanically polished first to remove fine scratches. Bright dipping is almost always followed by anodizing immediately after the final rinse, both to protect the smooth surface and to present a wide range of colors. In planning a product intended for bright dipping, it is important to use care in selecting the aluminum alloy so that the desired surface brightness and color clarity are achieved. Alloy 6463 is an example of an alloy specifically developed for bright-dip applications.

The extruded crash bar parts for commercial doors have been bright-dipped to yield a spectacular finish.



Anodizing

Anodizing is an electrochemical process that forms a durable, porous anodic oxide layer on the surface of aluminum, adding to the protection provided by its natural oxide film.

Aluminum Alloy Reference For Anodizing

Series (AA)*	Alloying Constituent	Metal Properties	Coating Properties	Uses	A.Q.** Types	Non-A.Q.** Types	Finishing Advise
1xxx	None	soft conductive	clear bright	cans architectural	none	1100 1175	Care should be taken when racking this soft material. Good for bright coatings. Susceptible to etch staining.
2xxx	Copper	very strong hard low elongation	yellow poor protection	aircraft mechanical	none	2011 2017 2024 2219 2224	Since copper content is >2%, these produce yellow, poor weather-resistant coatings. Don't mix with other alloys on load.
3xxx	Manganese	strong small grain	grayish-brown	cans architectural lighting	none	3003 3004	Difficult to match sheet-to-sheet (varying degrees of gray/brown). Used extensively for architectural painted products
5xxx	Magnesium	strong ductile fluid	clear good protection	architectural welding wire lighting	5005 5657	5052 5252	For 5005 - keep silicon <0.1% and magnesium between 0.7% and 0.9%, maximum of ±20% for job. Watch for oxide streaks.
6xxx	Magnesium and Silicon	strong ductile	clear good protection	architectural structural	6005 6060 6063 6360 6463	6061 6101	Matte - iron >0.2% Bright - iron <0.1% 6063 best match for 5005; 6463 best for chemical brightening
7xxx	Zinc	very strong	clear good protection	automotive ordinance	none	7029 7046 7075	Zinc over 5% will produce brown-tinted coatings. Watch zinc in effluent stream. Good for bright coatings.

* AA -Aluminum Association

** AQ -Anodizing Quality -material suitable for architectural anodizing applications

Table derived from Technical Bulletin #4-13, © 2013 Aluminum Anodizers Council. Used with permission.

Alloys

All aluminum extrusion alloys may be anodized. The anodic film can vary in both color and density based on the alloy.

The thickness of the anodic oxide layer can be controlled in accordance with the performance requirements of the end use of the anodized product. The American Architectural Manufacturers Association (AAMA) applies the following definitions in its specification, AAMA 611-98:

Class II Architectural greater than 0.4 mils*
Class I Architectural greater than 0.7 mils*

*Note: One mil equals one one-thousandth of one inch.

Anodized aluminum with less than 0.4 mil thickness of anodic oxide often may be used for indoor applications. Such so-called decorative finishes may include bright dipping for enhanced reflectivity.

Class II architectural finishes are commercial anodic finishes used in interior applications or exterior applications that receive regularly scheduled cleaning and maintenance, such as store fronts.

Class I architectural finishes are used for the most critical outdoor applications, where maximum protection is required. The finishes may be transparent, translucent or opaque, depending on the alloy and electrolyte.

The anodic finish greatly increases the resistance to corrosion and abrasion over a mill-finished product, without altering the texture of the metal's surface.

Anodizing Processes

Anodizing is a process in which the aluminum profile is immersed in a tank containing an acid-based electrolyte; a current is passed through the solution, carefully controlling the temperature of the electrolyte. The aluminum profile serves as the anode, so the electrolyte releases oxygen ions at the surface of the profile. The oxygen immediately combines with the surface aluminum to form a hard aluminum oxide film.

The anodizing process typically includes three or four pretreatment steps:

- ▶ **Alkaline cleaning** removes organic contaminants like oils, greases, marking pens, finger prints, or shop dirt.
- ▶ **Acid cleaning** (optional) is used to remove inorganic contaminants like oxide films and intermetallics, which might interfere with a quality finish.
- ▶ **Etching** takes place in a hot caustic solution that includes ingredients to level and sequester the aluminum that is removed by the process. This yields a matte or satin finish and minimizes the effect of die lines.
- ▶ **Deoxidize and desmut** steps remove oxides and intermetallics, which appear as gray to black loose particles on the surface of the etched aluminum.



Profiles and parts are fastened to a rack and immersed in a bath so the electrical current can pass through and form the protective anodic oxide layer. A consequence of racking is the inherent rack mark at the point of attachment.

Unlike other finishes in which a separate coating is applied, the anodic oxide layer is an integral part of the aluminum surface since it is formed by oxidation of the surface atoms themselves.

Several anodizing processes are described on the next page. They differ principally in the type of electrolyte solution used, the voltage and current density applied, and the bath temperature. Anodic coatings may vary significantly in thickness, hardness, porosity, and protective value, depending on the process used and the length of treatment time.



Most anodized products have an extremely long life span. Anodizing provides protection, durability, aesthetics, ease of maintenance, economic advantages, extensive color options, and more.



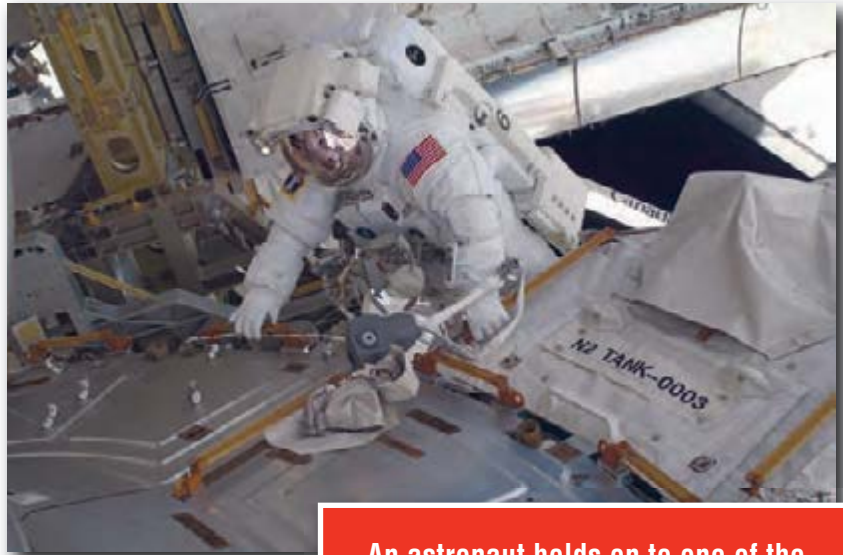
Types of anodizing processes include these:

Sulfuric (Acid) (the most common process) produces comparatively thick, transparent and absorptive oxide films, suitable for receiving both organic and inorganic dyes and metal oxides for electrolytic color. It can also produce thin films for pretreatment for organic coatings.

Chromic (Acid) produces gray or greenish-gray coatings, less porous than the sulfuric acid coatings but with excellent corrosion resistance. This process is used in the aerospace industry. It is also suitable for dyeing, producing opaque colors, and provides an excellent base for organic coatings.

Oxalic (Acid) provides a hard impervious coating with a slightly golden tone. Oxalic-acid-anodized aluminum, like sulfuric-acid-anodized aluminum, may be colored with organic, inorganic, or electrolytic coloring processes.

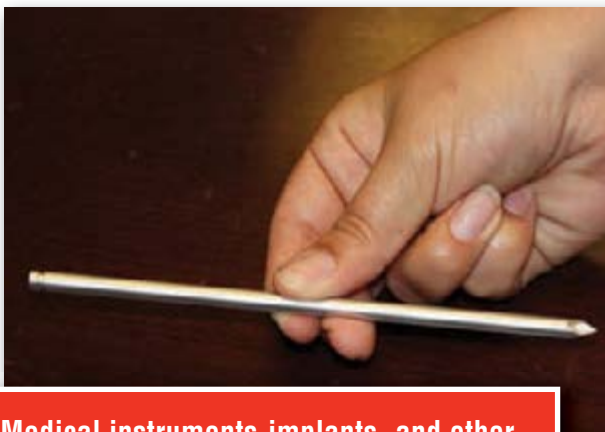
Phosphoric (Acid) produces a porous anodic oxide sometimes used as a base for electroplated coatings and for bonding in the aerospace industry.



An astronaut holds on to one of the many EVA (extra-vehicular activities) anodized extruded aluminum handrails used to tether astronauts, equipment, and tools to the International Space Station.

Boric (Acid) provides a hard, impervious, nonabsorptive film with exceptionally high electrical resistance. This process is used for highly specialized electrical applications.

Hardcoat Anodizing produces a much thicker film. Functional hardcoating, or hard anodizing, is a modification of sulfuric anodizing, performed at high current densities and low temperatures. Sometimes additives are mixed into the electrolyte to produce a denser, more abrasion-resistant oxide film, imparting high wear resistance to the product; typical coating thickness is 1.5 to 7.0 mils.



Medical instruments, implants, and other medical devices may be hardcoated for improved wear resistance.

Anodic coatings can be colored by various methods:

Organic dyes The anodic film is impregnated with various colors of organic dyes.

Inorganic dyes The process is similar to organic dyeing but has better light fastness.

Integral color Selected alloys are anodized in a sulphophthallic electrolyte, yielding a bronze to black color. This color becomes an integral part of the oxide film.

Hardcoating This process yields an opaque integral film that may range in color from gold to bronze and gray to black, depending on alloy, temper, oxide film thickness and the type of process.

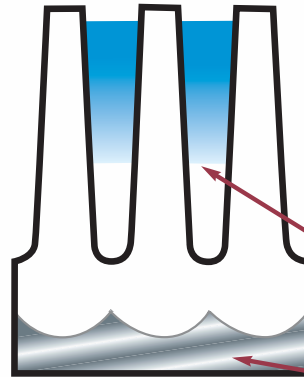
Electrolytic color In what is sometimes called a two-step method, the extrusion is first anodized in a sulfuric acid bath, followed by the electro-deposition of a metal oxide in the unsealed anodic pore. This process gives a champagne to black color that is extremely stable when properly sealed. These lightfast inorganic colors are exceptionally well-suited for exterior exposures.

Over-dye process A basic electrolytic color is first deposited, followed by immersion in an organic dye. Many different colors are available.

Multicolor process This electrolytic coloring process produces all the colors of the rainbow. The part is first anodized, then colored in a metal oxide bath using special electrical systems. Colorfastness is similar to that for all other electrolytic color processes.

Organic Dye

Organic dye is distributed throughout the coating, but is concentrated near the surface and in the middle area of the anodic pores.

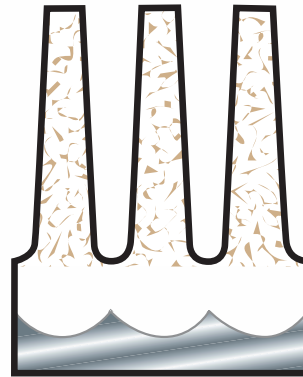


Aluminum Oxide Film

Surface of Aluminum Substrate

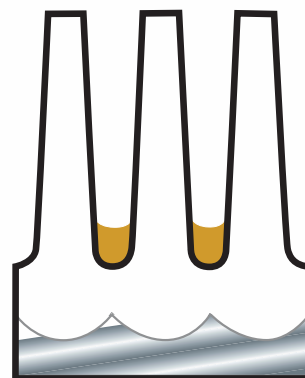
Integral Color

Colored metal oxides are bound directly onto the anodic film.



Electrolytic Color

Metal is deposited deep into the anodic pores.



Sealing

In the context of anodizing aluminum, sealing does not refer to a separate coating, but to a process that closes the pores of the anodic oxide surface. Sealing the anodic oxide layer means rendering it inert, so that the surface of the anodized aluminum profile is nonabsorbent, nonreactive, and resistant to staining and corrosion. A wide variety of sealing processes may be employed. They include:

Hot Water De-ionized, high-quality water free of silica is used at or near the boiling point (212° F, 100° C).

Hot Water with Additives These additives are used to prevent seal bloom, smut, and powdering. In general, the sealing time is accelerated and the bath life prolonged.

Mid-Temperature Seals In this, the most common sealing method, the anodized profile is immersed in a solution containing nickel acetate or other metal ion at 170 to 190° F (77 - 88° C), along with proprietary ingredients such as dispersants, buffering agents and wetting agents, which enhance the seal quality.

Room Temperature Seals This system, which uses nickel fluoride at 85 to 95° F (29 - 35° C), is not suitable for organic dyes.

Non-Nickel Seal This mid-temperature seal utilizes other metal salts to replace nickel.

The anodizing process, when applied properly, offers the consumer a beautiful, long-lasting, cost-efficient product that will never chip or peel.

Specifications

The tables found on the following pages contain useful specifications for anodic finishes.

Anodic Coating Designations

Type of Finish	Designation ¹	Description	Examples of Methods of Finishing ²
General	A10	Unspecified	
	A11	Preparation for other applied coatings	3 μ (0.1 mil) anodic coating produced in 15% H ₂ SO ₄ at 21°C ± 1°C (70°F ± 2°F) at 129 A/m ² (12 A/ft ²) for 7 min. or equivalent
	A12	Chromic acid anodic coatings	To be specified
	A13	Hard, wear and abrasion resistant coatings	To be specified
	A1X	Other	To be specified
Protective & Decorative Coatings less than 10 μ (0.4 mil) thick	A21	Clear coating	Coating thickness to be specified. 15% H ₂ SO ₄ used at 21°C ± 1°C (70°F ± 2°F) at 129 A/m ² (12 A/ft ²)
	A211	Clear coating	Coating thickness – 3 μ (0.1 mil) minimum. Coating weight – 6.2 g/m ² (4 mg/in ²) minimum.
	A212	Clear coating	Coating thickness – 5 μ (0.2 mil) minimum. Coating weight – 12.4 g/m ² (8 mg/in ²) minimum.
	A213	Clear coating	Coating thickness – 8 μ (0.3 mil) minimum. Coating weight – 18.6 g/m ² (12 mg/in ²) min.
	A22	Coating with integral color	Coating thickness to be specified. Color dependent on alloy and process methods.
	A221	Coating with integral color	Coating thickness – 3 μ (0.1 mil) minimum. Coating weight – 6.2 g/m ² (4 mg/in ²) minimum.
	A222	Coating with integral color	Coating thickness – 5 μ (0.2 mil) minimum. Coating weight – 12.4 g/m ² (8 mg/in ²) minimum.
	A223	Coating with integral color	Coating thickness – 8 μ (0.3 mil) minimum. Coating weight – 18.6 g/m ² (12 mg/in ²) min.
	A23	Coating with impregnated color	Coating thickness to be specified. 15% H ₂ SO ₄ used at 27°C ± 1°C (80°F ± 2°F) at 129 A/m ² (12 A/ft ²) followed by dyeing with organic or inorganic colors.
	A231	Coating with impregnated color	Coating thickness – 3 μ (0.1 mil) minimum. Coating weight – 6.2 g/m ² (4 mg/in ²) minimum.
	A232	Coating with impregnated color	Coating thickness – 5 μ (0.2 mil) minimum. Coating weight – 12.4 g/m ² (8 mg/in ²) minimum.
	A233	Coating with impregnated color	Coating thickness – 8 μ (0.3 mil) minimum. Coating weight – 18.6 g/m ² (12 mg/in ²) min.
	A24	Coating with electrolytically deposited colors	Coating thickness to be specified. Application of the anodic coating, followed by electrolytic deposition of inorganic pigment in the coating.
	A2X	Other	To be specified.
Architectural Class II ³ 10 to 18 μ (0.4 to 0.7 mil) coating	A31	Clear coating	15% H ₂ SO ₄ used at 21°C ± 1°C (70°F ± 2°F) at 129 A/m ² (12 A/ft ²) for 30 min. or equivalent.
	A32	Coating with integral color	Color dependent on alloy and anodic process.
	A33	Coating with impregnated color	15% H ₂ SO ₄ used at 21°C ± 1°C (70°F ± 2°F) at 129 A/m ² (12 A/ft ²) for 30 min. followed by dyeing with organic or inorganic colors.
	A34	Coating with electrolytically deposited color	Application of the anodic coating followed by electrolytic deposition of inorganic pigment in the coating.
	A3X	Other	To be specified.
Architectural Class I ³ 18 μ (0.7 mil) and thicker coatings	A41	Clear coating	15% H ₂ SO ₄ used at 21°C ± 1°C (70°F ± 2°F) at 129 A/m ² (12 A/ft ²) for 60 min. or equivalent.
	A42	Coating with integral color	Color dependent on alloy and anodic process.
	A43	Coating with impregnated color	15% H ₂ SO ₄ used at 21°C ± 1°C (70°F ± 2°F) at 129 A/m ² (12 A/ft ²) for 60 min. followed by dyeing with organic or inorganic colors or equivalent.
	A44	Coating with electrolytically deposited color	Application for the anodic coating followed by electrolytic deposition of inorganic pigment in the coating.
	A4X	Other	To be specified.

1. The complete designation must be preceded by AA – signifying Aluminum Association.
2. Examples of methods of finishing are intended for illustrative purposes only.
3. Aluminum Association Standards for Anodized Architectural Aluminum.
4. One mil equals one one-thousandth of one inch.

Alcoa Designations*	
ALCOA DESIGNATION	FILM THICKNESS ⁴
Alumilite 200	minimum .15 mils
Alumilite 201	minimum .2 mils
Alumilite 202	minimum .3 mils
Alumilite 203	minimum .36 mils
Alumilite 204	minimum .4 mils
Alumilite 214	minimum .6 mils

Anodic Coatings for Aluminum and Aluminium Alloys

	Chromic Type I	Sulfuric Type II	Hard Coat Type III
Coating weight mg/sq ft, minimum	Class 1 200 Class 2 500	Class 1 600 Class 2 2500	4,320
Coating Thickness (inches)	0.00005-0.0003	0.0001-0.0010	0.0005-0.0045
Salt Spray, hours minimum	336	336	-
Abrasion Resistance mg, maximum	-	-	40 (2024) 20 (other alloys)
Light -Fastness	Color difference 3 units (A)	Color difference 3 Units (A)	-

Type III - Unsealed except when used for exterior applications requiring corrosion protection.

(A) - Class 2

Coating Weight	ASTM B137
Coating Thickness	ASTM B244 FTM #151, Method 520
Salt spray	ASTM B117 (336 hours)
Light-Fastness	FTM #141, Method 6151 or 6152 ASTM D2244 (200 hours to light without water spray)
Abrasion Resistance	FTM #141, Method 6192 CS-17 wheels 1000 g load 70 rpm for 10,000 cycles 2024 40 mg Other 20 mg

1. This table represents the United States Department of Defense requirements and quality control standards under Military Specification MIL-A-8625F for chromic, sulfuric, and hard anodic coatings.

ASTM = American Society for Testing and Materials FTM = Federal Test Method

Coating of Aluminum Profiles

There are two principal reasons for applying a coating to aluminum profiles. First, to control the appearance for purposes of color coordination, uniformity, or visual appeal. Second, to protect the substrate from environmental damage due to acid rain, sulfur pollution, corrosion, or excess oxidization.

The type of finish selected for aluminum profiles depends upon the use of the product and the preferences of the market. In some instances, no coating is required at all; the only aspect of finishing the designer or specifier need address is the surface texture and appearance. Mechanical finishing may be all that is required.

However, if the aluminum substrate is to be coated it generally requires some cleaning and pretreatment.

Coating Performance Specifications

The North American residential and architectural glass and aluminum market routinely specifies coatings relative to three performance specifications written by the American Architectural Manufacturers Association (AAMA). The specifications provide three levels of performance (good, better, best) for aluminum that is cleaned, pretreated, and coated with an organic coating.

- 1. AAMA 2603** Voluntary Specification, Performance Requirements and Test Procedures for Pigmented Organic Coatings on Aluminum Extrusions and Panels.
- 2. AAMA 2604** Voluntary Specification, Performance Requirements and Test Procedures for High Performance Organic Coatings on Aluminum Extrusions and Panels.
- 3. AAMA 2605** Voluntary Specification, Performance Requirements and Test Procedures for Superior Performing Organic Coatings on Aluminum Extrusions and Panels.

Liquid and powder coatings are available in a range of chemistries, performance properties, finishes, and cost.

Coating Application

There are two basic types of paint lines, vertical and horizontal, used to apply coatings to aluminum profiles. Both systems yield quality coated products and can accommodate a variety of extruded shapes and sizes.

The most efficient and environmentally friendly way to coat aluminum profiles is by electrostatic spray applications, which operate on the principle that materials carrying unlike electrical charges attract one another, and those carrying like electrical charges repel one another. In the case of electrostatic liquid spray applications, the coating is atomized by the combined influence of a mechanical device (e.g., air gun, turbo disc, or bell) and an electrostatic charge as it leaves the application equipment. In the electrostatic spray of powder coatings, the fine powder particles are delivered with low air pressure and electrostatically charged as they leave the application equipment.

In both cases the finely atomized charged particles are attracted to the grounded aluminum profile. This attraction enhances the coating of edges and recessed areas while improving the transfer efficiency. The higher transfer efficiency results in material savings and reduced waste and labor cost. Furthermore, the coating film thickness is more uniform over the part without the inconvenience of turning the object repeatedly to paint from every angle.

In the last several years, new spray delivery systems and material recovery technologies have been introduced to allow for faster color changes for liquid and powder coatings, further reducing waste and labor cost.

Note: Electrostatic application has no effect on the quality of the coating material. It is simply a more efficient way to transfer the paint to the aluminum substrate.



On a vertical coating line, aluminum extrusions are hung vertically when coated.



On a horizontal coating line, aluminum extrusions are held horizontally, on a rack, when coated.

Cure

The paint cure is achieved by baking the coated parts for a specified time at a specified temperature per the coating supplier recommendations. The degree of cure often can be judged by pencil hardness and/or solvent resistance. The proper cure helps to ensure that the desired coating performance characteristics are met.

Coating Performance Properties

Although there are differences between liquid and powder coatings, both perform two essential functions:

▶ **A cosmetic function.**

The coating gives an aesthetically pleasing appearance to the substrate.

▶ **A protective function.**

The coating protects the substrate from environmental damage.

It is important, therefore, to look beyond the superficial appearance of the finish and address the physical properties demanded by the product's environment of use. The AAMA 2603, 2604, and 2605 specifications address many performance characteristics and are excellent reference resources.



The following typical traits to be considered are addressed in the AAMA specifications:

- ▶ Hardness
- ▶ Flexibility
- ▶ Mar resistance
- ▶ Chemical resistance
- ▶ Corrosion resistance
- ▶ Chalk resistance
- ▶ Color requirements
- ▶ Initial gloss and gloss retention
- ▶ Protection from color loss due to ultra-violet radiation (e.g., sunlight)
- ▶ Other properties unique to specific environments of use.

Coating Selection

The core elements of any coating are the binder and pigments. The binder provides the adhesion to the aluminum profile and the pigments provide the color. The binder and pigments are dispersed in solvents in the case of liquid coatings. Powder coatings do not contain solvents.

Liquid Coatings

Liquid coatings can be classified based on the amount of *volume solids* they contain. The solid components of liquid coatings are the pigments and binders. The remainder of the composition, the solvents, generally contain volatile organic compounds (VOCs), which are driven off during the curing or baking process. The volume solids form the actual film left on the profile or extrusion when the VOCs are gone.

Classification of liquid coatings by percent solids is expressed as follows:

Classification	Percent Volume Solids
Conventional Solids	up to 40%
Medium Solids	40-55%
High Solids	55-70%

Liquid coatings yield a uniform film thickness, resulting in a smooth finish that may be preferred for some applications.



Powder coatings offer the designer a wide array of colors and the extruder options to achieve performance requirements required by AAMA specifications.

Powder Coatings

Powder coatings do not typically contain solvents or VOCs. The products are applied as a solid on the aluminum profile. During the oven curing process, the solid particles fuse together to form a liquid, homogeneous film. As the coated profile cures in the oven the film hardens. This fully functional film has final physical properties that meet many stringent performance criteria while also meeting environmental regulations limiting the use of volatile organic compounds (VOCs), inherent in many solvent-based liquid coatings.

Powder coatings show performance characteristics similar to liquid coatings when both are based on the same resin chemistry; e.g., a polyester powder coating will perform equally to a polyester liquid coating when subjected to the same weathering and physical property requirements.

Like liquids, powders offer the designer a wide array of colors, durable finishes, and other specifications. With the new powder coatings available today, extruders have powder options to meet AAMA 2603, AAMA 2604 and AAMA 2605 performance requirements.

Coating Technology Comparison

The following comparison between the most commonly used spray coating technologies applies to both powder and liquid. The type of binder contained in the coating differentiates these technologies. The most commonly used spray coating technologies are polyester, acrylic, modified polyester, and fluoropolymer.

Polyester coatings are very popular on aluminum profiles and provide good performance for many end uses. They are available as a powder coating and at a variety of volume solids relative to liquid coatings. The majority of the time they are used as a single coat system and often used to meet the AAMA 2603 specification.

Liquid acrylic coatings are usually supplied as conventional solids and are typically applied as a single coat. They have excellent application and mar resistance properties and are often designed to meet the AAMA 2603 specification.

Acrylic powder coatings due to compatibility issues with other powder technologies, are seldom used in the coating of aluminum extrusions.

Modified polyester liquid and powder coatings offer many of the same advantages as regular polyesters, along with improved durability. They tend to offer better gloss retention and often are designed to meet the AAMA 2604 specifications.



Fluoropolymer coatings (those with a minimum of 70-percent fluoropolymer resin) offer the highest level of durability in the architectural market with excellent color and gloss retention and overall weatherability. They are often specified by architects for large commercial construction projects and have become more popular in the high-end residential market. In the liquid process, these are conventional solids coatings and typically require a primer as a two-coat system.

Fluoropolymer powder coatings are applied as single or two-coat coating systems. Depending on the color, fluoropolymer coatings may require an additional clear coat to achieve the color and gloss requirements listed in the AAMA 2605 specification. They offer excellent performance, but are slightly softer than polyester, modified polyesters, and acrylic coatings. Fluoropolymer coatings are the chemistry of choice for meeting the AAMA 2605 specifications.

The following tables offer a more detailed comparison of the performance properties of Polyester, Acrylic, Modified Polyester, and Fluoropolymer coatings.

Specification Comparison

Item	AAMA 2603	AAMA 2604	AAMA 2605
Dry Film Thickness - min. in exposed area	.8 mils	1.2 mils	1.2 mils
Pretreatment	multistage cleaning, chrome or chrome-free	multistage cleaning, chrome or chrome-free	multistage cleaning, chrome \geq 40mg/sq ft
Color Change	slight	no more than 5 delta E	no more than 5 delta E
Outdoor Exposure Time	1 year south Florida exposure	5 years south Florida exposure	10 years south Florida exposure
Chalking Resistance	slight chalking	no more than #8 ASTM	no more than #8 ASTM
Film Adhesion	dry and wet adhesion/boiling water	dry and wet adhesion/boiling water	dry and wet adhesion/boiling water
Abrasion Resistance	no requirement	falling sand test ACV 40 minimum	falling sand test ACV 40 minimum
Chemical Resistance	muriatic acid/mortar resistance	muriatic acid/mortar resistance/nitric acid	muriatic acid/mortar resistance/nitric acid
Corrosion Resistance	1500 hours salt spray 1500 hours 100% humidity	3000 hours salt spray 3000 hours 100% humidity	4000 hours salt spray 4000 hours 100% humidity

Resin Comparison

Resin Type	VOC ¹	Color Range	# of Coats	Performance ²	Properties	Applications
Polyester	low	wide selection	1	AAMA 2603	good film integrity, good color retention, good exterior durability, wide gloss range	primary & replacement windows, light fixtures, miscellaneous extruded aluminum profiles
Acrylic	high	wide selection	1	AAMA 2603	good film integrity, good color retention, good exterior durability, wide gloss range	primary & replacement windows, light fixtures, miscellaneous extruded aluminum profiles
Siliconized Polyester	medium	wide selection	1 or 2	AAMA 2603	better than pure polyester; improved durability	same as polyester; light commercial applications
Fluoropolymer	high	somewhat limited	2 (3-4) (color depndt.)	AAMA 2604 and 2605	best overall weatherability, longest color life and gloss retention, best flexibility and chemical resistance	spandrel panels, curtainwall, store fronts, windows, column covers, louvers, mullions, high exposure areas

1. Relative level of VOCs (as shown here) applies only to liquid coatings; powder coatings contain little or no VOCs.

2. Not all coatings will meet these performance characteristics.



Section

5

Extrusion Dies



ALUMINUM
EXTRUDERS
COUNCIL

Aluminum Extrusion
Manual
4.2 Edition

Section 5



Photos courtesy of Werner Co. and Craig Werner.

Extrusion Dies

Extrusion dies can be made to form a virtually limitless array of profiles and sizes.

The cost and lead times for aluminum extrusion tooling are typically less than for the tooling required by vinyl extrusion, die casting, forming, roll forming, impact extrusion, stamping, or pultrusion.

Several factors influence the actual cost and lead time of a specific die. The best combination of product performance, quality, and cost is achieved when the customer, the product designer, the die vendor, and the extruder collaborate to develop the optimum product. Details and design tips for extrusion dies and related tooling are offered in the pages that follow.

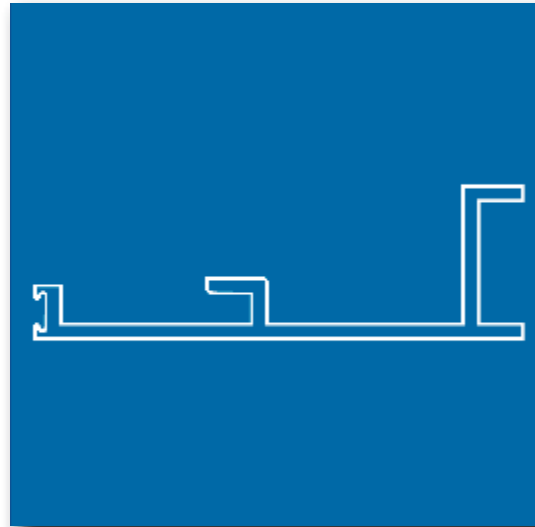
Introduction to Extrusion Dies

There are three basic types of extrusion dies: solid dies, semihollow dies, and hollow dies, which produce solid profiles, semihollow profiles and hollow profiles respectively.

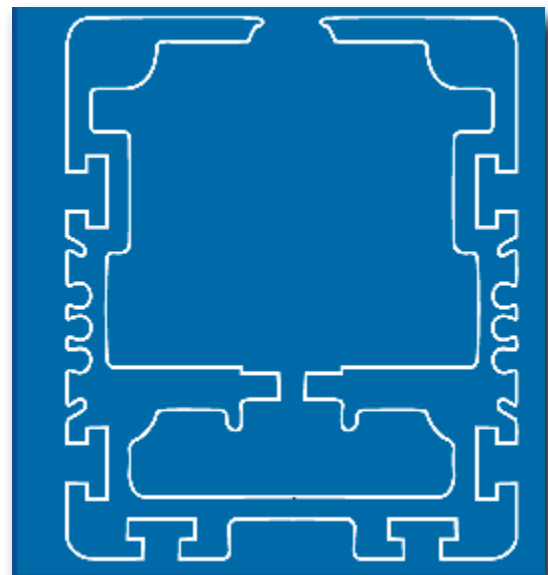
Extrusion dies are essentially thick, circular steel disks containing one or more orifices of the desired profile. They are normally constructed from H-13 tool steel and heat-treated to the desired condition.

In a typical extrusion operation, the extrusion die will be placed in the extrusion press along with several supporting tools. These tools, also made from hardened tool steel, are known as backers, bolsters and sub-bolsters. The backer, bolster, and sub-bolster provide support for the die during the extrusion process and contribute to improved tolerance controls and extrusion speeds.

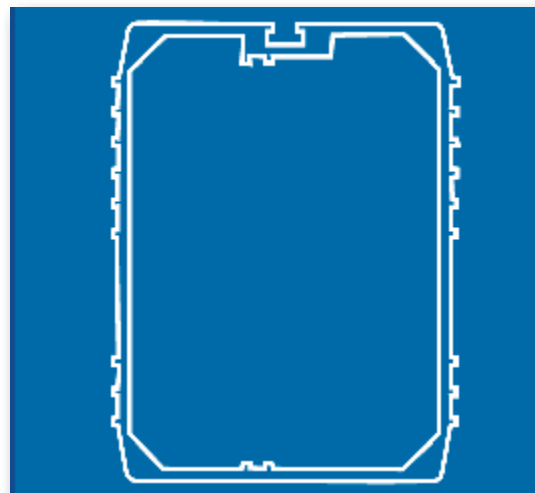
A tool stack for a hollow die is similar to that used for a solid die. A hollow die is a two-piece construction, one piece forming the inside of the hollow profile and the other piece forming the outside of the profile. It likewise requires the use of additional support tools.



A Solid Profile



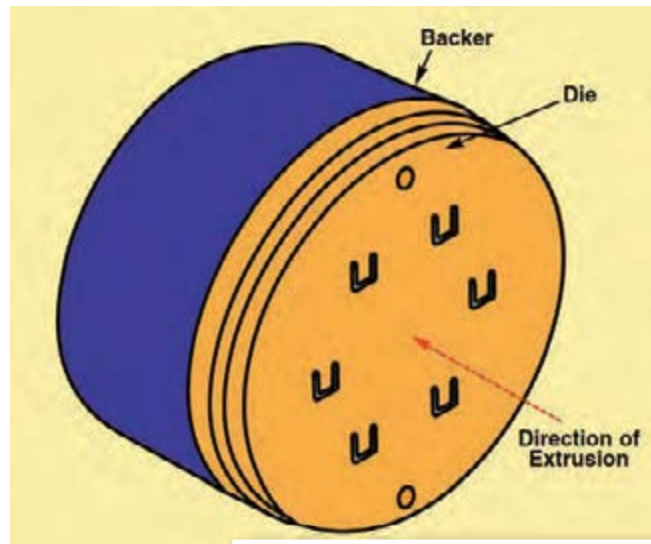
A Semihollow Profile



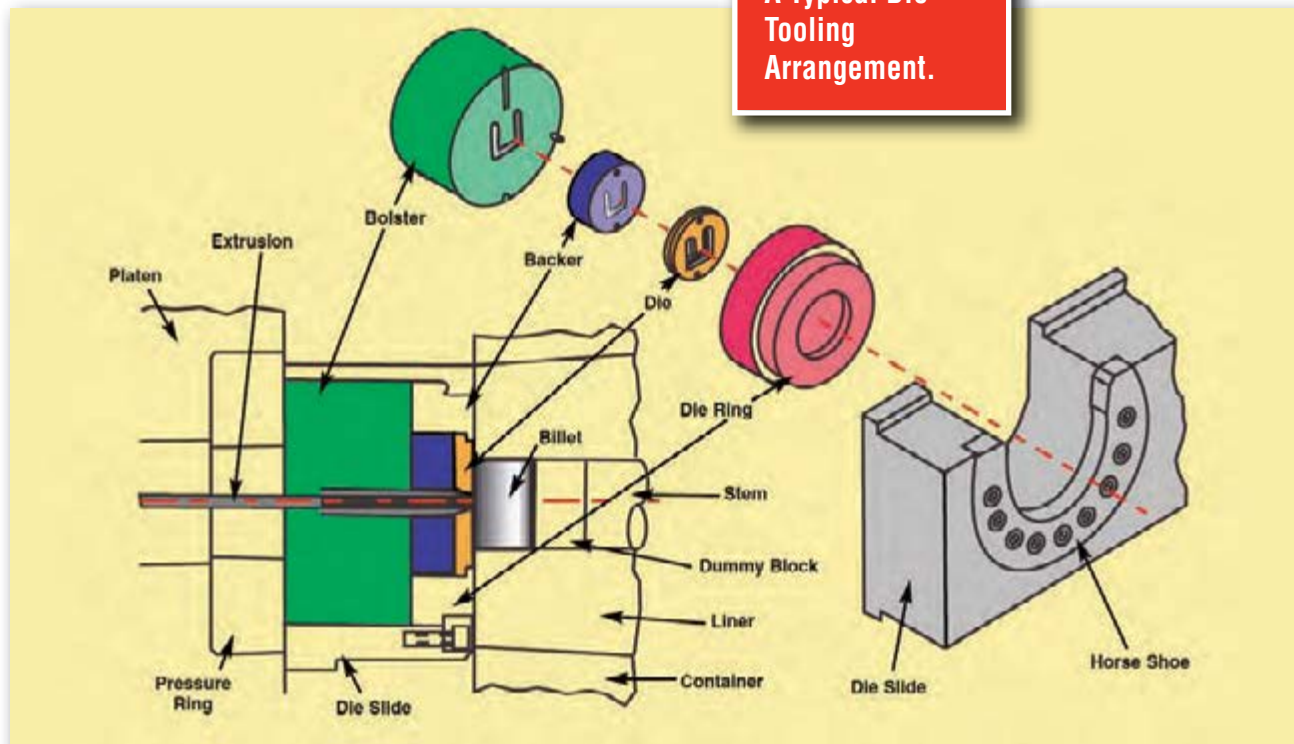
A Hollow Profile

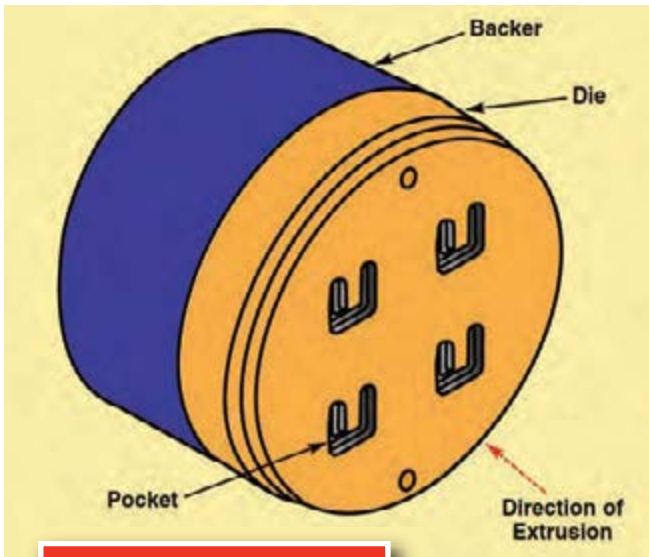
Solid Dies

Solid dies are used to produce profiles that do not contain any voids. Various styles of solid dies are used, depending on the equipment and manufacturing philosophy of the extruder. Some prefer to use flat-face style dies while others prefer to use recessed pocket or weld-plate style dies. A pocket die has a cavity slightly larger than the profile itself, approximately $\frac{1}{2}$ " to $\frac{3}{4}$ " deep. This cavity helps control the metal flow and allows the billets to be welded together to facilitate the use of a puller. Both pocket and weld-plate type dies provide for additional metal flow control, compared to that of the flat-face type die.



This six-hole solid die will extrude six separate profiles simultaneously.



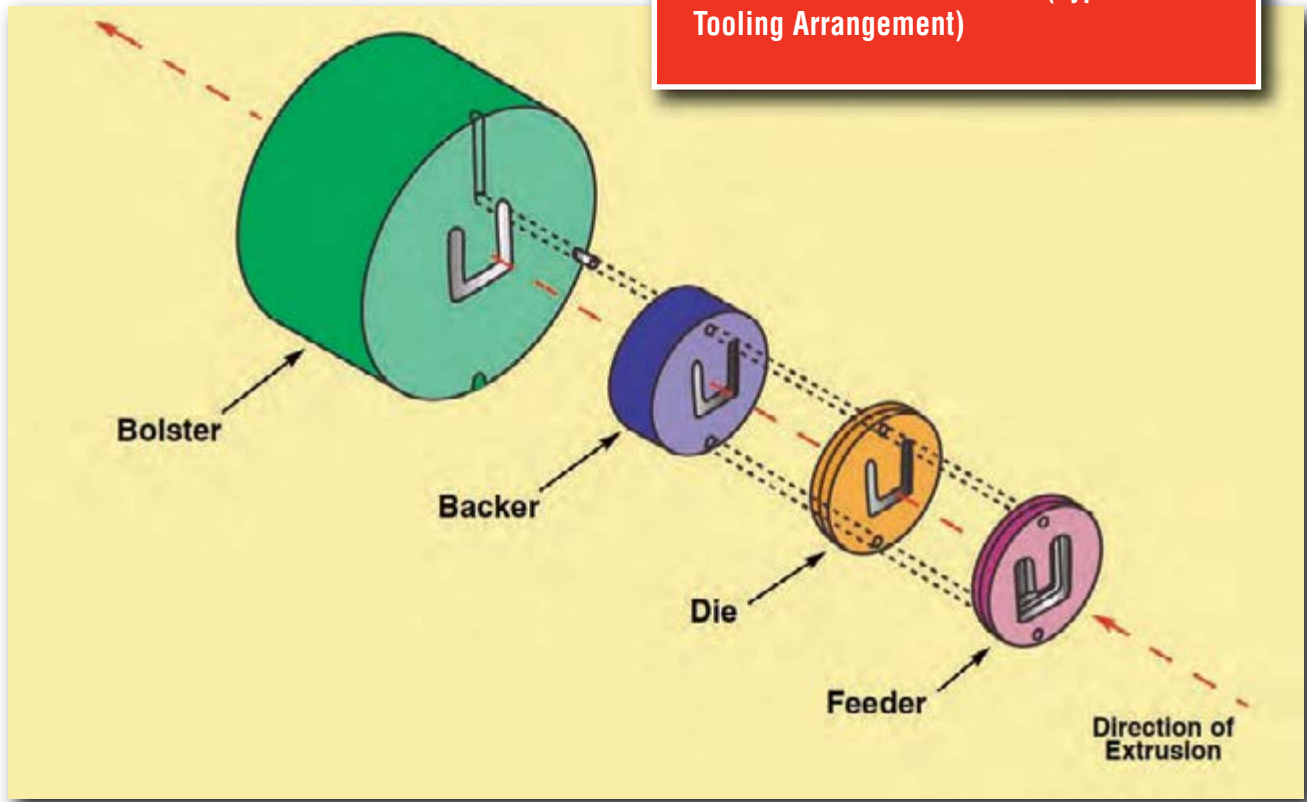


Four-Hole Pocket Die

More Solid Dies

A weld plate is a steel disk that is placed (often pinned and/or bolted) in front of a solid die. It has an orifice that controls the flow of aluminum to the die orifice. Weld, or feeder plates serve to provide continuous extrusion from one billet to the next, and/or control contour; and/or spread the aluminum.

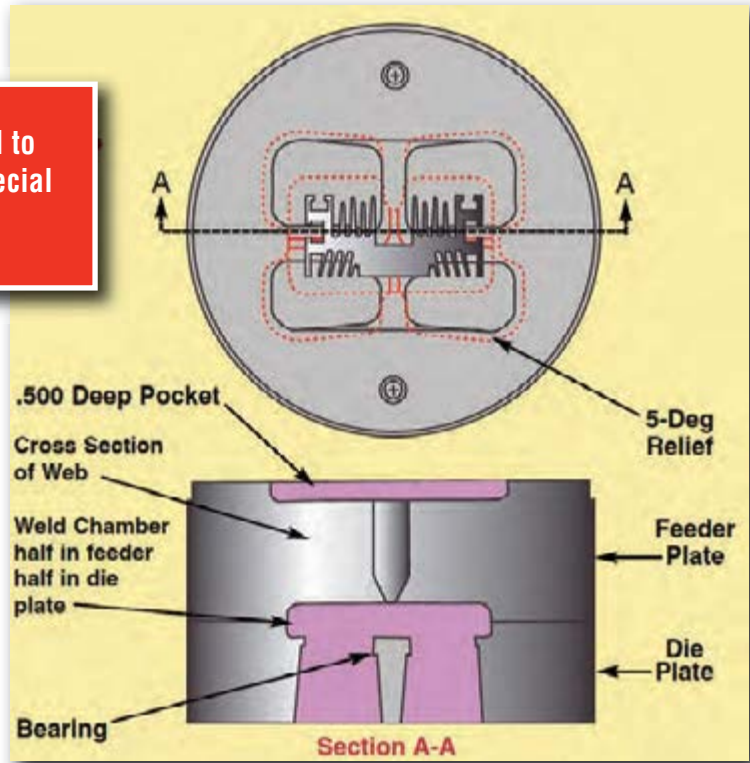
Solid Die with Feeder Plate (Typical Die Tooling Arrangement)



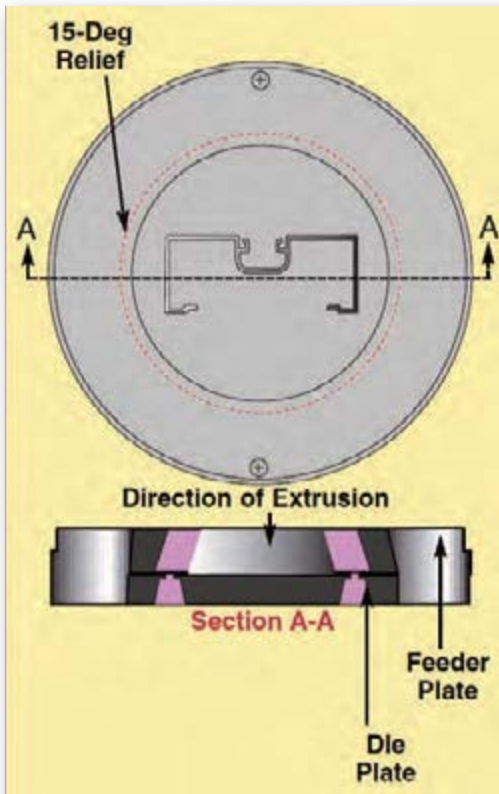
Contour Feeder Plate

A feeder plate, in this example, is used to control contour for dies that require special dimensional tolerances.

Semihollow Feeder (Heat Sink)

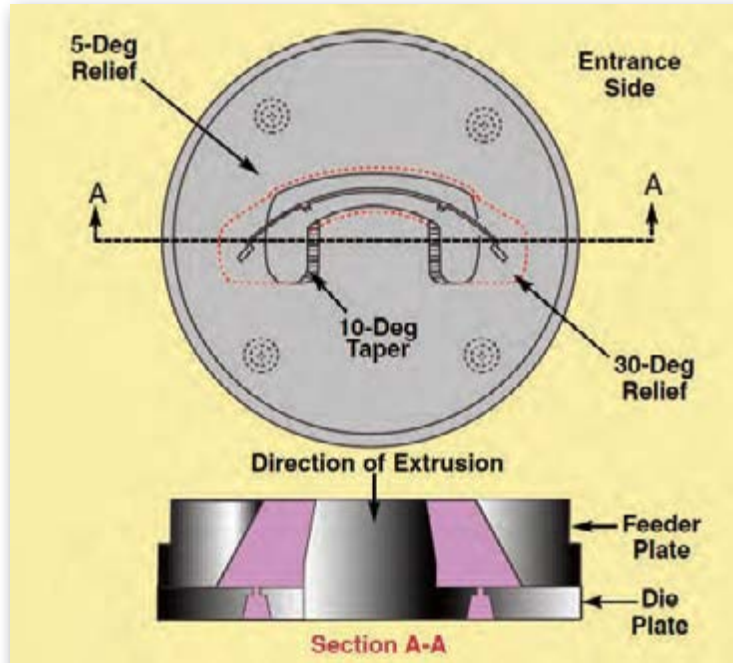


Baffle Feeder



A feeder plate, as shown, is used to weld billets together. The first billet is pushed through the die stack. All subsequent billets weld together, allowing continuous extrusion, which facilitates the use of modern material handling equipment.

Spreader Feeder



A feeder plate, such as this, is used to spread the aluminum to needed areas when the circle size of a profile is larger than 90 percent of the billet diameter.

Hollow Dies

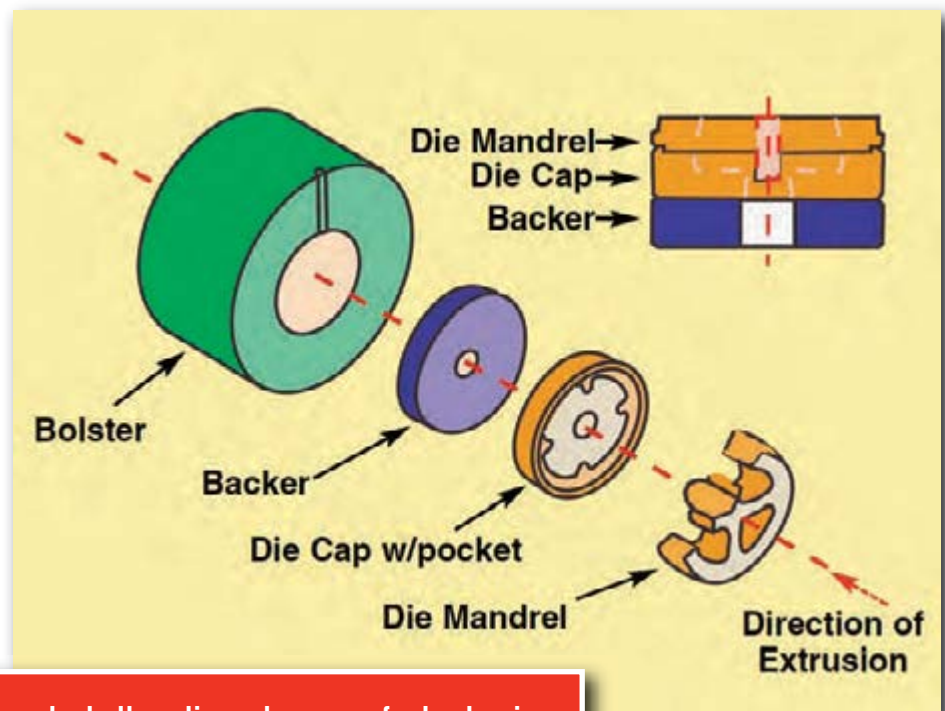
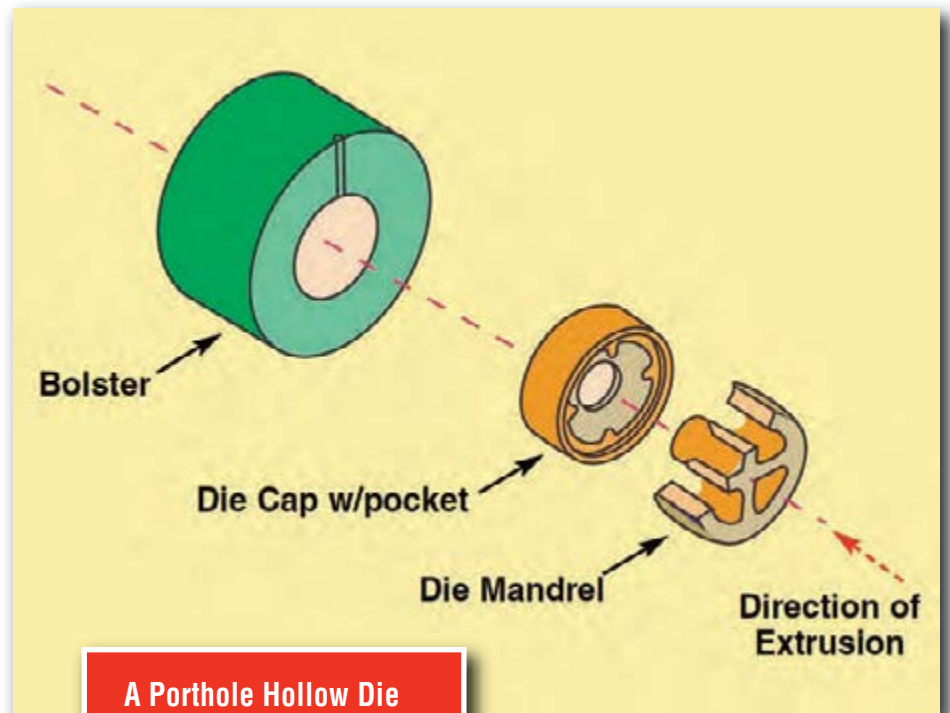
A hollow die produces profiles with one or more voids. The profile could be as simple as a tube with one void or as complex as a profile with many detailed voids.

The most common type of hollow die is the porthole die, which consists of a mandrel and cap section; it may or may not have a backer.

The mandrel, also known as the core, generates the internal features of the profile. The mandrel has two or more ports; the aluminum billet separates into each port and rejoins in the weld chamber prior to entering the bearing area. The ports are separated by webs, also known as legs, which support the core or mandrel section.

The cap, which creates the external features of the profile, is assembled with the mandrel.

The backer, when used, provides critical tool support and is immediately adjacent to, and in direct contact with, the exit side of the cap.

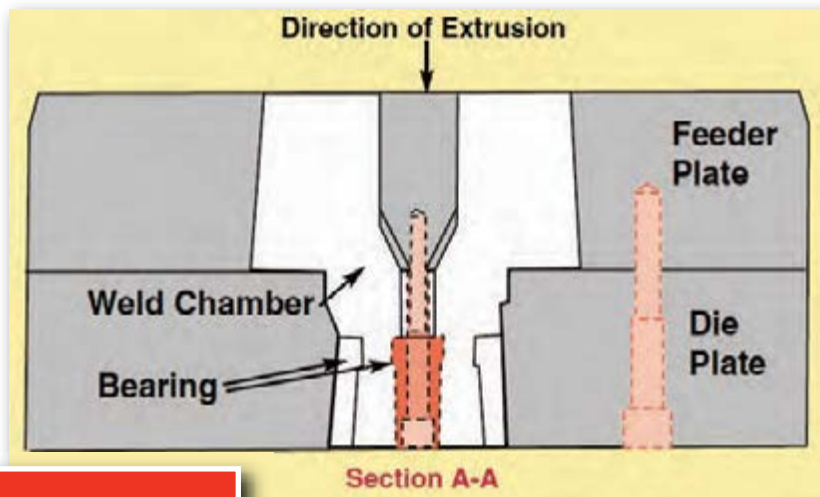
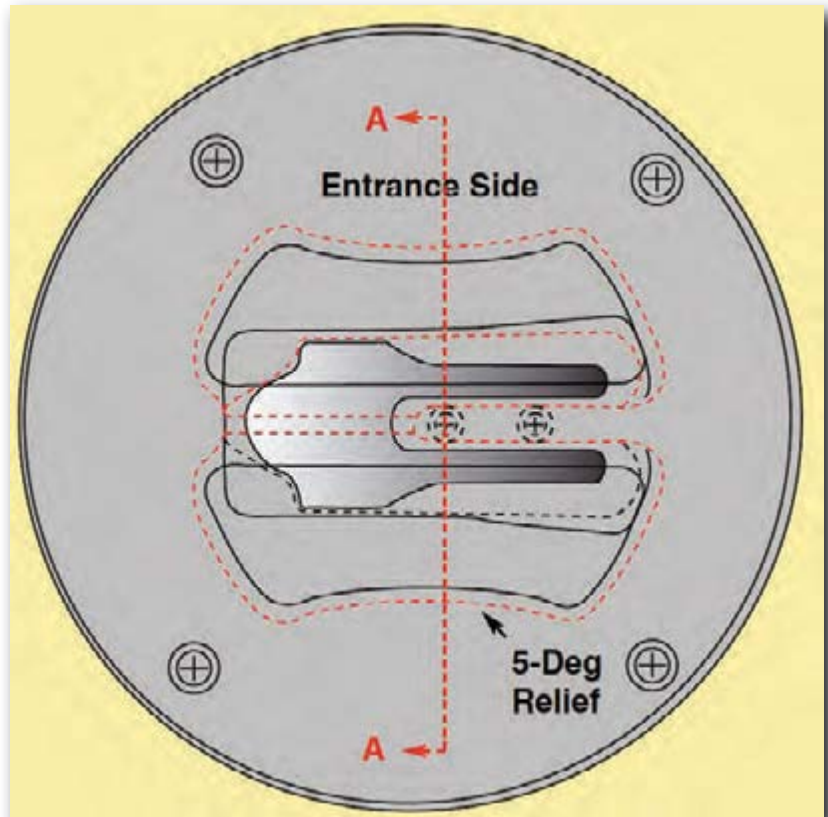


Semihollow Dies

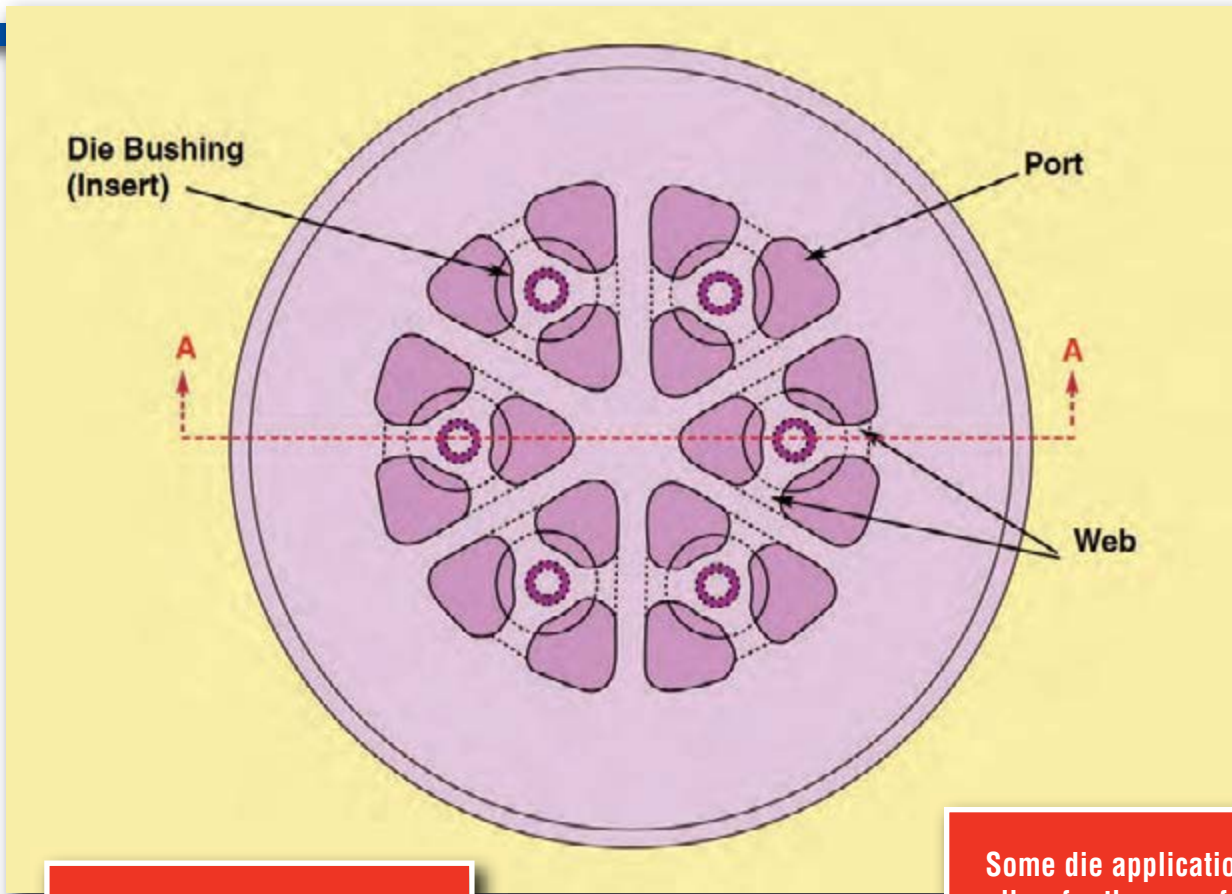
A semihollow die is used to produce profiles having semihollow characteristics as defined in Aluminum Standards and Data (published by The Aluminum Association, Inc.).

Briefly, a semihollow profile partially encloses a void; however, a solid shape also may partially enclose a void, and the distinction may not be obvious. The semihollow classification derives from a mathematical comparison between the area of the partially-enclosed void and the mathematical square of the size of the gap. This ratio (Area/Gap^2) is called the tongue ratio.

Depending on the tongue ratio, semihollow dies can be constructed as flat, recessed-pocket, weld-plate, or porthole design. Porthole dies are more prevalent in the production of semihollow profiles.

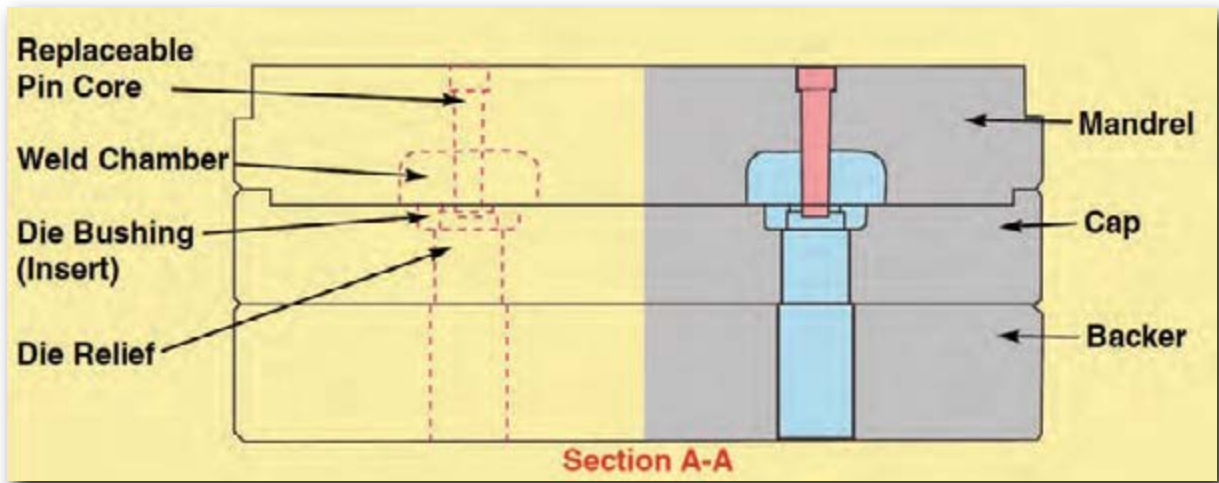


In this example of a porthole-type design, the die "tongue" is bolted to the weld plate for additional support.



Inserted/Replaceable Parts

Some die applications allow for the use of replaceable inserts.



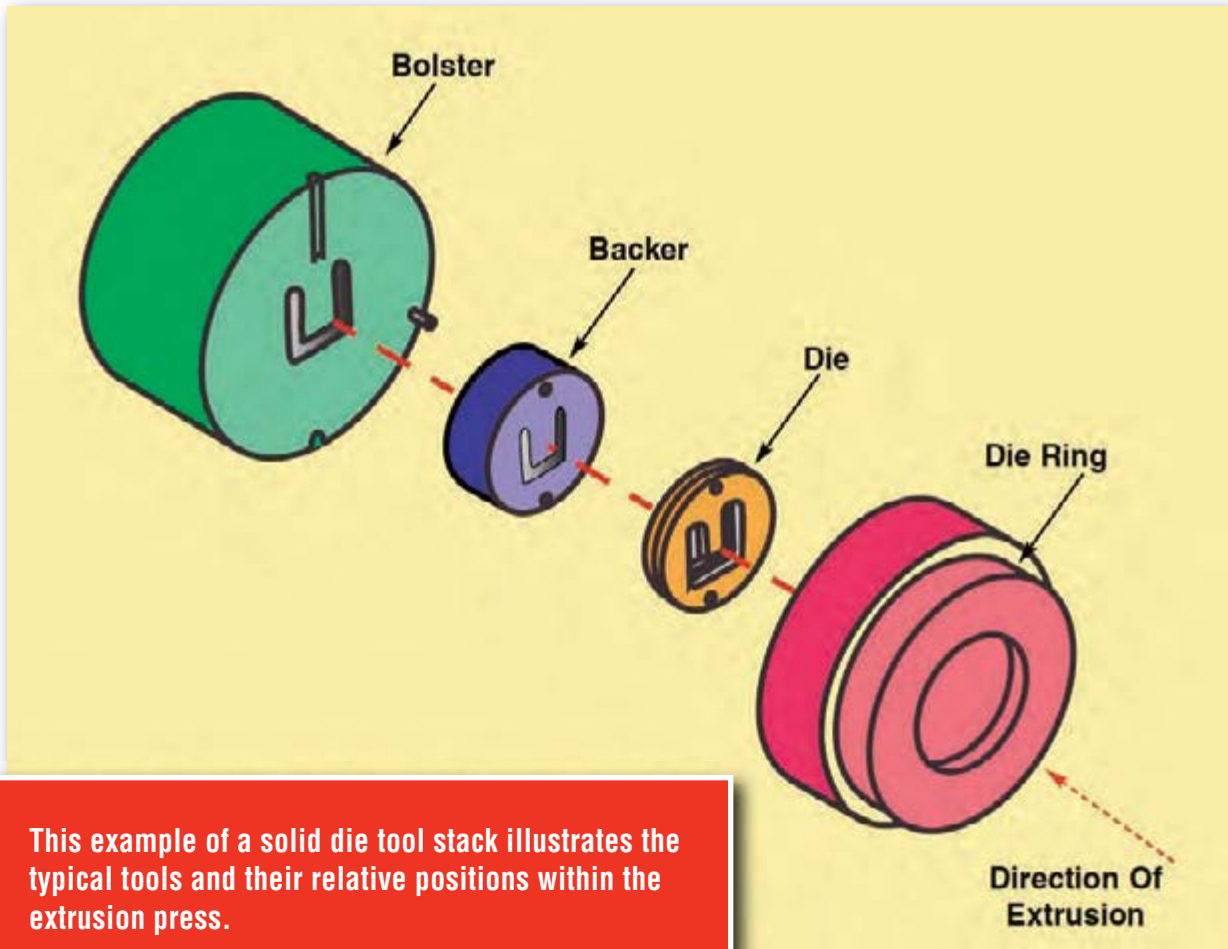
Some die applications allow for the use of replaceable inserts. These inserts are made from materials such as carbide, ceramic, or various commercial compounds. Typically, replaceable inserts possess greater wear resistance, allowing for longer extrusion runs than possible with H-13 tool steel. They typically can be replaced at a fraction of the cost of a complete non-inserted tool, even though the initial tool costs are higher.

Support Tooling

The support tooling reinforces the extrusion die from the extreme pressure of the extrusion forces. In most cases, a die is supported by a backer, which is supported by a bolster.

Backer: A steel disk with the same diameter as the die, but usually two or three times the thickness of the die. The aperture is somewhat larger than the exit side of the die. The backer may be fitted with pins and/or bolts that interlock the backer and the die.

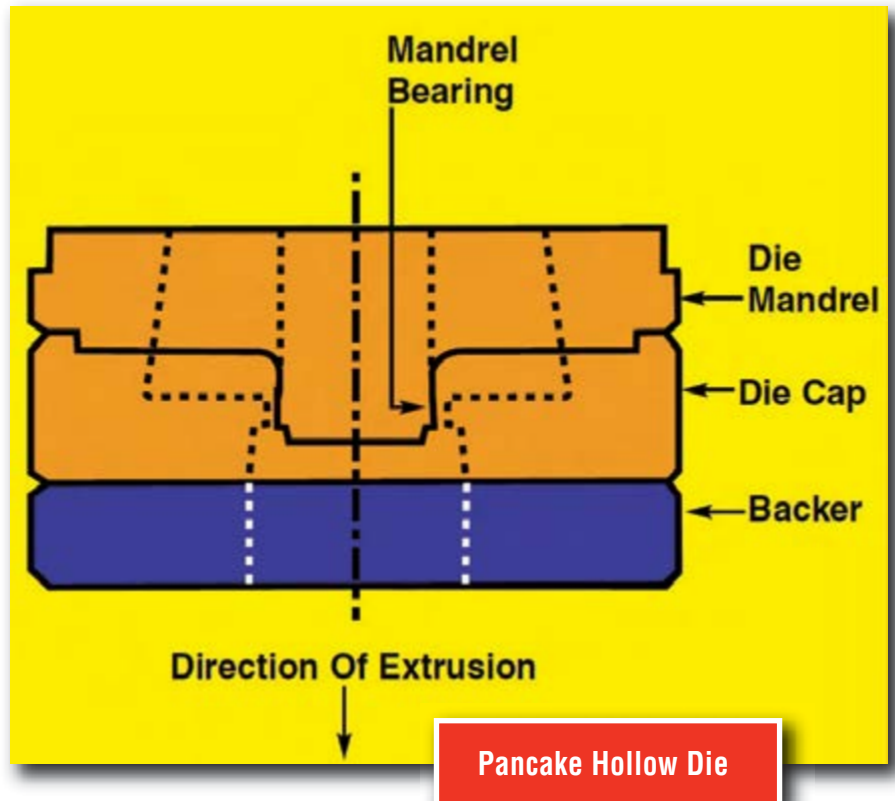
Bolster: A steel disk, which is normally the same diameter as the die ring (that holds the die and backer) and thicker than the backer. The aperture is somewhat larger than the backer.



Custom Tooling

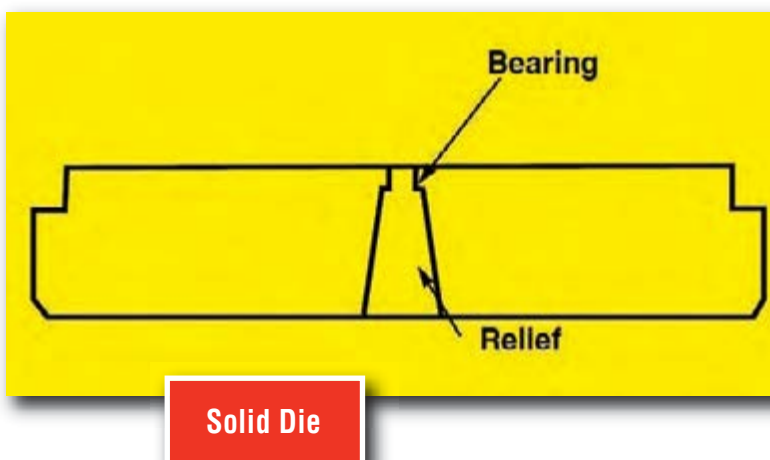
A die is only as good as the tooling behind it. If the profile to be extruded has commercial dimensional tolerances, wall thicknesses that are acceptable, and die tongue ratios that do not require much support, then standard tooling most likely is acceptable. On the other hand, if the profile to be extruded has less than standard dimensional tolerances, walls that are thin, and die tongue ratios that need considerable support, or is uniquely shaped, then custom tooling may be recommended. Failure to utilize custom tooling when appropriate could result in excessive die deflection, breakage, and/or an inability to meet tight dimensional tolerances.

Although custom tooling is more expensive in the beginning, the long-term benefits outweigh the initial cost.



Wear of Extrusion Dies

The life cycle of an extrusion die is generally determined by the wear of the bearing. The bearing is the surface of the extruding aperture at right angles to the die face that controls the metal flow and velocity by means of friction. The bearing, therefore, is the primary determinant of control and finish of the profile. Any deterioration of the bearing--in light of the surface finish required--will lead to premature failure of the die.



Enhancing Die Life

Die life can be extended by various methods. One method is nitriding. Nitriding is a heat-treat process that makes the bearing surface extremely hard. If monitored properly, this process can be repeated several times before a new die needs to be made.

Typical Renitriding Guide

Wall Thickness	Approx. Net Lbs. Extruded	Type of Die	Lbs. Extruded Before Bearing Deterioration Appears On Un-nitrided Dies	Lbs. Extruded Before Bearing Deterioration Appears On Nitrided Dies
.040 - .060	42,000	hollow	2,500	6,500
.040 - .060	74,000	solid	4,000	7,000
.061 - .080	88,000	hollow	3,500	9,500
.061 - .080	97,000	solid	5,000	10,500
.081 - .100	93,000	hollow	4,500	11,000
.081 - .100	109,000	solid	6,000	13,000
.101 - .130	114,000	hollow	5,500	12,500
.101 - .130	151,000	solid	7,500	14,500
.131 - .170	142,000	hollow	6,500	14,000
.131 - .170	183,000	solid	9,000	16,000
.171 - .220	161,000	hollow	7,000	15,500
.171 - .220	344,000	solid	9,000	17,500

Note: Above numbers are based on Mill Finish condition and standard Aluminum Association dimensional tolerances. Actual die life will vary, depending on alloy selection, the desired extrusion surface quality, and dimensional tolerancing.

Section

6

Designing with Aluminum Extrusions



ALUMINUM
EXTRUDERS
COUNCIL

Aluminum Extrusion
Manual
4.2 Edition

Section 6



Designing with Aluminum Extrusions

To many designers and materials specifiers, extruded aluminum is the material of choice for countless applications. Experts choose aluminum profiles because extrusion offers so many design options:

- ▶ various alloys can be readily formed into complex shapes;
- ▶ extrusion tooling is inexpensive;
- ▶ lead times for custom shapes or prototypes are relatively brief;
- ▶ many different finishes are available;
- ▶ extruded products offer significant sustainability benefit due to aluminum's recyclability, and
- ▶ the potential for signifying high recycled content.

Wherever extremely tight dimensional tolerances are called for, designers count on aluminum profiles to meet exacting specifications. However complex its cross-section may be, an aluminum component produced by extrusion does not require joining or assembly, and is thus likely to retain its integrity better than components assembled from multiple parts. Yet profiles can be joined by all major methods in use today, including adhesive bonding, welding, soldering, or brazing, as well as through use of clips, bolts, rivets, or other fasteners. They can even be designed to snap-fit together with other extruded profiles.

Creative designers are discovering new freedom through aluminum extrusion. No longer tethered to conventional ideas of standard shapes and limited characteristics of traditional materials, designers are limited only by the scope of their imagination. Aluminum profiles are their material of choice.

Designing with Extrusions

Design Decision – Why Use Aluminum Extrusion?

When there is no limit except your imagination, just think of the possibilities.

By offering designers a near net shape of their choice, in a timely manner, through a relatively low-cost process, aluminum extrusions are unrivaled among structural materials for design selection. From idea through design, to the production of die . . . through extrusion, fabrication, and final finish . . . by providing the end product with aluminum extrusion, you can design exactly the shape you need and let the production process serve you. Consider the many valuable characteristics of aluminum and the versatility of the extrusion process.

Function

The first consideration in design, function is the key to successful form and fit within the component's actual use.

Advantages

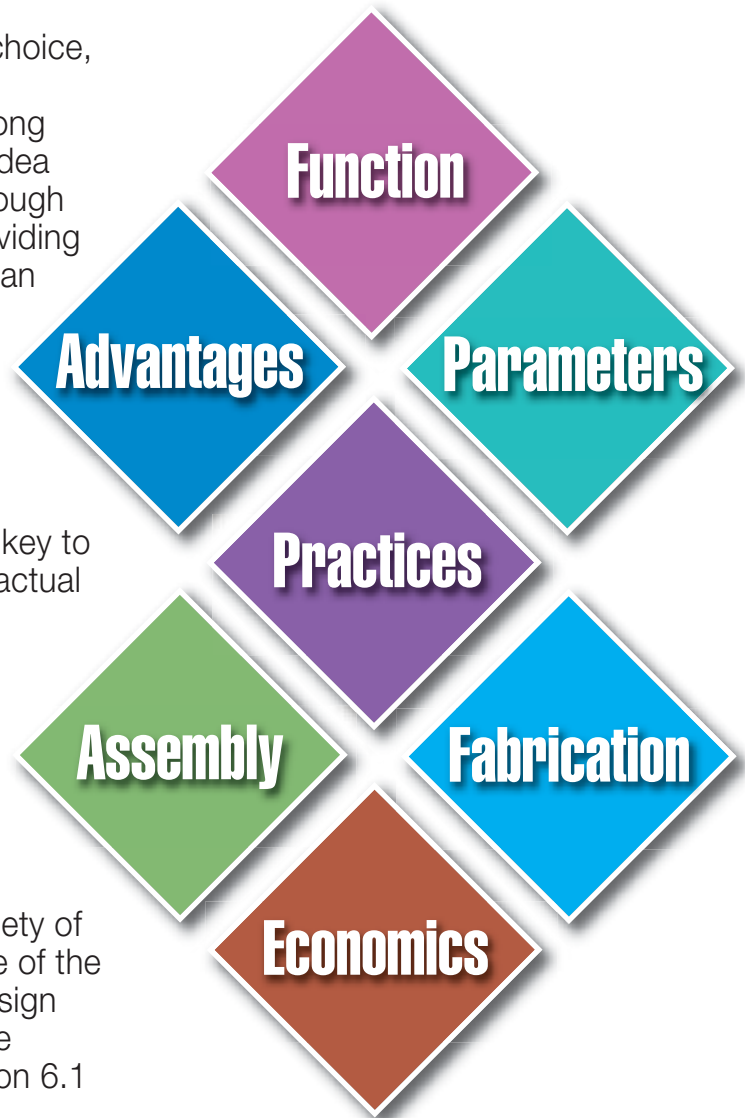
Aluminum profiles offer a number of design advantages by virtue of the extrusion process itself.

Fabrication

Aluminum extrusions adapt themselves to a variety of fabrication processes which can take advantage of the inherent characteristics of aluminum and the design advantages of the extrusion process to meet the criteria required for the final product. See Section 6.1 on Fabrication following this chapter for more information.

Economics

Both on a direct and indirect basis, economics of the finished product can be enhanced through creative designs utilizing aluminum extrusions. Aluminum is readily recycled, thus reducing life-cycle costs; aluminum is lightweight, thus reducing shipping costs.



Design Decision - Function

Designers are encouraged to explore the vast opportunities available through the use of aluminum extrusions and to set high expectations for the performance of extruded aluminum components and end products. Of course, it is then the designer's challenge to figure out what it takes to meet these key criteria. From a functional perspective, it is important to ask what it is you want the part to do, not what the part should look like. In considering function, prepare a list of the following:

- ▶ What are the parts' essential functions?
- ▶ What essential shapes and dimensions do these functions require?
- ▶ How do these essential elements relate to each other?
- ▶ What secondary functional elements are necessary to connect, support, or strengthen the overall component?
- ▶ What other critical elements exist that may effect the final product?

Modeling Programs to Assist in Design

Finite Element Analysis is a modeling method for optimizing a design to have minimal weight and cost, while fully understanding how the design behaves in operation.

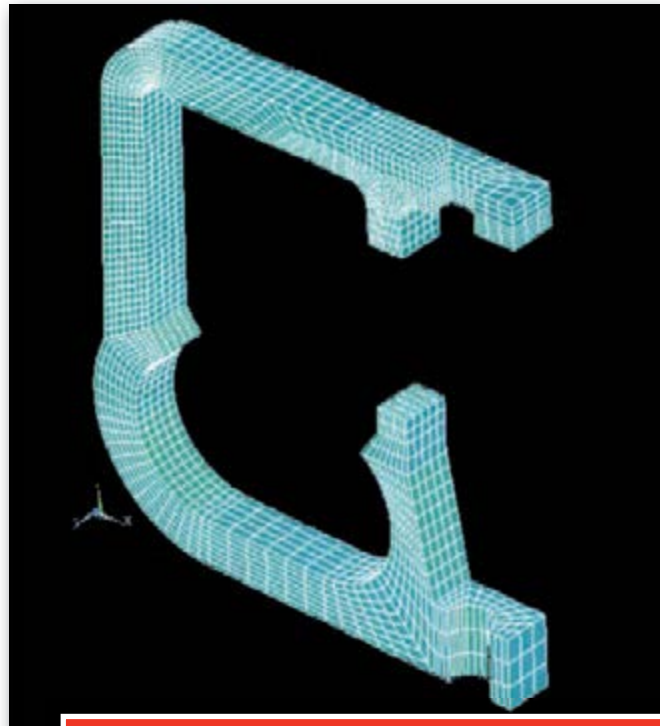
Thermal Analysis is a modeling method by which to pre-determine junction temperature based on surroundings to develop the optimum plan for heat transfer.

Structural Analysis is a modeling method used to identify the points of stress and strain based on material used, the supporting points, the load applied, and the contact points.

Thermal Conductivity for Various Metals

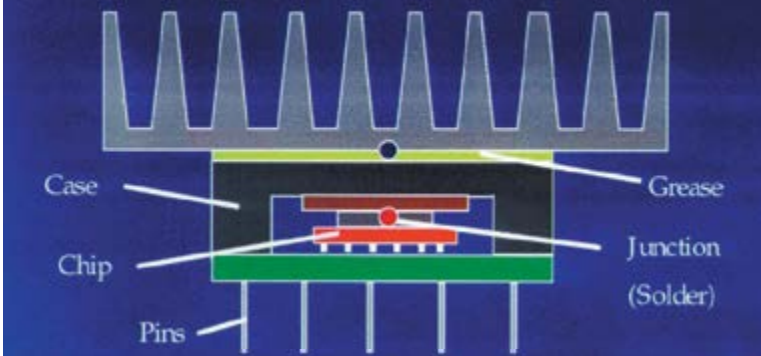
Pure Metal	Thermal Conductivity	Estimated Cost/Pound*	Relative Performance
Gold	14.7	\$27,833.60	0.0005
Silver	20.2	523.36	0.0385
Copper	18.7	3.72	5.0228
Zinc	5.4	.857	6.3010
ALUMINUM	9.7	.892	10.8740

Note: *Costs are based on market conditions as of 10/20/2012 and will vary depending on the metal market values.

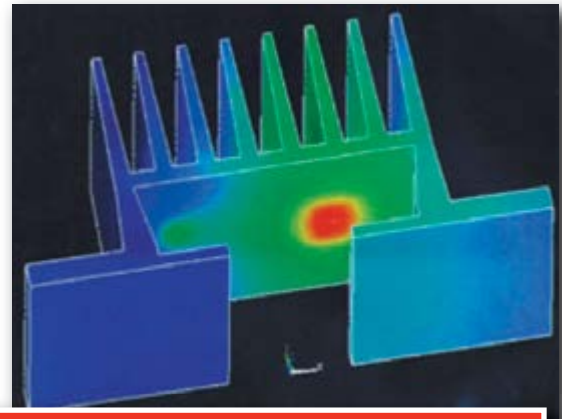


Through Finite Element Analysis, designers can get the design right the first time, reduce material costs, and execute their designs through the product's eventual functions.

Junction Temperature

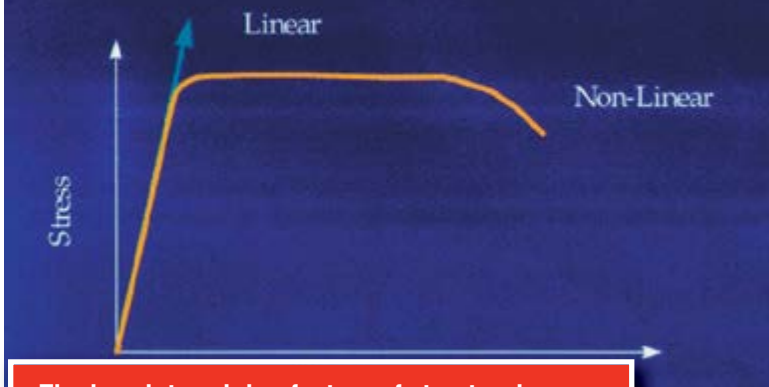


This diagram shows several components in an electronic assembly. Thermal analysis is used to predict the junction temperature (at center of diagram). Cooling occurs due to the natural thermal conductivity of aluminum, through the extruded heat sink at the top of the assembly.

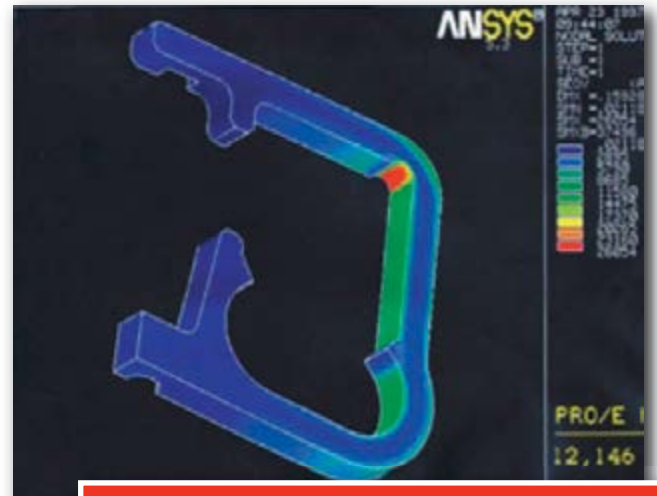


For thermal analysis, the thermal model of the heatsink as shown is used to determine the specific point of highest heat concentration (as shown in red) and how the design will dissipate the temperature throughout the extruded profile.

Material



The key determining factors of structural analysis are stress and strain. Significant parameters include: materials, supports, loading, and contact points.



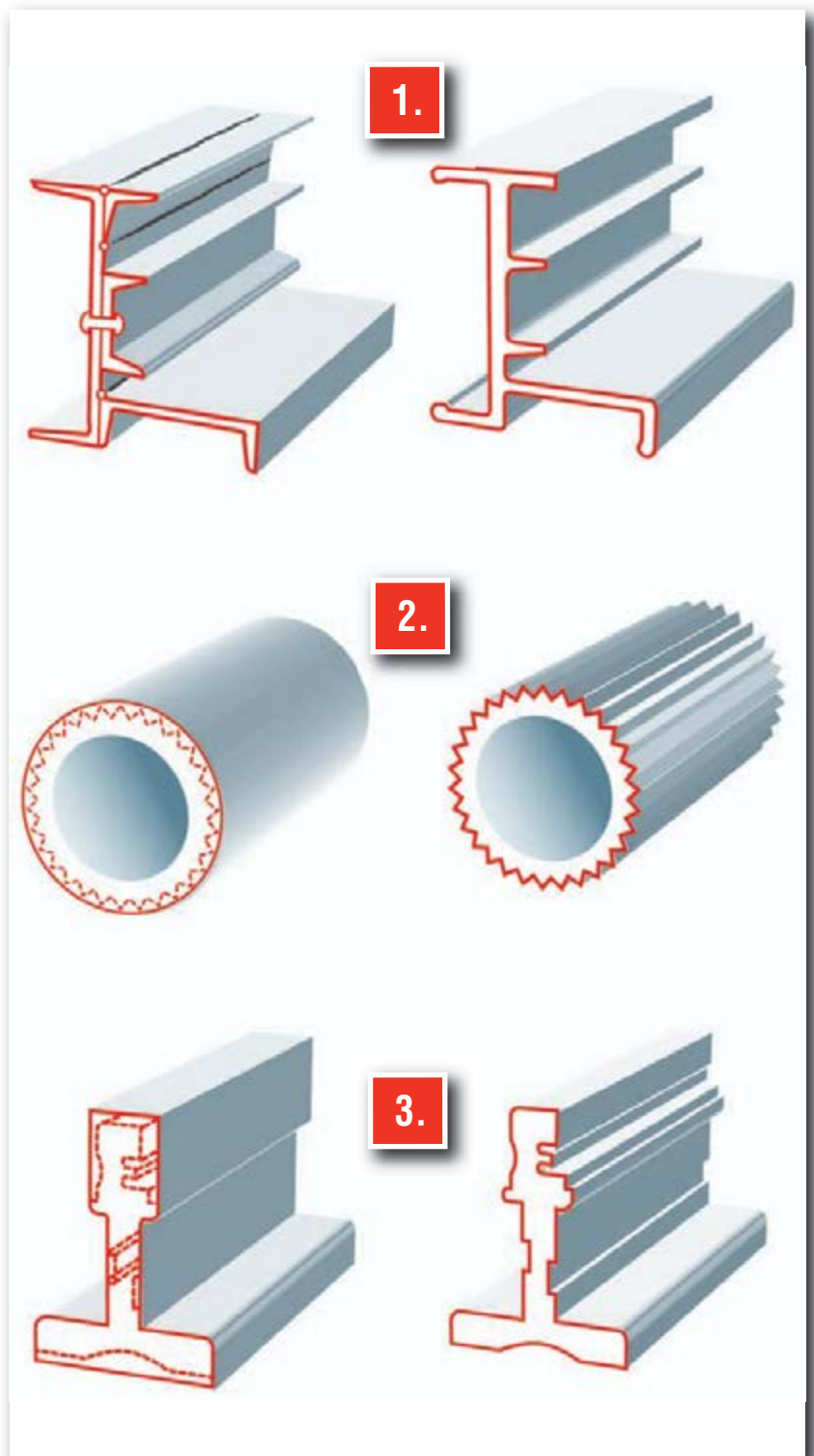
For structural analysis, the structural model of the extruded profile as shown displays the stress on the section in its application and at which specific point (as shown in red) the shape has its most stress or weakest point in terms of structural strength.

Function

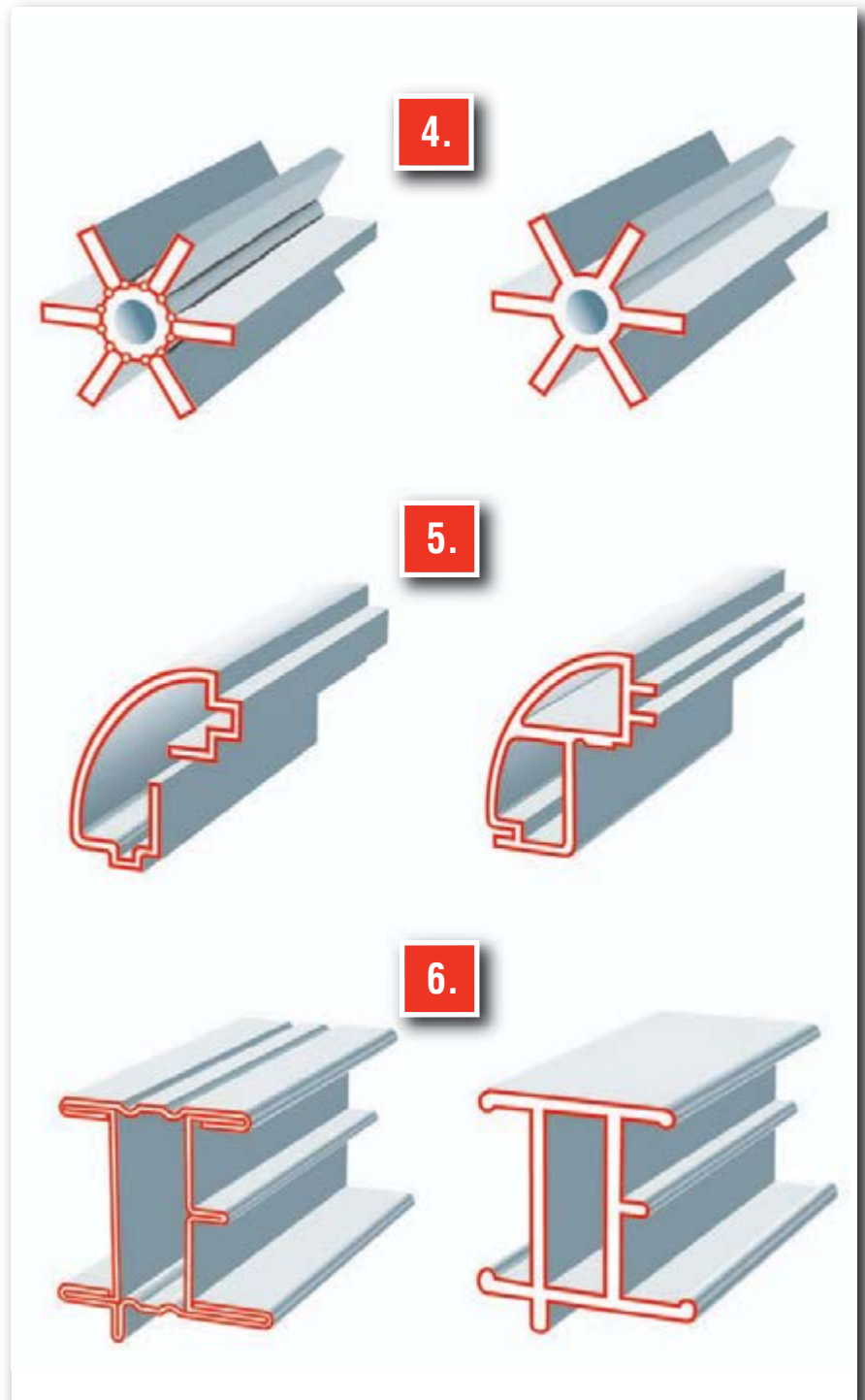
Design Decision – Advantages with Aluminum Extrusions

There are any number of ways in which extruded aluminum can be applied to meet design challenges more effectively, more efficiently, or more economically than alternative methods of manufacture. The following illustrations offer just a few common examples.

1. As shown, several rolled shapes, riveted together, can be replaced by a single extruded profile, resulting in higher strength while eliminating joining costs.
2. Machining costs often can be reduced by extruding the desired component to exact (or near net) size and shape requirements.
3. Weight can be greatly decreased by putting the metal only where needed. The extrusion process can put the metal exactly where needed.



4. Welded assemblies frequently can be eliminated by designing an appropriate extrusion. In this way, costs can be reduced while both strength and accuracy are increased.
5. Sturdy multi-void hollow profiles are available to replace roll-formed alternatives, often at reduced set-up costs and shortened lead times.
6. Improved stiffness and strength can be achieved through extrusion. Here, a detailed hollow profile replaces a crimped tubular section, at a reduced manufacturing cost.



Design Decision - Parameters

In the detailed development of an aluminum extrusion design, the following five factors (each of which is described in detail over the next few pages) should be considered:

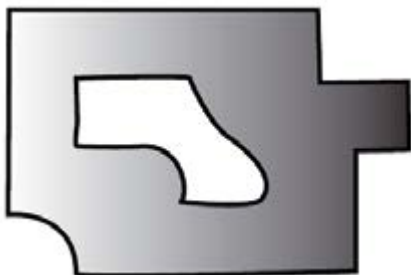
1. Shape (Profile) Configuration. Extruded profiles are described in three general categories: solid, semihollow, and hollow.



A solid profile is the least complex. It may assume a variety of forms, as long as its cross-section has no voids.



A semihollow profile partially encloses a void. It is defined by its tongue ratio, and further categorized according to standard industry classification tables.



A hollow profile completely encloses a void. A single profile may contain multiple voids.

- 2. Tolerances.** Section 8 offers detailed information on standard dimensional tolerances and geometric tolerancing.
- 3. Surface Finish.** Surfaces can be finished in a variety of ways, as discussed in Section 4.
- 4. Alloy.** There are a number of aluminum extrusion alloys, each with distinct characteristics and properties. They are discussed in Section 7.
- 5. Circumscribing Circle Size.** Sometimes referred to as the circumscribing circle diameter (CCD), this is the most common industry measurement of a profile's diameter.

Profile Configuration

A solid extruded profile is any shape that is not a hollow or semihollow.

This covers a wide range including, for example, compact cross-sections with or without projections, angular or curved shapes, and those wrap-around shapes whose tongue ratios are too low for the semihollow class.



A solid Profile.

Extruded rod is a solid product with a round cross-section at least 0.375-inch in diameter.

Extruded bar is a solid product whose cross-section is square, rectangular, hexagonal or octagonal, and whose width between parallel faces is 0.375-inch or greater.

If the dimension across any of these products is less than 0.375-inch, it is classified as wire.

Classification--Semihollow Extruded Profiles

Gap Width (Inches)	CLASS 1 RATIO		CLASS 2 RATIO	
	Group A Alloys ¹	Group B Alloys ²	Group A Alloys ¹	Group B Alloys ²
0.040-0.062	2.0	1.5	2.0	1.0
0.063-0.124	3.0	2.0	2.5	1.5
0.125-0.249	3.5	2.5	3.0	2.0
0.250-0.499	4.0	3.0	3.5	2.5
0.500-0.999	4.0	3.5	3.5	2.5
1.000-1.999	3.5	3.0	3.0	2.0
2.000 and more	3.0	2.5	3.0	2.0

Parameters

1. Group A alloys are 1060, 1100, 1350, 3003, 5454, 6061, 6063
2. Group B alloys are 2011, 2014, 2024, 5083, 5086, 5456, 5066, 7001, 7075, 7178, 7079

A semihollow profile is one that partially encloses a void—for example, a circle or rectangle with a gap in one side; but a solid profile can also partially enclose a void, and the difference may not be obvious. It is defined mathematically, by comparing the area of the partially-enclosed void to the gap size. This ratio (Area/Gap²) is called the tongue ratio.



A Class 2 semihollow profile.

If the tongue ratio is larger than a certain number, the profile is classified as semihollow; if the ratio is smaller, the profile is considered a solid. Semihollow profiles are further classified as “Class 1” or “Class 2” according to standard industry tables, such as the example shown here.

A hollow profile is simply an extruded profile which, anywhere in its cross-section, completely encloses a void. The void itself may have any sort of shape, and the complete profile may include a variety of other forms; but if any part of it encloses a void, it's classified as a hollow profile.

Hollow profiles are further classified as Class 1, Class 2, or Class 3 based on analysis of the void and the overall profile geometry.



A Class 1 hollow profile.

Tube and Pipe are specific product forms.

Tube is a hollow section that is long in comparison to its cross-sectional size. It is symmetrical and has uniform wall thickness, except as affected by corners. It may be round or elliptical, or square, rectangular, hexagonal, or octagonal. “Extruded tube,” as the name indicates, is tube produced by hot extrusion; “drawn tube” is produced by subsequently drawing an extruded tube through a die, yielding tighter tolerances and greater strength for thin wall tubing

Pipe is a tube with certain standardized combinations of outside diameter and wall thickness. These are commonly designated by “Nominal Pipe Sizes” and by “ANSI (American National Standards Institute) Schedule Numbers.”

Dimensional Tolerances

For many applications, in which the extrusion will be part of an assembly of components, dimensional tolerances are critical. A designer should be aware of the standard dimensional tolerances to which extrusions are commercially produced. These tolerances generally cover such characteristics as straightness, flatness, and twist, and such cross-sectional dimensions as thickness, angles, contours, and corner or fillet radii.

The published standard dimensional tolerances may be very easy to achieve or very difficult, depending on the profile. The complexity of profile possibilities makes it impossible to publish standard dimensional tolerances that meet all situations, so a discussion of tolerances with suppliers is recommended.

Aluminum extrusions are often designed to minimize or eliminate the need for machining. If desired, extrusions can be produced to closer-than-standard dimensional tolerances, generating cost savings in secondary operations; such savings may range from modest to very significant, depending on circumstances. The designer should carefully consider the requirements of the application and other special tolerances only where they are really needed.

If extruded parts are to interlock in any manner, the designer should work with the supplier to make sure that dimensional tolerances will accommodate a proper fit.

For more on standard dimension tolerances, as well as an introduction to geometric tolerancing, please refer to Section 8.

Surface Finish

One advantage of aluminum extrusions is the variety of ways the surface can be finished, and this offers another range of choices to the designer.

As-extruded, or mill finish can range from structural, on which minor surface imperfections are acceptable, to architectural, presenting uniformly good appearance. It should be understood that under normal circumstances aluminum may be marred during routine handling because it is a soft metal, especially when it first leaves the die at high temperature. Special care is required if a blemish-free surface is desired. This should be discussed with the extruder and specifications made as necessary.

Finishes, other than mill finish, include scratch finishing, satin finishing, and buffing. Aluminum can also be finished by clear or colored anodizing, or by painting, enameling, or other coatings.

If a product will have surfaces that are exposed in use, where normal processing marks may be objectionable, the extruder should be told which surfaces are critical. Dies can be designed to orient the shape to protect those surfaces during the extrusion process; selection of the appropriate packaging can protect the product during shipment.

For more on finishing, please refer to Section 4.

Alloy Selection

Aluminum extrusions are made in a wide variety of alloys and tempers to meet a broad spectrum of needs. Selection is made to meet the specific requirements in strength, weldability, forming characteristics, finish, corrosion resistance, machinability, and sometimes other properties.

The complete list of registered aluminum alloys is quite long, but in practice a few alloys are chosen repeatedly for extrusion because of their versatility and characteristics. Extruders generally supply the most frequently used alloys. When specialized markets justify it, individual companies utilize additional alloys, which will vary with the needs of their major customers. Many extrusion alloys are regularly available.

The 6xxx-series aluminum alloys (those with four-digit registration numbers beginning with a 6) are selected for nearly 75 percent of extrusion applications. Alloys 6063 and 6061 are used most frequently.

Alloy 6063 is used for production of a broad range of solid, hollow, and semi-hollow profiles. It is easily welded, and it has a pleasing natural finish and excellent corrosion resistance. Alloy 6063 is used in architecture and in many moderate-stress applications. Often, 6060 is utilized as an alternative to 6063, providing comparable physical performance with enhanced surface finish.

Alloy 6061 is a good all-purpose extrusion alloy, combining relatively high tensile properties with good corrosion resistance, weldability, and machining characteristics used for production in a broad range of solid, hollow, and semi-hollow profiles. In the T6 temper, 6061 typically has a yield strength of 35,000 and 40,000 PSI, a strength comparable to structural steel. Alloy 6061 is used in many structural applications. Alloys 6082 and 6005A are also frequently used for similar applications.

Many other alloys are used for extrusions, to meet particular requirements. For example, to mention only a few:

Characteristics	Alloys
High strength	7075, 2014
High corrosion resistance	1100, 3003
High electrical conductivity	6101

For further details, please refer to Section 7. New alloys are introduced occasionally, so the designer should consult current alloy and temper tables and discuss specific needs with the extruder.



Circumscribing Circle Size

One common measurement of the size of an extrusion is the diameter of the smallest circle that will entirely enclose its cross-section—its circumscribing circle.

This dimension is one factor in the economics of an extrusion. In general, extrusions are most economical when they fit within a medium-sized circumscribing circle: that is, one with a diameter between one and ten inches.

Most common profiles are less than 18 inches in diameter, but a few extruders are capable of producing extrusions with a much larger circumscribing circle diameter (CCD), some as large as 32 inches.

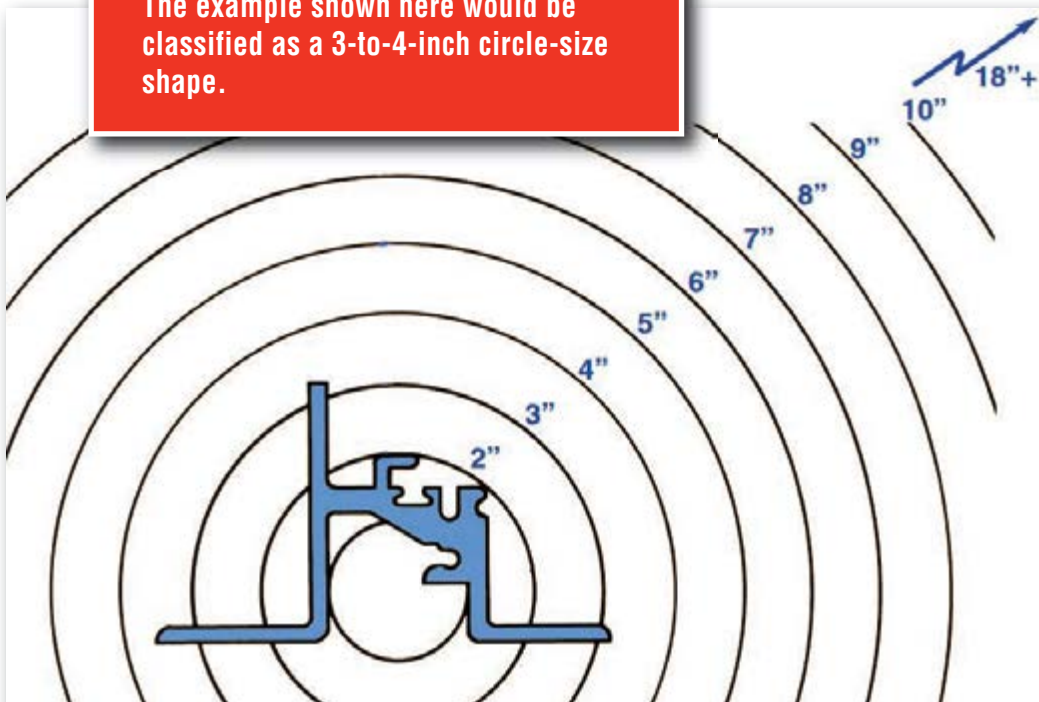
Cross Section Area in sq inches	Circumscribed Circle Size In Inches					Corresponding Profile weight (lbs/ft)
	<1	1 to 7	7 to 10	10 to 14	>14	
< 0.50	–	x	x	x	x	< 0.6
.050 to .100	G	G	–	x	x	0.06 to 0.12
.100 to 1.0	W	W	–	x	x	0.12 to 1.18
1.0 to 2.5	x	W	W	–	x	1.18 to 2.94
2.5 to 10	x	W	W	G	L	2.94 to 11.76
>10	x	x	W	G	L	>11.76

x	Not available
–	Limited Availability
G	Generally Available
W	Widely Available

NOTE:

- There are many presses available with up to 7" diameter containers
- There are fewer presses available with 7" to 10" diameter containers
- There are even fewer presses available with 10" to 14" diameter containers
- There are very few presses available with greater than 14" diameter containers

The example shown here would be classified as a 3-to-4-inch circle-size shape.



Design Decision - Practices

To develop a good extrusion design, the following key characteristics should be addressed:

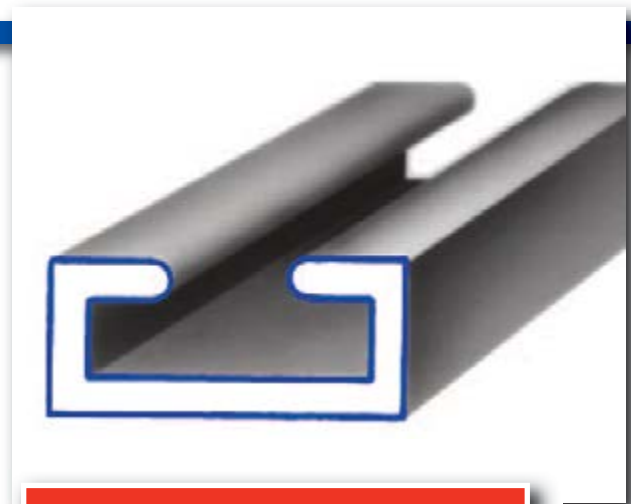
- ▶ Specify the appropriate metal thickness
- ▶ Keep metal thickness as uniform as possible
- ▶ Use metal dimensions for tolerances
- ▶ Design with surface finish in mind
- ▶ Smooth transitions
- ▶ Use webs where possible
- ▶ Use ribs to straighten
- ▶ Round corners wherever possible, avoiding sharp edges
- ▶ Incorporate indexing marks.

Specify the Most Appropriate Metal Thicknesses

Specify metal thicknesses that are just heavy enough to meet your structural requirements. Even in low stress areas, however, keep sufficient thickness to avoid risking distortion or damage. Some shapes tend to invite distortion during the extrusion process (such



Metal thicknesses should be appropriate.



Rounded corners ease the flow of metal.

as an asymmetrical profile or thin details at the end of a long flange); such tendencies exert more influence on thin-walled shapes than on those with typical metal thickness.

Keep Metal Thickness As Uniform As Possible

Extrusion allows you to put extra metal where it is needed—in high-stress areas, for example—and still save material by using normal dimensions elsewhere in the same piece. Adjacent-wall thickness ratios of less than two-to-one are extruded without difficulty, but large differences between thick and thin areas may create dimensional control problems during extrusion. It is best to maintain near uniform metal thickness throughout a shape if possible. When a design combines thick and thin dimensions, streamline the transitions with a radius (a curve, rather than a sharp angle) at junctions where the thickness changes sharply.

Practices

Use Metal Dimensions for Best Tolerance

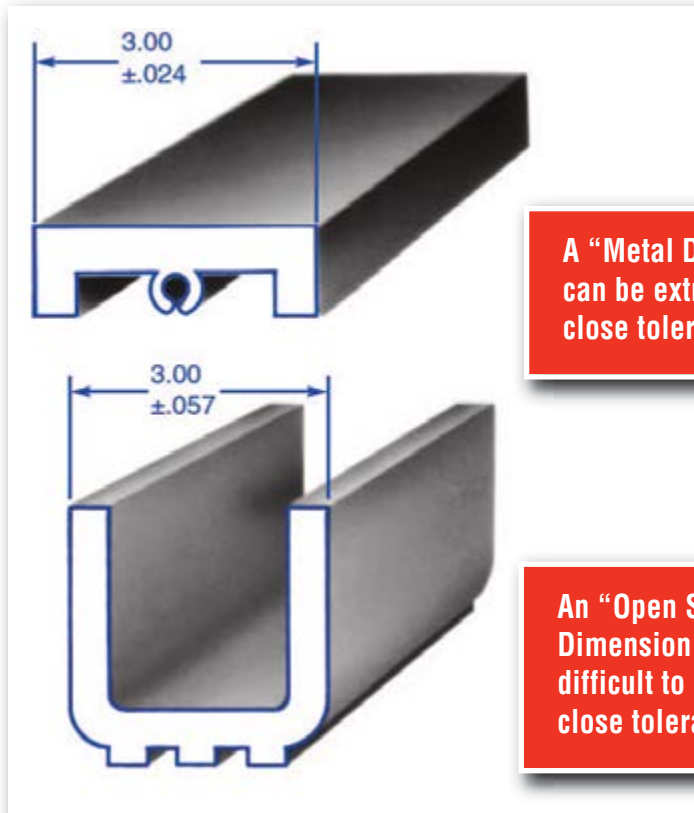
Dimensions measured across solid metal are easier to produce to close tolerances than those measured across a gap or angle. So rely on so-called metal dimensions as much as possible when designing close-fitted mating parts or other shapes requiring closer tolerances. Standard industry dimensional tolerances are entirely adequate for many applications, but special tolerances can be specified if necessary.

Design with Surface Finish in Mind

Always indicate “exposed surfaces” on your design drawing so the extruder can give them special attention and protect their finish during both extrusion and post-extrusion handling.

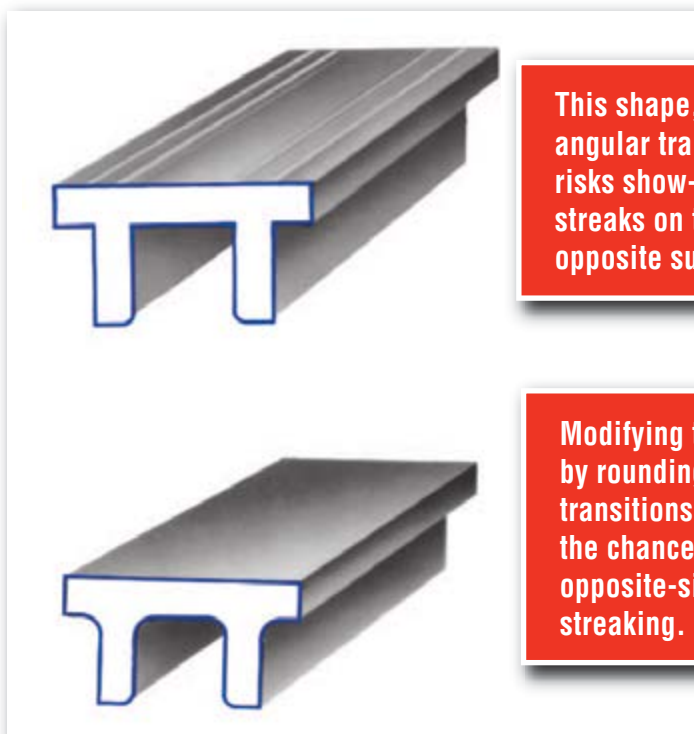
As a general rule, the narrower the exposed surface, the more uniform its finish.

Webs, flanges, and abrupt changes in metal thickness may show up as marks on the opposite surface of an extrusion, particularly on thin sections. The marking of exposed surfaces can be minimized by thoughtful design.



A “Metal Dimension” can be extruded to close tolerances.

An “Open Space Dimension” is more difficult to hold to close tolerances.



This shape, with sharp angular transitions, risks show-through streaks on the opposite surface.

Modifying the shape by rounding the transitions reduces the chance of opposite-side streaking.

Smooth All Transitions in Thickness

Transitions should be streamlined by a generous radius at any thick-thin junction.

Web Gives Better Dimensional Control

Metal dimensions are more easily held than gap or angle dimensions. The web also allows thinner wall sections in this example.

Ribs Help Straightening Operation

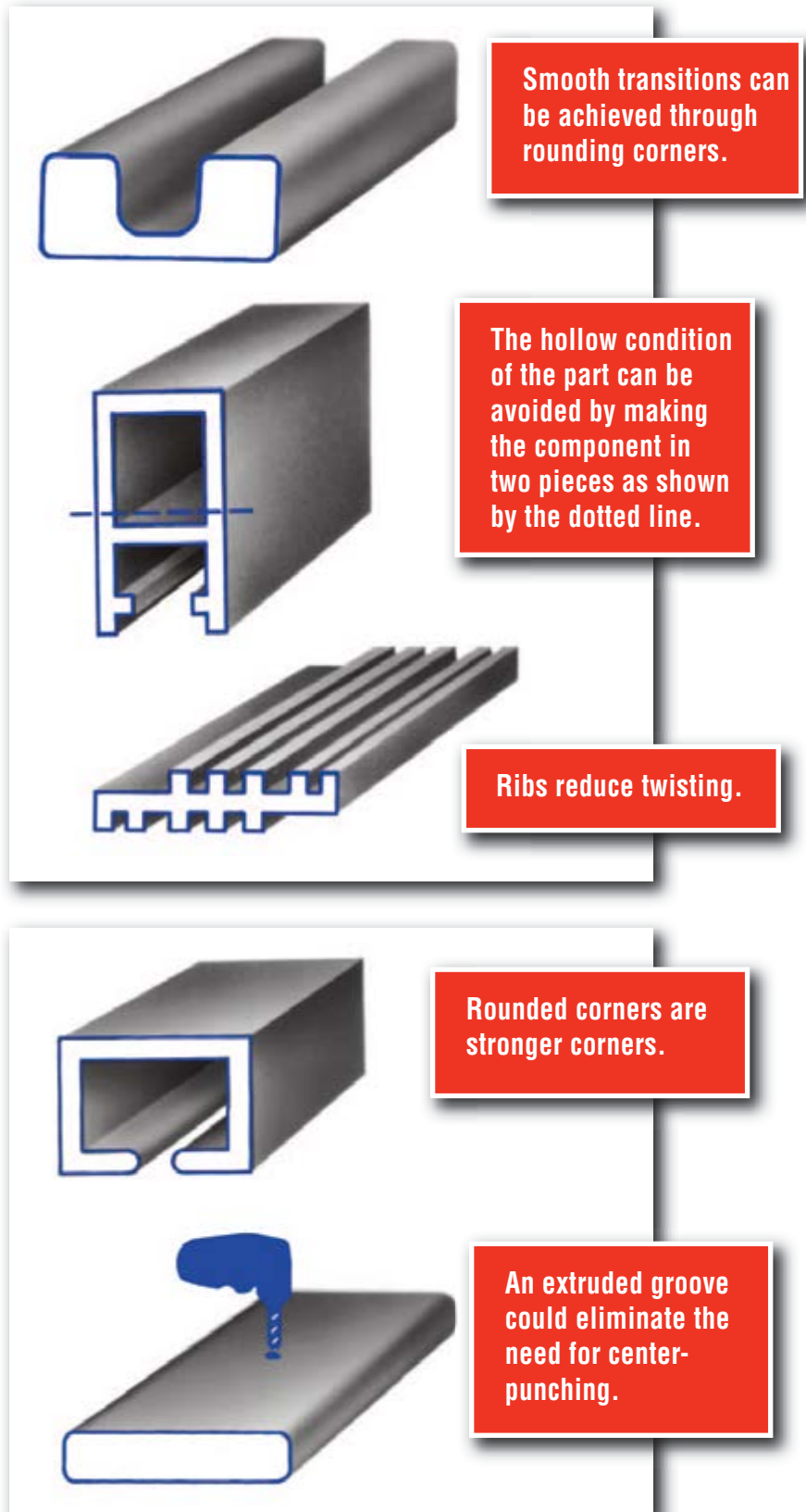
Wide, thin sections can be hard to straighten after extrusion. Ribs help to reduce twisting, and to improve flatness.

Rounded Corner Strengthens Tongue

The die tongue is less likely to snap off when the corners of the profile are rounded at the narrowest area of the void.

Built-In Indexing Mark

Shallow extruded grooves make drilling, punching, and assembly easier by eliminating the need for center-punching. An index groove can also be used to help identify pieces that are similar in appearance, or to distinguish an inside (rather than an outside) surface.

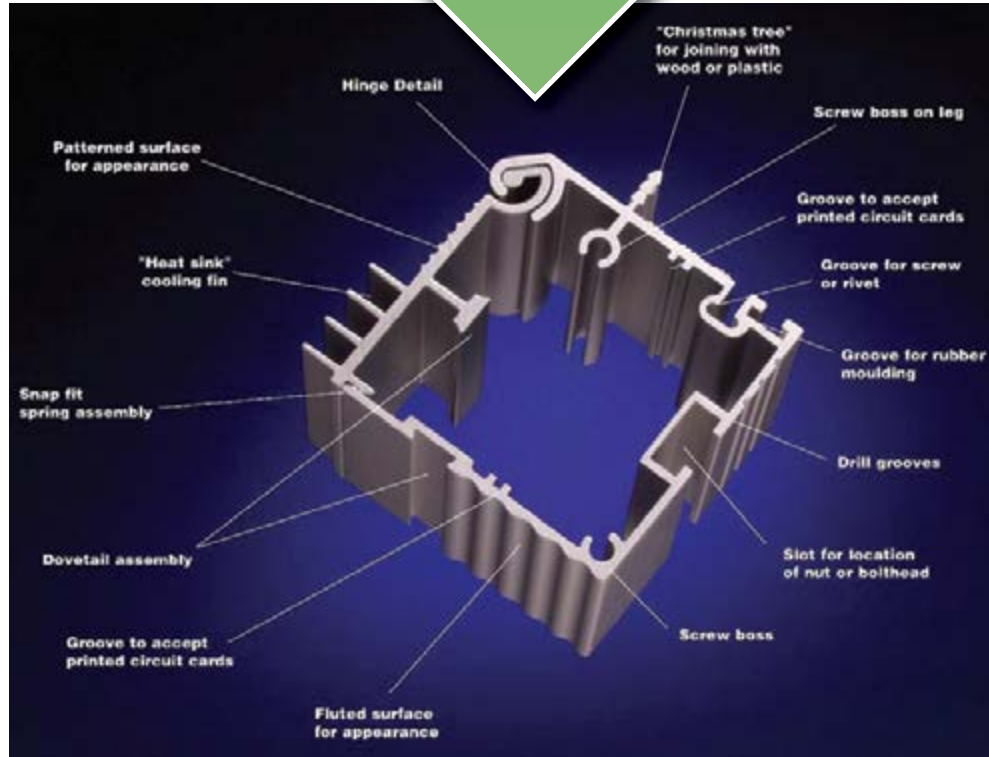


Design Decision - Assembly

Extruded shapes can incorporate essential design features such as screw bosses, card slots, or drill guides. Thus, aluminum profiles enhance the usefulness of the part produced.

The joining of aluminum extrusions can be accomplished by way of nine distinct methods that can be designed into the profiles themselves:

1. Nesting
2. Interlocking
3. Snap-fit
4. Three-piece interlock
5. Combination
6. Slip-fit
7. Hinge joint
8. Key-lock joint
9. Screw slot



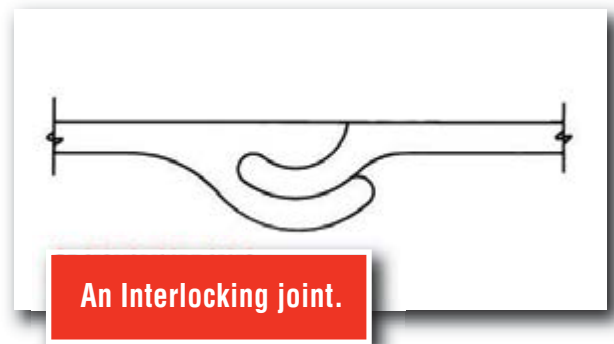
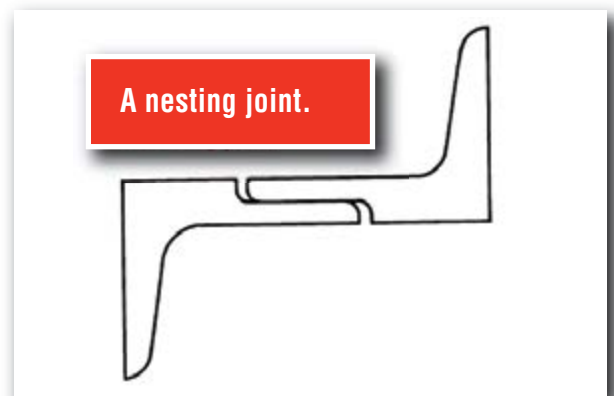
Courtesy of Werner Co.

Nesting Joints

Nesting joints which include lap joints and tongue-and-groove joints, have mating elements that are shaped to be assembled with little or no self-locking action.

Interlocking Joints

The interlocking joint is, in effect, a modified tongue-and-groove. But instead of being straight, the two mating elements are curved, therefore, they cannot be assembled or (more to the point) disassembled by simple straight-line motion. They are assembled by a rotating motion and will not separate without a corresponding counter-rotation. As long as the parts are held in their assembled position, they strongly resist separation and misalignment in both the horizontal and the vertical directions.



Snap-Fit Joints

A “snap-fit” or “snap-lock” joint is one which is self-locking and requires no additional fasteners to hold the joint together.

The mating parts of a snap-fit joint exert a cam action on each other, flexing until one part slips past a raised lip on the other part. Once past this lip, the flexed parts snap back to their normal shape and the lip prevents them from separating. After it is snapped together, this joint cannot be disassembled unintentionally.

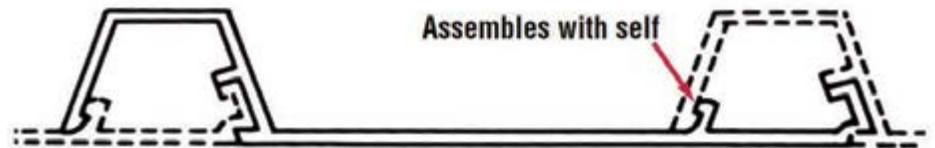
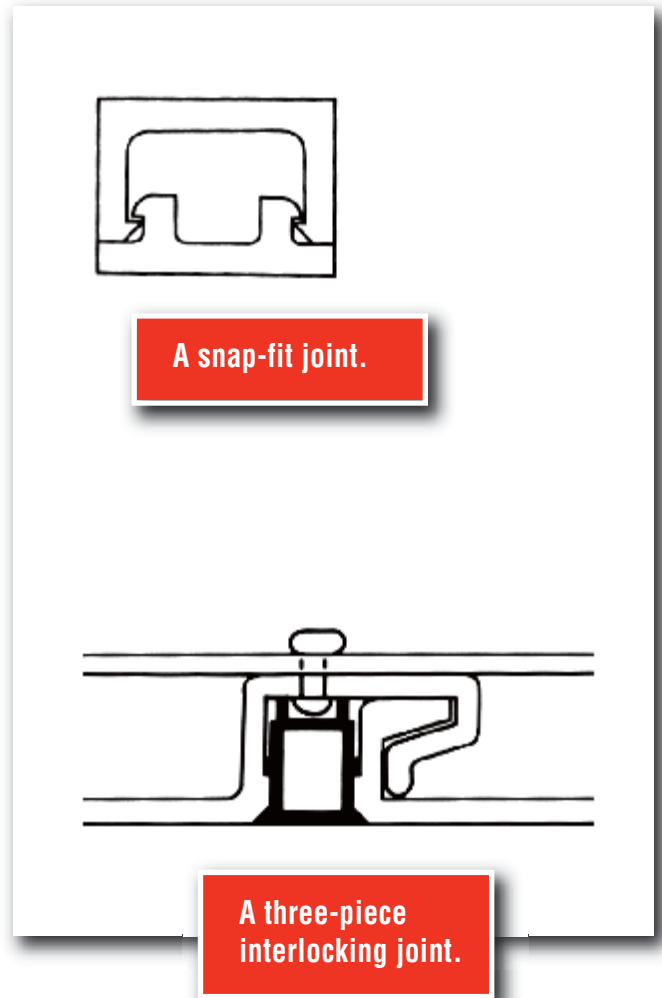
A Three-Piece Interlocking Joint

A three-piece joint can be designed with a blind (hidden) fastener interlocking the two principal extrusions. Such a design presents one side with a smooth appearance and no visible mounting hardware.

Combination Joints

Nesting, interlocking and snap-fit joints can be combined in the same extruded assembly.

For example, snap-fit elements can easily be combined with rotating elements.



In example at above, a single extruded shape is designed for mating with identical parts that are rotated into assembly and then snap-locked rigidly into position without auxiliary fastening. The tight surface-to-surface contact in this design also provides resistance to sliding between the parts.

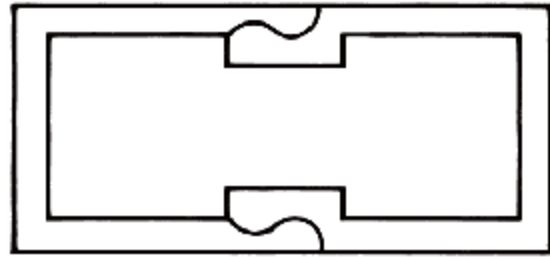
Slip-Fit Joints

Slip-fit joints are assembled by sliding two extruded mating parts together in the direction of their length. They are generally classified either as close-fitting, rigid dovetail joints or as loose, freely-rotating hinge joints.

Dovetail joints are useful in many products where a simple, strong, permanent connection is required.

Hinge Joints

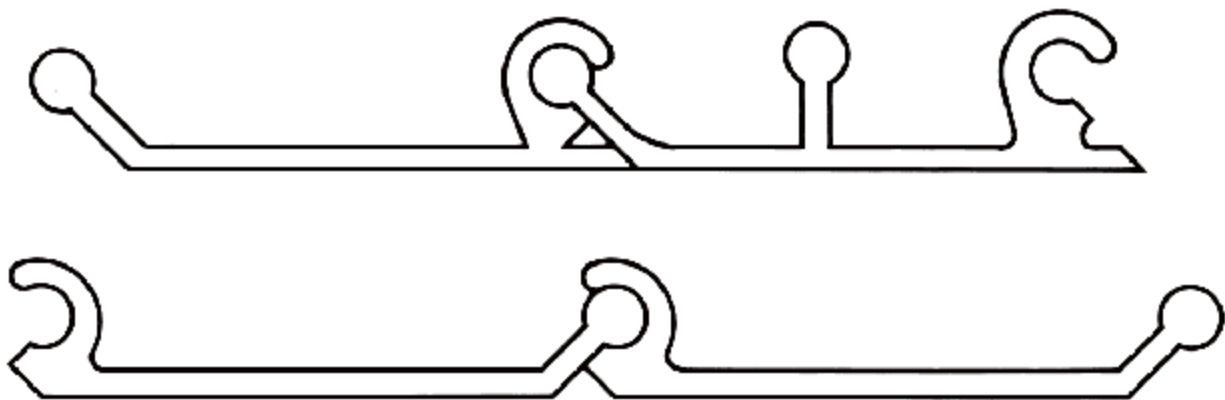
The cross-section of the components of a hinge joint have ball-and-socket shapes that allow them to rotate without separating. Hinge action through 60 to 90 degrees is easy to obtain; incorporating adequate reinforcement, hinge joints may be designed to rotate beyond 90 degrees. Since the hinge joint is relatively “loose,” provisions should be made to prevent lateral (side-to-side) slippage.



This dovetail joint is a type of slip-fit joint.



A pair of extruded components make up this hinge joint.



A number of profiles could be assembled in series for this type of hinge joint.

Key-Locked Joints

These unusual joints have two or more primary elements which are locked together only when an additional specialized part, the key, is slid into position.

The joint shown here is used to connect two or more panels. In the illustration, two panels and their extruded joining elements are seen edge-on from the top or bottom. The three hook-profiled extrusions nest together, but are not in fact joined until an extruded pin with a special profile is inserted into the space at the center, locking them in place.

Keyed interlocks of this type permit rapid, easy assembly and disassembly, making them particularly adaptable to temporary and portable installations, as well as relatively permanent structures.



This unique key-locked joint won an award in an international extrusion design competition cosponsored by the Aluminum Association and the Aluminum Extruders Council.

Assembly

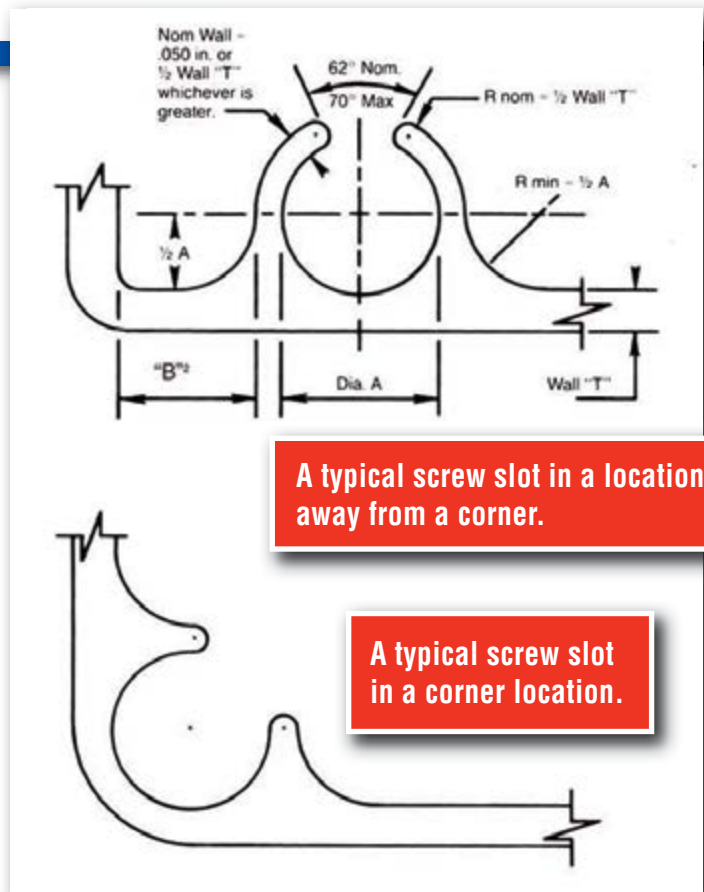
Screw Slots

Screw slots are often used to facilitate the assembly of aluminum profiles. Standard screw slots, as illustrated here, should always be used with self-tapping screws.

The screw slot should be designed so that the area of the void and the metal thickness surrounding it are symmetrical about the center line of the gap.

The type F self-tapping screw is recommended for use with the extruded screw slot. This screw has threads which approximate machine screw threads, plus a blunt point that will stay within the screw slot.

Typical "sheet metal" screws are not recommended, since their thread projects to the very point and thereby can "walk" unevenly through the slot opening.



Type F Screws and Diameters				
NC	Self-Tapping Screw Type F	NF	Screw OD Inches	A Diameter Inches
4-40 ¹		4-48 ¹	0.112	0.099 + 0.006
6-32 ¹		6-40 ¹	0.138	0.120 + 0.006
8-32		8-36	0.164	0.147 + 0.007
10-24		10-32	0.190	0.169 + 0.007
12-24		12-28	0.216	0.190 + 0.007
1/4 x 20		1/4 x 28	0.250	0.228 + 0.007

1. Not recommended for incorporation on inside wall of hollow or semihollow profiles.
 2. The recommended location for screw slots on the inside of hollow or semihollow profiles is at the corners. When not located at corners, dimension "B" must be as least 0.250.

Design Decision - Economics

The following are among the variables that influence the economic advantages of utilizing aluminum extrusions:

1. Product shape
2. Alloy and temper
3. Tolerances
4. Surface finish
5. Length
6. Packaging
7. Quantity



Product Shape

Shape certainly influences product economics: in general (although not always), semihollow extrusions are more economical than hollows; solid profiles are more economical than semihollows; and symmetrical profiles are more economical than asymmetrical shapes.

Extrusions, however, can often save a manufacturer money in hidden ways. A more complex extrusion may be worth a higher initial expense when it creates savings in reduced machining, forming, joining, assembling, shipping or other costs.

Alloy and Temper

There may be several alloys and tempers that would be suitable for production of a given extruded product. The selection is usually made on the basis of structural requirements or the type of fabrication needed. Nevertheless, it's a good idea to look for the most economical alloy among several that may be functionally equivalent for the intended application.

Dimensional Tolerances

Profiles produced to industry-standard dimensional tolerances are usually more economical than those requiring special tolerances.

Product fabrication and assembly techniques sometimes change, making special tolerances less necessary. Periodical review of an extrusion design may reveal an opportunity to reduce costs by easing or eliminating special tolerances, or using tolerances broader than the standard.

Surface Finish

Careful production, handling, and shipping can deliver extrusions with premium-quality surface finishes.

But a premium finish may not be needed on all faces of an extruded profile, and as circumstances change the need for premium finishes may diminish or disappear. It may be possible, upon review of an extrusion design, to reduce or eliminate premium finish specifications.

Length

At relatively low product volumes, fabricators often purchase extrusions in economical warehouse lengths. As production volume increases, however, even greater savings may be gained by purchasing extrusions in exact required lengths or multiples of exact lengths, to reduce scrap generation.

Packaging

Proper packaging can protect extrusions in shipment and determine the condition of the product when it arrives. The choice of packaging varies according to the size and shape of the profile. From small hand packs and palletized boxes to bundles weighing thousands of pounds, the cost depends on the selection of the appropriate pack.

Quantity

Even small quantity extrusion runs usually are very cost effective compared to other processes—particularly when secondary savings such as reduced machining, finishing, and assembly are taken into consideration. At large volumes, manufacturers can benefit from the volume prices available on large mill runs of a shape.

Design Decision – Check List

The following check list offers a dozen major factors to be reviewed in making design decisions.

Addressing each item will help you to design the best product at the best value.

- ✓ Drawing or print
- ✓ End use
- ✓ Alloy and temper
- ✓ Quality specifications
- ✓ End-use length/purchase length
- ✓ Tolerance
- ✓ Fit and assembly
- ✓ Surface finish/exposed surfaces
- ✓ Secondary fabrications
- ✓ Quantity - this order/annual requirements
- ✓ Packaging, handling, shipping
- ✓ Required dates for sample, prototype production, finished product.



Practices

Structural Considerations

Often extrusions will be used in structural applications – not just the obvious like this pedestrian bridge, but also in applications such as:

- ▶ Canopies
 - ▶ Skylights
 - ▶ Solar mounting & racking systems
 - ▶ Bleacher seating
 - ▶ Highway signage
 - ▶ Trailers
- ...and more.

In such applications, it is critical to determine whether the structure:

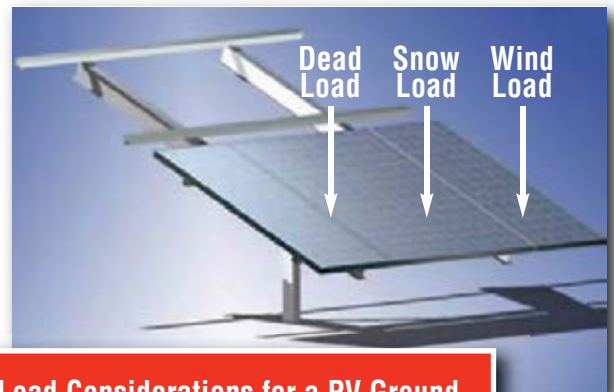
- ▶ Is strong enough to support planned loads, with an adequate safety factor
- ▶ Has sufficient strength for service conditions including vibration, wind and snow loads, thermal expansion/contraction and connector slip
- ▶ Is sufficient for fatigue and corrosion.

A thorough discussion of structural considerations is beyond the scope of this Edition of the Extrusion Manual. However, the considerations and analytic processes are similar to those for other materials – yet use the characteristics of the specified aluminum alloy/temper combination. The following are essential references and will provide key guidance:

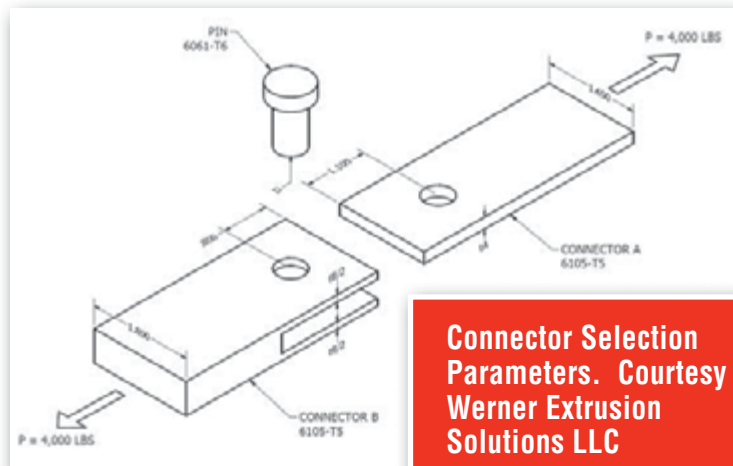
- ▶ Aluminum Design Manual, 2010, The Aluminum Association (formulae, safety factors, tabular performance data in a format similar to the AISC steel manual)
- ▶ Welding Aluminum – Theory and Practice, 2002, The Aluminum Association
- ▶ Inch Fastener Standards, the Industrial Fastener Institute.



The Quaqtq bridge in northern Quebec, Canada is a pony-truss bridge made of 6061-T6 aluminum extrusions. Courtesy of MAADI Group Inc.



Load Considerations for a PV Ground Mount Assembly. Courtesy of Werner Extrusion Solutions LLC



Connector Selection Parameters. Courtesy of Werner Extrusion Solutions LLC



Section

6.1

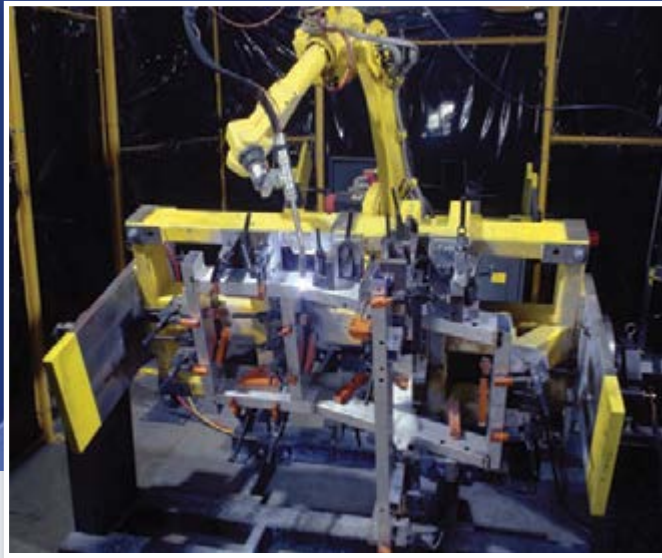
Aluminum Fabrication



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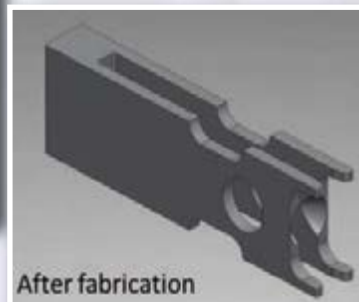
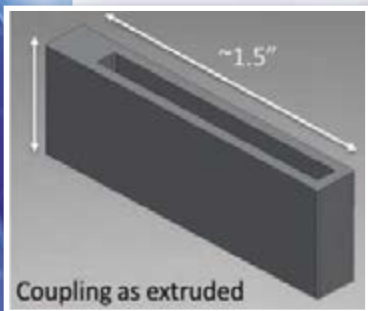
Section 6.1



Aluminum Fabrication

While the ability to create near net shapes, often of complex profiles, is a major advantage of the extrusion process, in most applications additional fabrication will be required to transform the extrusions into components, subassemblies, or even final products.

Whether the need is to cut, drill and tap an extruded aluminum solid bar to create this electrical connector.



Or to machine this extruded hollow to create one of the 64 “shutters” that control the radiation dosage in a radiotherapy system for oncologists.

Fabrication

Fabrication

Or to fabricate and join a number of extruded components to produce this engine cradle. Such desired components and assemblies can be readily created by utilizing most standard metal fabrication and joining processes.

Whether you need to cut, punch, pierce or drill, machine, bend, mill or deburr extrusions, the processes, although often differing slightly from those used for ferrous metals, are straight-forward. Similarly, when there is a need to join extrusions to create an assembly, there are a variety of mechanical, welding and adhesive bonding technologies that can be utilized.

The sequence below shows the creation of a support structure for military tents, starting with a cut section of a “cross-hatch” extrusion. The “ears” are then shaped and pierced, and a short U-shaped extrusion section – with a punched hole -- is welded on. The resulting part is powder-coated and fitted with a mechanical fastener, and then assembled to painted, extruded legs to complete the assembly, which was the final part shipped by the extruder.



Extruded components have been machined and joined to produce this engine cradle.



Many extruders today have significant in-house fabrication capabilities, and therefore can deliver not only profiles but completed components and/or assemblies similar to the tent support. With their engineering resources and in-depth knowledge of both extrusions and aluminum fabrication, they can be a valuable resource in your product development process.

The remainder of this section will address the more common extrusion fabrication techniques, and highlight some of the special considerations.

The Basics: Cutting, Punching, Drilling, Machining



Maybe the requirement is for a transmission mount with annual quantities in the hundreds of thousands...

...or for an arena speaker system with quantities in the hundreds. There are a wide variety of manual, semi- or fully-automated cutting, punching and machining approaches that extruders will use.

Often, if volumes are sufficiently high, dedicated cells, perhaps with robotic handling, will be used. In other cases, multi-purpose equipment such as CNCs or punch presses will be utilized.



Aluminum's properties lend themselves to precision machining – as evidenced by this creative application. This decorative fence, which surrounds the field of the El Paso Chihuahuas minor league baseball team, was created from 200 CNC milled 6063 extrusions, anodized to a copper hue. The architect's intent was to provide partial views, mimicking the knot-holes in an old-time wooden fence.



Bending

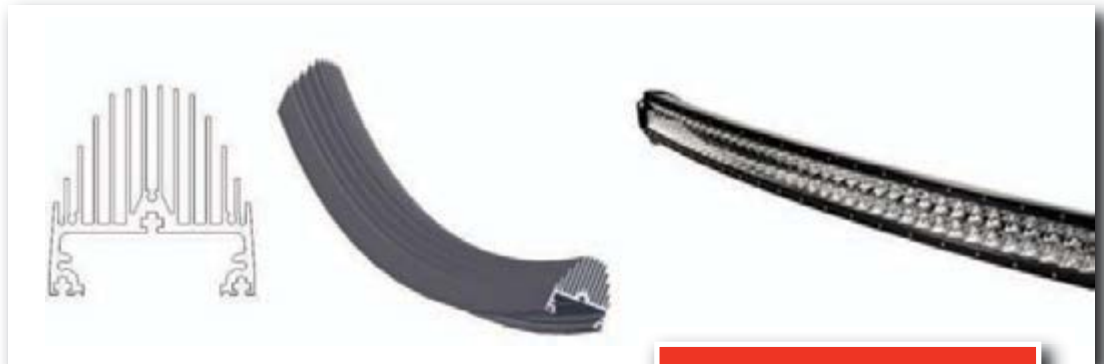
A number of bending technologies – e.g. stretch bending, chain bending, CNC bending – are commonly employed with extrusions, with the choice of approach dictated by the alloy and geometry of the part.

In this example, chain bending is used to form a bumper for a Class 8 truck from a large extruded profile.



The minimum bending radius of a specific extrusion will depend on its size, its alloy and temper, the complexity of its shape, and the characteristics of the bending process.

Note that bending extruded components differs significantly from bending ferrous parts, primarily due to the “springback” that must be considered. It is often advantageous to bend an extrusion in a low-strength condition (e.g., T4) and then heat treat to achieve the final desired temper. Such an approach was used in creating the aftermarket LED light bar for automotive use shown below.



This 6360 extrusion was bent "the wrong way" prior to final heat treat to create an automotive light bar.

In this case, the heat sink extrusion (6360 alloy with a challenging 11:1 tongue ratio) was stretch-bent over a form to a 99" radius in the T4 condition and then heat treated to the desired T6. Note that the part as extruded will age naturally over time, thereby changing its bending properties.

It is for this reason, as well as the springback consideration noted previously, the bending of extrusions – particularly of challenging shapes or hollows – is best left to extruders or fabricators with aluminum bending expertise, rather than relying on general fabrication vendors.

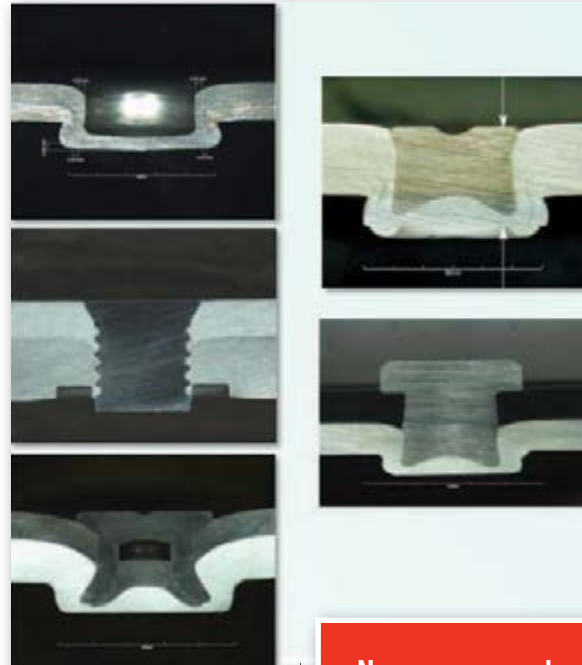
Joining

Aluminum extrusions may be joined – to other aluminum components (sheet, extrusion or castings) or to other materials – with a wide variety of metal-joining methods. With the recent growth in aluminum usage for lightweighting vehicles, and the development of multi-material vehicle architecture, there has been a huge expansion of welding, mechanical fastening and adhesive technologies aimed at multimaterial joining. An excellent reference is the Aluminum Automotive Joining Manual, a collaboration between AEC, the Aluminum Association and the European Aluminium Association (EAA). This 280+ page reference document resides on the EAA website and can be accessed via the following chapter links:

- [Introduction to Joining](#)
- [Characteristics of Fusion Welding](#)
- [Arc Welding](#)
- [Beam Welding](#)
- [Resistance Welding](#)
- [Brazing](#)
- [Solid State Welding](#)
- [Mechanical Joining](#)
- [Adhesive Bonding](#)
- [Hybrid Joining Techniques](#)
- [Joining of Dissimilar Materials](#)

Mechanical joining

In addition to traditional screws and rivets, there are a variety of new clinches, flow-drill fasteners, self-piercing rivets (SPRs), etc. on the market. The choice of fastener will be dictated by the materials to be joined, the thickness of materials, the ease of access to the joining location in the assembly process, etc.



Numerous mechanical fasteners can be used to join aluminum or steel sheet to extrusions.

Welding

There are a variety of welding techniques that can be used when joining aluminum, but as with bending, welding aluminum has important differences from welding steel, and is best left to an experienced aluminum welding shop. The higher thermal conductivity and low melting point of aluminum alloys can easily lead to burn-through unless welders follow procedures specific to aluminum. Both manual and robotic welding can be used.

In addition to MIG and TIG welding for aluminum there are now new spot welding techniques developed in automotive assembly which allow welding of aluminum to steel. Friction stir welding also is a relatively new technology that is particularly suitable for linear joining of flat sections, such as the floor assembly (constructed of 3 thin wall extrusions) for a Mercedes vehicle shown here.

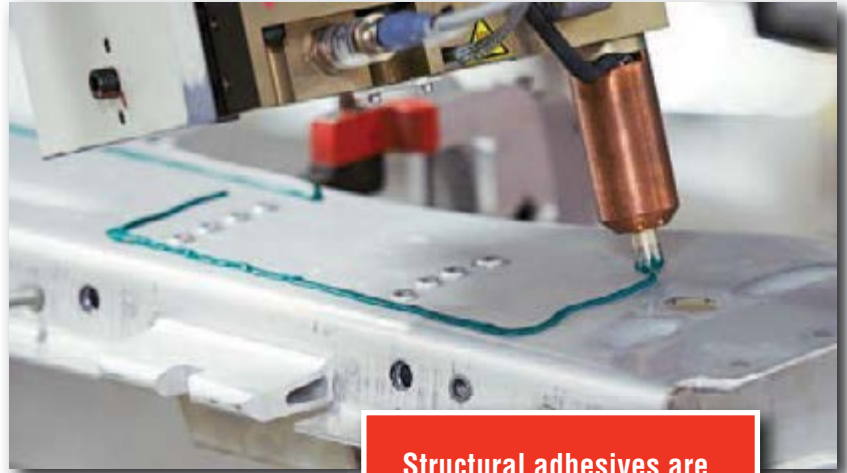


This floor section for a Mercedes sedan was produced using friction stir welding (FSW)

While originally developed for joining larger aluminum panels, advances in friction stir welding technology are now permitting welding of smaller components, and are showing promise in the joining of aluminum and steel.

Adhesive bonding

Adhesive bonding is another technology that has seen rapid development, especially for joining aluminum to other materials in the automotive market. Ford's F-150, for example, uses over 100 meters of structural adhesive, along with 140 Flowdrill screws and 70 Tox clinches. Note that today's adhesives often do more than simply provide joining. When joining dissimilar materials, they can also provide isolation between the parts, thereby minimizing the potential for galvanic corrosion. Further, with a continuous bond, they provide a more rigid, and quieter structure. Having been proven in the auto environment, we see bonding technology migrating to other markets.



Structural adhesives are increasingly being used in automotive applications and other assemblies.

Extrusions and Joining

While the above discussion focuses on the major joining technologies, joining can be enhanced, or simplified, by incorporating various design features into the extrusion profiles.

- As noted earlier in the design section, the extrusions themselves can be designed to incorporate screw slots or to incorporate snap fit and/or interlocking joining
- As an aid to riveting, a guideline can be extruded into the surface marking the precise location of the rivet line.
- Fillet welding can be facilitated by incorporating a weld preparation, such as a “vee groove”, into the extruded shape.
- If an extrusion is to be joined to an adjacent material by adhesive bonding or fit into a casting and adhered with adhesives, extruding a stand-off into the surface can help assure the proper part-to-part spacing for optimal adhesive strength.

Photo credits

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Hydro Extrusion North America

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Pennex Aluminum

Taber Extrusions



Section
7

Aluminum Extrusion Alloys



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Section 7



Aluminum Extrusion Alloys

Alloys are mixed metals that offer a wide array of specific material properties. Many metals have limited usage in their purest forms and are alloyed with other elements to gain strength or other physical properties. The characteristics of various finished aluminum products are determined, in part, by the composition of the alloy. Magnesium and silicon, for example, together make for a very popular alloy class that is heat-treatable and offers good overall characteristics.

When alloyed with other elements, aluminum can be made strong enough to build highway bridges, light enough to construct jet aircraft, or sufficiently corrosion-resistant to use in saltwater environments.

With so many available choices of alloy and temper, each with its own distinctive properties and characteristics, it is important to make a selection appropriate to the end use of the product. The following section contains valuable information pertaining to a wide range of extrusion alloys.



Extrusion Alloys

An aluminum extrusion alloy is simply a mixed metal, made from a predetermined mixture of one or more elements together with aluminum. Some of the common elements alloyed with aluminum include copper, magnesium, manganese, chromium, silicon, iron, nickel, and zinc. These alloying elements are usually added to aluminum in amounts ranging from 0.05 to 7.0 percent. Product performance is determined in part by the alloy composition and in part by the method of production. The production method, in turn, strongly influences the temper of the alloy which is obtained through various types of mechanical and thermal treatments. Structural and certain physical properties are influenced significantly by the choice of alloy and temper.

Alloying aluminum with elements, such as manganese, magnesium, copper, silicon and/or zinc, produces a variety of desirable characteristics, including corrosion-resistance, increased strength, or improved formability. The proper balance of alloying material depends on the intended application of the finished piece. For example, aluminum alloyed in the 5xxx and 6xxx series is particularly suitable for application in bridge design.



©Photo courtesy of MADDI Group.

This structurally strong and corrosion-free aluminum bridge is the longest aluminum pony-truss-style pedestrian bridge in Canada, in the city of Brossard, Quebec. Aluminum alloy 6061-T6 was used to manufacture this bridge.

Alloy Series and Their Constituents

Principal Alloying Element	Designation
>99% pure Aluminum (Al)	1xxx
Copper (Cu)	2xxx
Manganese (Mn)	3xxx
Silicon (Si)	4xxx
Magnesium (Mg)	5xxx
Magnesium and Silicon (MgSi)	6xxx
Zinc (Zn)	7xxx
Other	8xxx

Various properties may make certain alloys particularly desirable:

- Very light weight (one-third the density of steel and concrete)
- High strength (comparable to steel and steel/concrete composites)
- Excellent low-temperature performance (strength and ductility as high or higher at sub-zero temperatures as at room temperature)
- Exceptional corrosion resistance (aluminum won't rust like common steel)
- Ease of fabrication by many techniques, (readily assumes unique structural configurations, has excellent weldability, good machinability).

Major Alloying Elements

The following table represents the major aluminum alloy series and their principal constituents. Aluminum alloys are grouped by major alloying elements; each series exhibits a unique set of properties and characteristics.

Wrought Alloy Designation	Major Alloying Elements and Typical Alloy Characteristics
1xxx Series	<p>Minimum 99% aluminum High Corrosion resistance. Excellent finishability. Easily joined by all methods. Low strength. Poor machinability. Excellent workability. High electrical and thermal conductivity.</p>
2xxx Series	<p>Copper High strength. Relatively low corrosion resistance. Excellent machinability. Heat treatable.</p>
3xxx Series	<p>Manganese Low to medium strength. Good corrosion resistance. Poor machinability. Good workability.</p>
4xxx Series	<p>Silicon Not available as extruded products.</p>
5xxx Series	<p>Magnesium Low to moderate strength. Excellent marine corrosion resistance. Very good weldability.</p>
6xxx Series	<p>Magnesium & Silicon Most popular extrusion alloy class. Good strength. Good extrudability. Good strength. Good corrosion resistance. Good machinability. Good weldability. Good formability. Heat treatable.</p>
7xxx Series	<p>Zinc Very high strength. Poor corrosion resistance. Good machinability. Heat treatable.</p>

Effects of Alloying Elements

The addition of alloying elements modifies the properties and characteristics of aluminum. Such aspects as density, electrical and thermal conductivity, thermal expansion, mechanical properties, ability to finish and harden, and corrosion resistance are all affected by combining the alloying elements with aluminum.

Manganese, for example, increases the mechanical strength of alloys in the 3xxx group. Zinc, in combination with magnesium and copper, produces a material that can be age-hardened, as in alloys 7075. Hard alloys such as 7075 must be thermally treated away from the extrusion press in a separate furnace. Alloys vary in their relative ease of extrudability. Many extrude easily, others are considered relatively easy, while a few are quite difficult to extrude and require procedures that slow the process. Alloys 6063, 6101, and 6463, for example, are rated as having excellent extrudability, while 7075 and 7178 are categorized as difficult to extrude.

Because of its adaptability to a number of large-volume uses, its many favorable characteristics, and its ease of extrudability, 6063 is used to produce a large percentage of aluminum profiles. New, cutting-edge aluminum alloys are being developed to produce even stronger, lighter extrusions for use in aviation and deep-space vehicles. Aluminum-lithium is one of the new alloy classes. Lithium, one of the lightest metals known, is about one-fifth as dense as aluminum. When combined with aluminum into a new alloy, it is 7- to 10-percent lighter and up to 30-percent stiffer than conventional aircraft alloys.

New alloys are periodically introduced to satisfy the changing needs of the marketplace. Designers and specifiers are encouraged to discuss with extruders the best-suited alloys for any given application.



New, cutting-edge alloys, including aluminum lithium, are being developed for aerospace applications.

Tempers

All aluminum alloys, regardless of product form, are classified as either heat-treatable or nonheat-treatable. Those alloys classified as nonheat-treatable develop maximum strength characteristics through cold work after extruding, if section shape permits. Nonheat-treatable alloys are found in the 1xxx, 3xxx, and 5xxx series.

Heat-treatable alloys attain their maximum strength through controlled heat treatment. This group has the highest strength of all aluminum alloys and includes the 2xxx, 6xxx, and 7xxx series.

The Temper Designation System lists the modification methods applied to heat-treatable and nonheat-treatable alloys:

- F** As Extruded: No special control over thermal conditions or strain-hardening; no mechanical property limits.
- O** Annealed: thermally treated to obtain the lowest strength temper.
- H** Strain-hardened: Cold working used to increase strength and hardness.
- T** Thermally Treated: Thermally treated to produce stable tempers other than F, O, or H.

A complete alloy-temper designation reads like this: “6063-T5.” This designation indicates a particular alloy of the 6xxx series (Mg and Si) which is thermally treated by being cooled from an elevated temperature and artificially aged.

Typical Tempers for Extrusions

O Fully annealed.

H112 Strain-hardened; used for nonheat-treatable alloys.

T1 Cooled from an elevated temperature and naturally aged.

T4 Solution heat-treated and naturally aged.

T5 Cooled from an elevated temperature and artificially aged.

T6 Solution heat-treated¹ and artificially aged.

1. For some alloys, this may be accomplished in-line at the extrusion press.

Aluminum is combined with other elements, such as magnesium, silicone or zinc to produce extrusion alloys. Structural and certain physical properties are influenced significantly by the choice of alloy and temper.



Available Tables

Selected Alloy Tables reprinted from the 2009 edition of the Aluminum Association publication *Aluminum Standards & Data* are available by following the link below. These tables are published as a courtesy by the Aluminum Association to users of the Aluminum Extruders Council's *Aluminum Extrusion Manual*.

Follow the links below to the Alloy tables published by The Aluminum Association.

[Table 1.2](#)

Foreign Alloy Designations and Similar AA Alloys

[Table 3.3](#)

Comparative Characteristics and Applications

[Tables 11.1](#)

Mechanical Property Limits – Extruded Wire, Rod, Bar and Profiles

[Table 12.1](#)

Mechanical Property Limits – Extruded Tube

[Table 16.3](#)

Property Limits – Rod, Bar, Tube, Pipe, Structural Profiles and Sheet – Electrical Conductors



Section

7.1

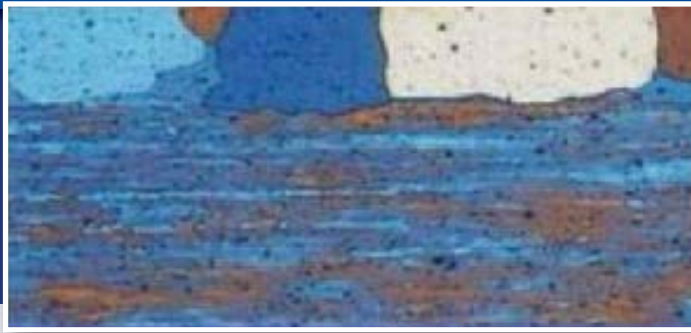
Microstructure



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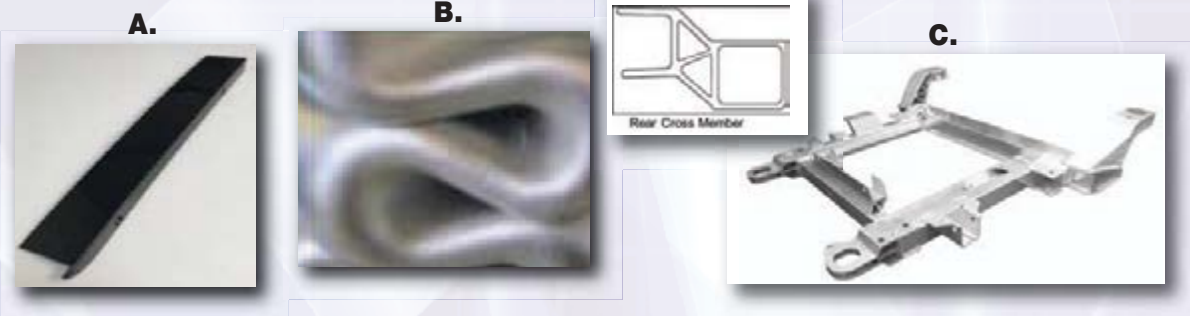
Section 7.1



Microstructure

As applications for extrusion have become more demanding – especially automotive applications – engineers are finding that specifying alloy and temper alone is often not sufficient to ensure that the parts they envision achieve the needed performance attributes.

To illustrate, let's consider 3 auto components, with vastly differing performance requirements:



Item A is an extruded cover for the B pillar of an SUV. With a high-gloss finish, surface quality is key. The part also requires bending to fit the profile of the vehicle and to form a 90° tab.

Component B is a section of a crush can (after testing) used in a vehicle crash management system. Key attributes include strength and ductility for controlled deformation in the event of a crash.

Part C is the rear cross member for the engine cradle pictured below. Strength and machinability are key.

Given the different applications and needed performance attributes of these three components, it may be a surprise that they are all the same alloy – 6063.

Clearly alloy alone is insufficient to define the needed extrusion performance for a given application. Adding temper certainly helps, but engineers are finding that specifying the desired **microstructure** can be key to achieving the performance they need.

What is it you need?

Based on the application of the extrusion, and the expected post-extrusion processing path, there are a variety of performance attributes that may be crucial:



Material Strength:	Yield, Tensile, Elongation
Response to processing:	Formability, Bendability, Heat Treatment
Surface Characteristics:	Corrosion Resistance, Adhesion, Surface Finish
Joinability:	Weldability, Bonding Capabilities, Riveting, FSW
Crushability:	Energy Absorption, "Toughness", Fracture Resistance
Machinability:	Response to Milling, Drilling, Cutting, Punching

As we'll see later, some of these attributes will fight each other (e.g. increased ductility may come with a cost of greater susceptibility to corrosion).

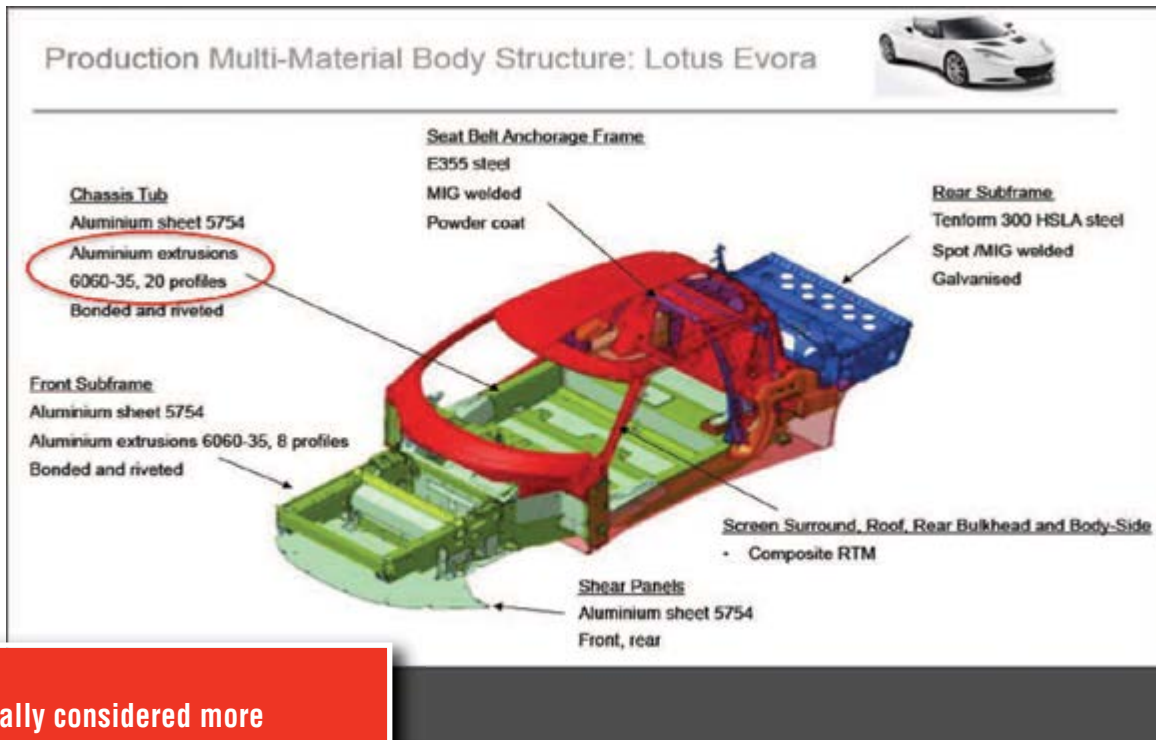
Fundamentally, the actual performance of any extrusion relative to these attributes is a function of:

- Profile geometry
- Chemistry
- Microstructure – which is driven by specifics of the extrusion process.

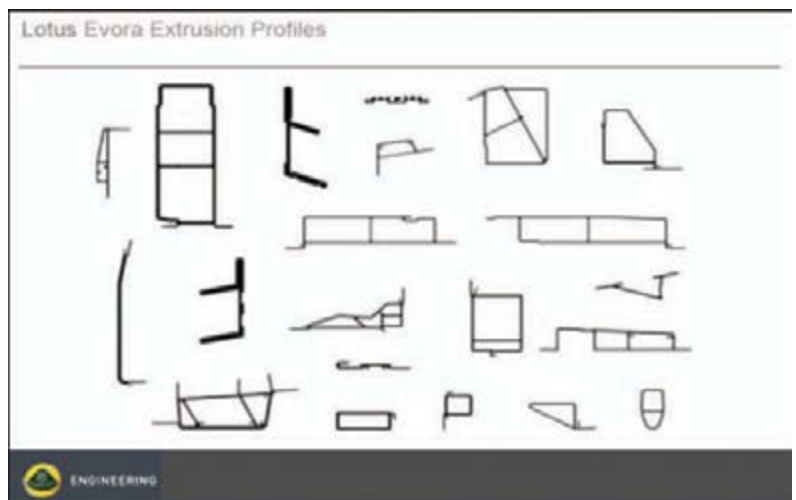
Profile Geometry

One of the most important attributes of the extrusion process is the ability to create complex shapes and put “the metal where it is needed.” While extruders like profiles with equal wall thicknesses and minimal voids, the reality is that variable thickness and the use of internal webs and reinforcements can provide strength that overcomes the presumed limitations of a “softer” alloy.

An excellent illustration is in Lotus Car’s use of a 6060 alloy in the chassis tub of their high-performance Evora sports car.



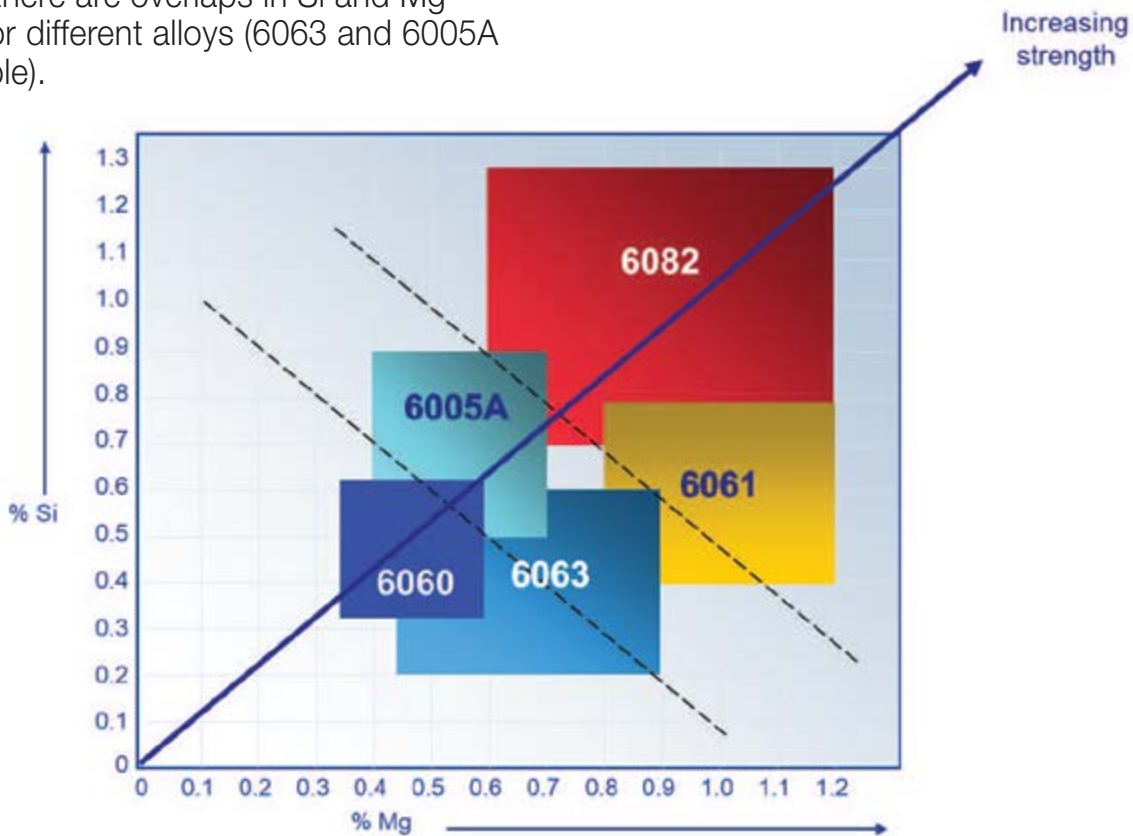
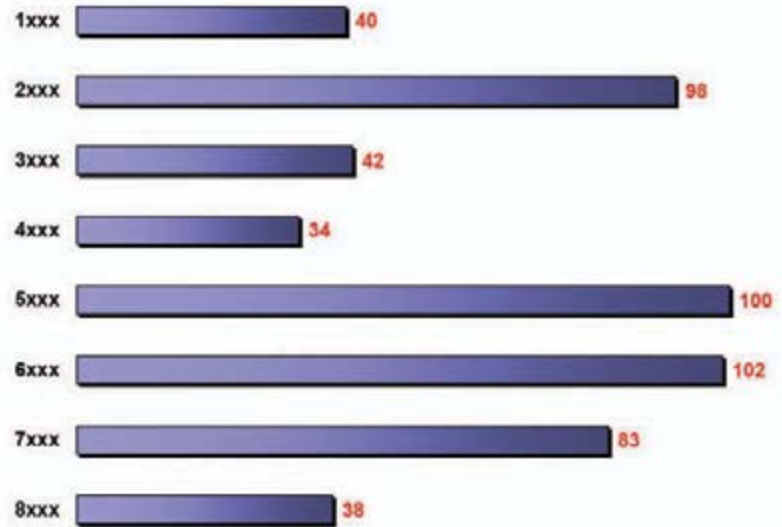
Normally considered more appropriate for less structural applications like windows and doors, 6060 offered Lotus a combination of high extrudability and sufficient structural strength due to the extrusion geometries employed and the riv/bond construction.



Chemistry

Currently there are over 640 alloys registered with the Aluminum Association, with additional alloys constantly being added. Over 100 of these are 6000-series alloys (i.e., those most often used for extrusions). And these numbers do not include proprietary alloy variants, of which there are many.

Further, any one alloy can have a variety of formulae as noted on the following chart, which depicts the Silicon (Si) and Magnesium (Mg) content for a variety of frequently used 6000-series alloys. Note also that there are overlaps in Si and Mg content for different alloys (6063 and 6005A for example).



Thus, there can be significant differences in performance and behavior for a given alloy, depending on its exact chemistry. As further illustration, note the impact of varying trace alloying elements on the performance of 6063 and 6061, two alloys whose Si and Mg composition can again overlap.

Alloy Composition

(Nominal AA spec)

	6063	6061	
Silicon (Si)	0.40%	0.60%]- Increases strength
Magnesium (Mg)	0.70%	1.00%	
Iron (Fe)	0.18%	0.35%	- Increases machinability
Copper (Cu)	0.05%	0.28%	- Increases strength, ductility, yet promotes
Manganese (Mn)	0.05%	0.05%	intergranular corrosion
Chromium (Cr)	0.05%	0.10%	- Promotes grain structure control
Zinc (Zn)			
Total Alloying Elements	1.43%	2.38%	
% Aluminum	98.57	97.62	

So, alloy chemistry is clearly important, and it is critical to discuss specific product requirements with your extruder to determine not only the alloy, but also the alloy composition most likely to deliver the part performance you need.

Microstructure

The final factor, in addition to profile geometry and alloy chemistry, that will dictate real-world part performance is the microstructure (i.e.: grain size, grain geometry, grain structure, Second phase particles, thickness of outer recrystallized layer, etc.) of the final extrusion. It is microstructure, in concert with chemistry, that will determine properties such as strength, formability, corrosion resistance, weldability, etc.



A recrystallized grain structure, such as shown in the micrograph at left, is typical of many extrusion processes. Grain size ranges between 25 and 400 microns, though the larger sizes should be controlled for formability concerns.



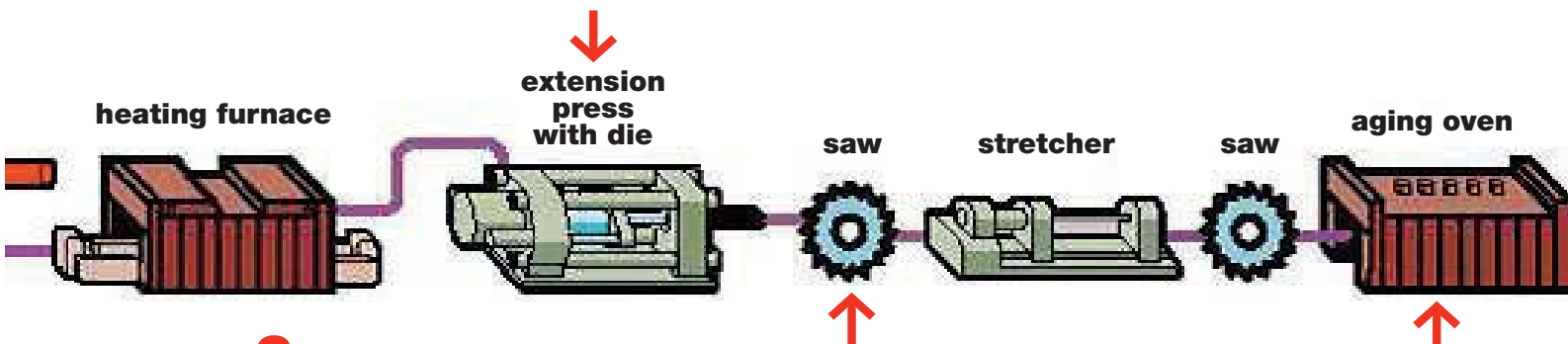
A fibrous grain structure will provide higher mechanical properties and improved fracture resistance, though with a reduction in ductility. This is characteristic of higher strength alloys with manganese and chrome content.



Often, a mixed grain structure results, as the outer layer recrystallizes first, precluding a fully homogeneous fibrous structure. Specifying the thickness and maximum grain size of the outer layer *can provide impressive mechanical properties without substantial cost.*

Accomplishing the desired grain structure is a function of chemistry and extrusion process parameters such as extrusion speed, tooling, billet and container temperature, die design and resultant metal flow, quench rate and post-quench aging, as depicted below.

1 Proper metal temperature through the die is required to put alloying elements into solution



2 Proper cooling/quenching after the press is required to trap Mg Si in solution, while avoiding distortion. The objective is to quench fast enough to avoid undesirable concentration of alloying elements and achieve desired hardness yet slow enough to minimize residual stresses and distortion.

3 Proper aging is required to grow & disperse the precipitates

A complete discussion of microstructure is beyond the scope of this manual. Rather, our objective is to highlight its importance and stress the value in a comprehensive discussion of part application and performance requirements with an extruder. Specifying grain structure and the thickness and maximum grain size of the outer layer will yield both better performance and improved manufacturability, repeatability and cost.



Depending on the alloy, the extrusion is cooled after emerging from the die, either naturally or through the use of air or water quenches. This is a critical step to ensure sufficient metallurgical properties after aging.



Section
8

Tolerances



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Section 8

Tolerances

How straight is straight enough? How flat is flat enough? How uniform must a wall thickness be in order to be acceptable? These are not abstract questions. Many products must be manufactured to exacting standards. The specified, acceptable range of deviation from a given dimension is known as a tolerance.

Tolerances are measurable, so they can be specified and mutually agreed upon by manufacturers and purchasers, by extruders and their customers. Aluminum profiles can be extruded to very precise special tolerances or to accepted standard dimensional tolerances.

The first portion of this section addresses standard dimensional tolerances by referencing selected tables from The Aluminum Association's 2009 Aluminum Standards & Data.

The Tables that pertain to Standard Dimensional Tolerances are linked below:

[Tables 11.5 through 11.14](#)

[Tables 12.2 through 12.5](#)

[Tables 12.10 through 12.14](#)

The following portion of this section is an introduction to geometric tolerancing.

Geometric tolerancing has been likened to a modern technical language that enables designers and engineers to communicate their requirements to the people who produce the components of an assembly.

When tolerances are met, parts fit together well, perform as intended, and do not require unnecessary machining. The aluminum extrusion process puts the metal where it is needed and offers the precision necessary to meet specified tolerances.



Geometric Tolerancing

Introduction to Geometric Dimensioning and Tolerancing

Taken together, geometric dimensioning and tolerancing (GD&T) can be used to specify the geometry or shape of an extrusion on an engineering drawing. It can be described as a modern technical language, which has uniform meaning to all. It can vastly improve communication in the cycle from design to manufacture. Terminology, however, varies in meaning according to the Geometric Standard being used; this must be taken into account in each case.

Geometric dimensioning and tolerancing, also often referred to in colloquial terms as geometrics, is based upon sound engineering and manufacturing principles. It more readily captures the design intent by providing designers and drafters better tools with which to “say what they mean.” Hence, the people involved in manufacturing or production can more clearly understand the design requirements. In practice, it becomes quite evident that the basic “engineering” (in terms of extruding, fixturing, inspecting, etc.) is more logically consistent with the design intent when geometric dimensioning and tolerancing is used. As one example, functional gauging can be used to facilitate the verification process and, at the same time, protect design intent. Geometric dimensioning and tolerancing is also rapidly becoming a universal engineering drawing language and technique that companies, industries, and government are finding essential to their operational well-being. Over the past 40 years, this subject has matured to become an indispensable management tool; it assists productivity, quality, and economics in producing and marketing products around the world.

Rationale of Geometric Dimensioning and Tolerancing

Geometric dimensioning and tolerancing builds upon previously established drawing practices. It adds, however, a new dimension to drawing skills in defining the part and its features, beyond the capabilities of the older methods.

It is sometimes effective to consider the technical benefits of geometric dimensioning and tolerancing by examining and analyzing a drawing without such techniques used, putting the interpretation of such a drawing to the test of clarity. Have the requirements of such a part been adequately stated? Can it be produced with the clearest understanding? Geometric dimensioning and tolerancing offers that clarity.

Often an engineer is concerned about fit and function. With many standard tolerances this may become a concern. Geometric tolerancing is structured to better control parts in a fit-and-function relationship.

The Symbols

Effective implementation of geometrics first requires a good grasp of the many different symbols and their functional meaning. The following symbols are those that are most commonly used within the extrusion industry.

The current standard, as of this writing, is from the American Society of Mechanical Engineers (ASME) through the American National Standards Institute (ANSI) in publication Y14.5 - 2009, Dimensioning and Tolerancing and is considered to be the authoritative guideline for GD&T.

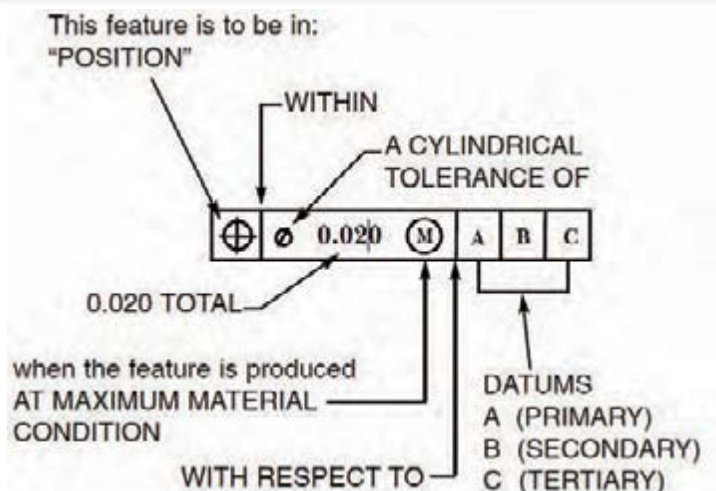
For definitions of basic terms used in geometric tolerancing, refer to the appendix at the end of this section.

Note: Tolerances used within the following examples are purely illustrative and may not reflect the standard tolerances used by the aluminum extrusion industry

Type	Designation
STRAIGHTNESS	
FLATNESS	
ANGULARITY	
PERPENDICULARITY	
PARALLELISM	
CONCENTRICITY	
POSITION	
CIRCULARITY	
PROFILE OF A LINE	
PROFILE OF A SURFACE	
CYLINDRICITY	
DIAMETER	
DATUM FEATURE	
MAXIMUM MATERIAL CONDITION (MMC)	
REGARDLESS OF FEATURE SIZE (RFS)	
LEAST MATERIAL CONDITION (LMC)	
TANGENT PLANE	

The Feature Control Frame

The feature control frame is a rectangular box containing the geometric characteristics symbol and the form, orientation, profile, runout, or location tolerance. If necessary, datum references and modifiers applicable to the feature of the datum are also contained in the frame.



Material Conditions

Maximum Material Condition

The abbreviation for maximum material condition is MMC and the symbol is the capital letter M with a circle around it. The maximum material condition occurs when a feature contains the most material allowed by the size tolerance. It is the condition that will cause the feature to weigh the most. MMC is often considered when the designer's concern is assembly. The minimum clearance or maximum interference between mating parts will occur when the part features are at MMC.

The most critical assembly condition is when External (Male) features are their largest and Internal (Female) features are their smallest.

The maximum material condition for external features occurs when the size dimension is at its largest.

The maximum material condition for internal features occurs when the size dimension is at its smallest.

MMC - abbreviation

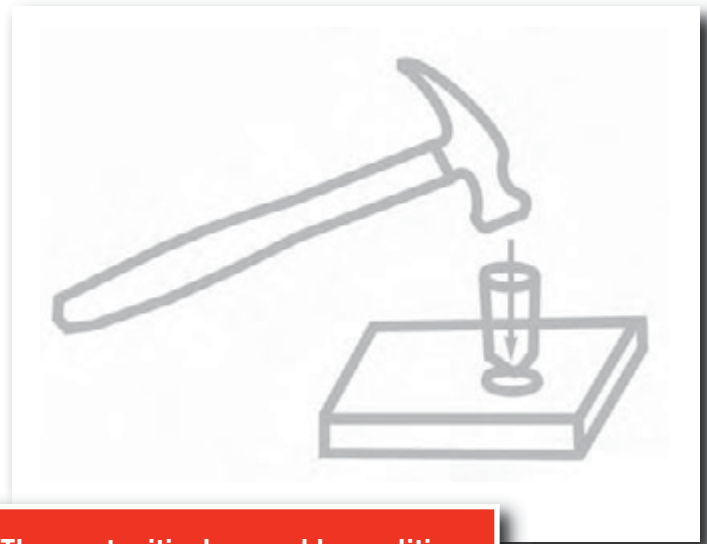
(M) - symbol

Least Material Condition

The abbreviation for least material condition is LMC and the symbol is L within a circle. Least material condition is the opposite of maximum material condition. In other words, it is a condition of a feature where it contains the least amount of material. For external parts, that occurs when the overall dimension is at a maximum. It is the maximum size of an internal feature.

LMC - abbreviation

(L) - symbol



The most critical assembly condition is when External (Male) features are their largest and Internal (Female) features are their smallest.

Regardless of Feature Size

The abbreviation for regardless of feature size is RFS, and the symbol is S within a circle. Regardless of feature size is a condition that is used when the importance of location and/or shape of a feature is independent of the feature's size and forces anyone checking the part to use open set-up inspection.

RFS - abbreviation

(S) - symbol

Rule #1 – “Where only a tolerance of size is specified, the limits of size of an individual feature prescribe the extent to which variations in its geometric form, as well as size, are allowed.”

Rule #2 – “For all applicable geometric tolerances, RFS applies with respect to individual tolerance, datum reference, or both, where no modifying symbol is specified. MMC, or LMC, must be specified on the drawing where it is required.”

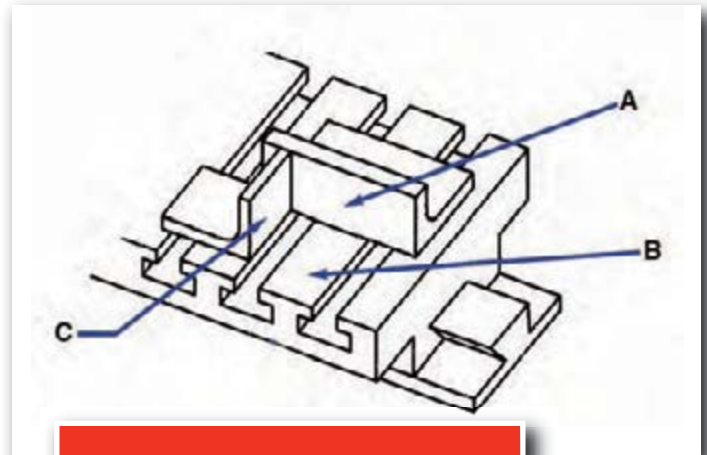
Datum

A datum is a theoretically exact point, axis, or plane that is derived from the true geometric counterpart of a specified datum feature. The datum is the origin from which the location or orientation of part features is established.

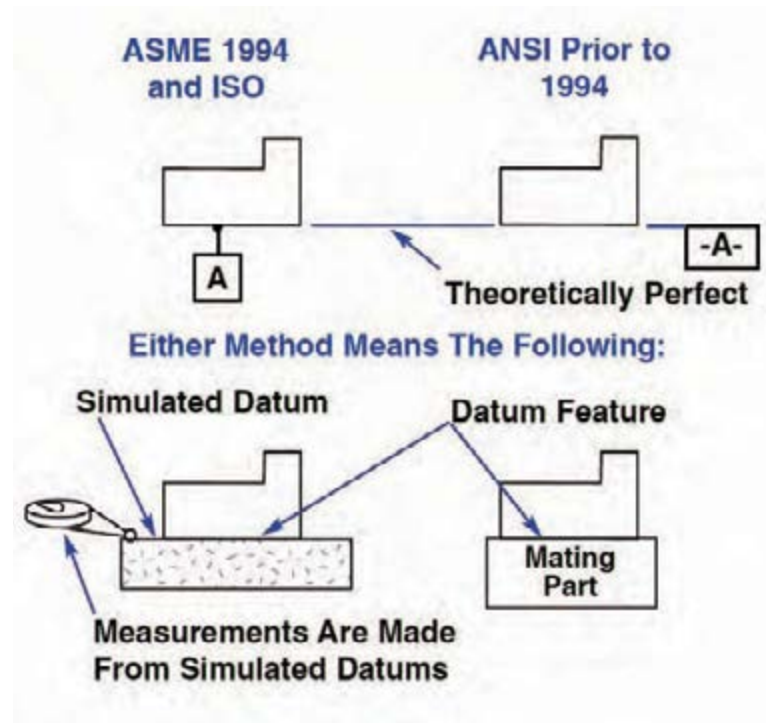
Confusion can arise if the drawing does not specify how a part is to be located. This is done by specifying datums on the drawing.

A drawing of a ball bearing would not require a datum because it is a single feature part. If a hole were drilled in the ball bearing, different measurements would result if the tolerance of the part were held to be on the feature of the ball or the hole. Adding a datum designation to one of these features and referencing to it would eliminate any confusion.

The datum feature is defined as the actual feature of a part that is used to establish the datum. Since it is not possible to establish a theoretically exact datum, they must be simulated. Typical ways to simulate a datum are to use surface plates, angle plates, gauge pins, collets, machine tool beds, etc. The intent of the standard is to hold or fixture the part with something that is as close to the true geometric counterpart as possible. The further the fixture deviates from the true geometric counterpart, the greater the set-up error and, therefore, the less reliable the measurement.



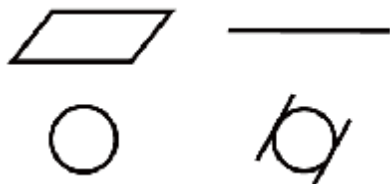
Simulated datums are what hold the parts in production, inspection, and their assembly.



The datums can be thought of as a navigation system for dimensions of the part. They might also be thought of as a “trap” for the part. On the lower drawing on the opposite page, the datum, in this case datum A, refers to a theoretically perfect datum plane. A surface plate in an inspection area would serve as a simulated datum and would make contact on the high points or extremities of the surface.

These high points are the same points that will make contact with the mating part in the final assembly. Measurements made from the surface plate to other features on the part will be the best method to predict whether the part will perform its intended function.

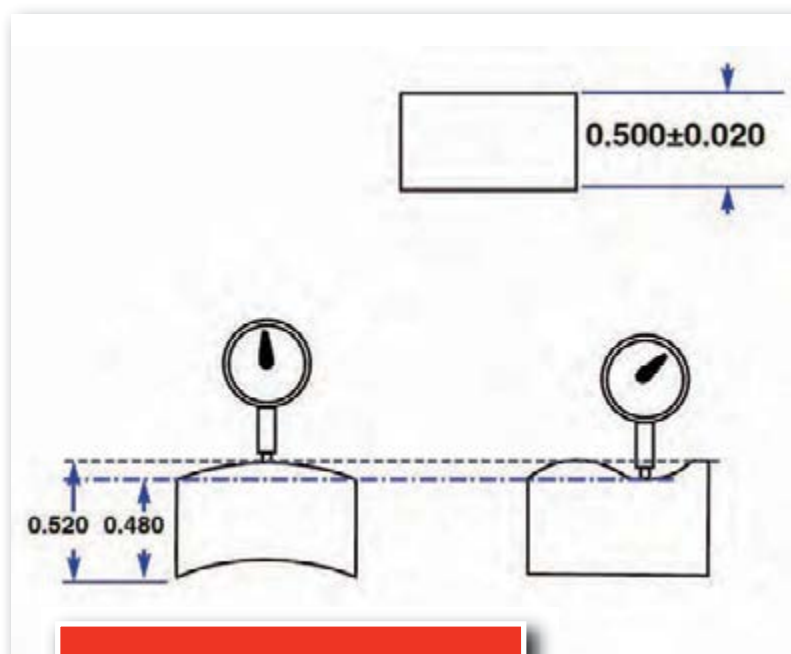
Tolerances of Form (Unrelated)



The geometric form of a feature is controlled first by a size dimension. Prior to the use of geometric dimensioning and tolerancing, size dimension was the primary control of form and did not prove to be sufficient. In some cases, it is too restrictive and in others, the meaning is unclear. Rule #1 (see page 3) clearly states the degree to which size controls form.

In this example, the 0.500 dimension established two parallel lines. One pair is 0.520 apart (the high limit) and the other pair is 0.480 apart (the low limit). The 0.480 can float within the 0.520. If the lower surface was perfectly flat (right-hand figure), the upper surface could be anywhere within a 0.040 tolerance zone.

In this extreme case, it can be said that the top surface must be flat within 0.040.



If the part is manufactured at MMC, both surfaces would have to be perfectly flat.






Flatness

Flatness is the condition of a surface having all elements in one plane.

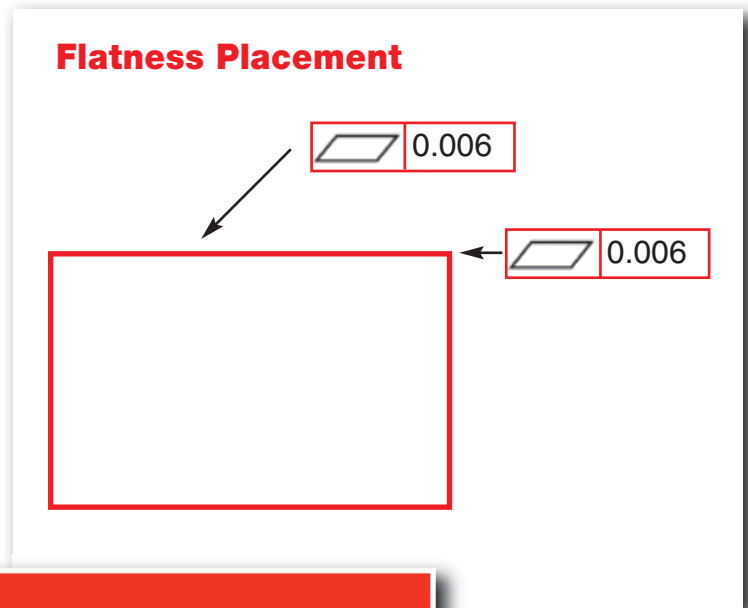
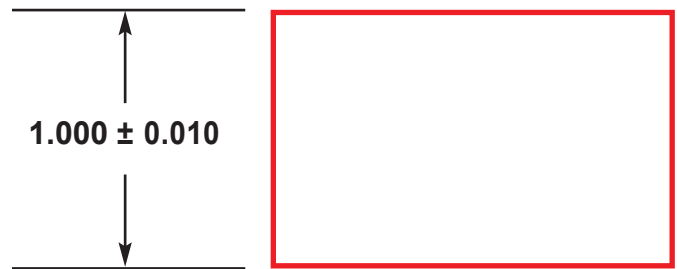
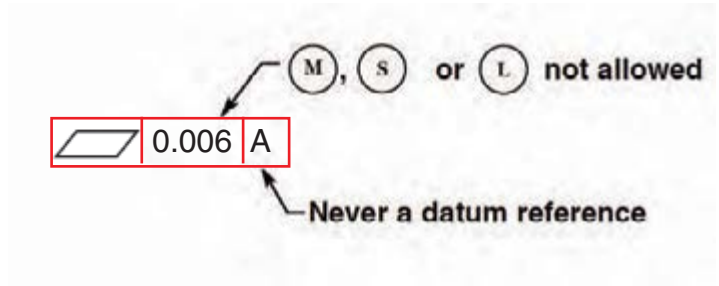
Flatness usually applies to a surface being used as a primary datum feature.

Other tolerances that provide flatness control include:

- ▶ Any size tolerance on a feature comprised of two internal or external parallel opposed planes.
- ▶ Any flat surface being controlled by:

Perpendicularity		0.008	A
Parallelism		0.008	A
Angularity		0.008	A
Profile of a Surface		0.010	A B
Total Runout		0.010	A

One way to improve the form of the surface is to add a flatness tolerance. This tolerance compares a surface to an ideal or perfectly flat plane. A flatness tolerance does not locate the surface.



The flatness requirement is placed in a view where the controlled surface appears as an edge. The feature control frame may be on either a leader line or an extension line. Since flatness can only be applied to flat surfaces, it should never be placed next to a size dimension.

Straightness (of an axis or center plane)

Straightness is a condition under which an element of a surface or an axis is a straight line.

The feature control frame must be located with the size dimension.

This tolerance is used as a way to override the requirement of perfect form at MMC (Rule #1).

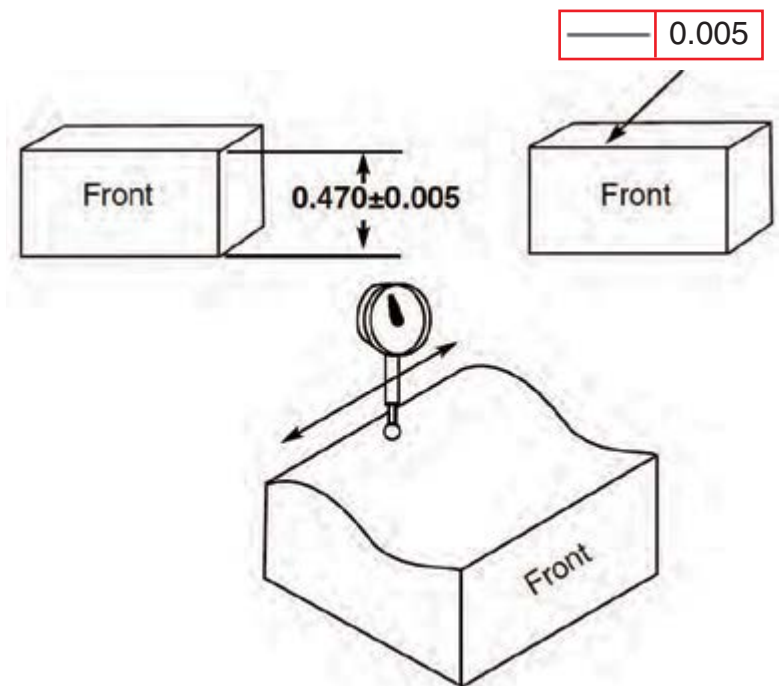
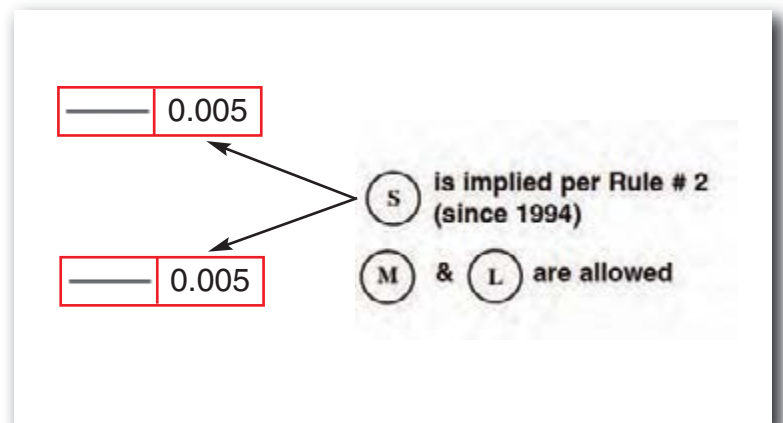
Other tolerancing that automatically provides this control are:

Any Size Tolerances ± 0.010

Circular Runout  0.006 A

Total Runout  0.010 A

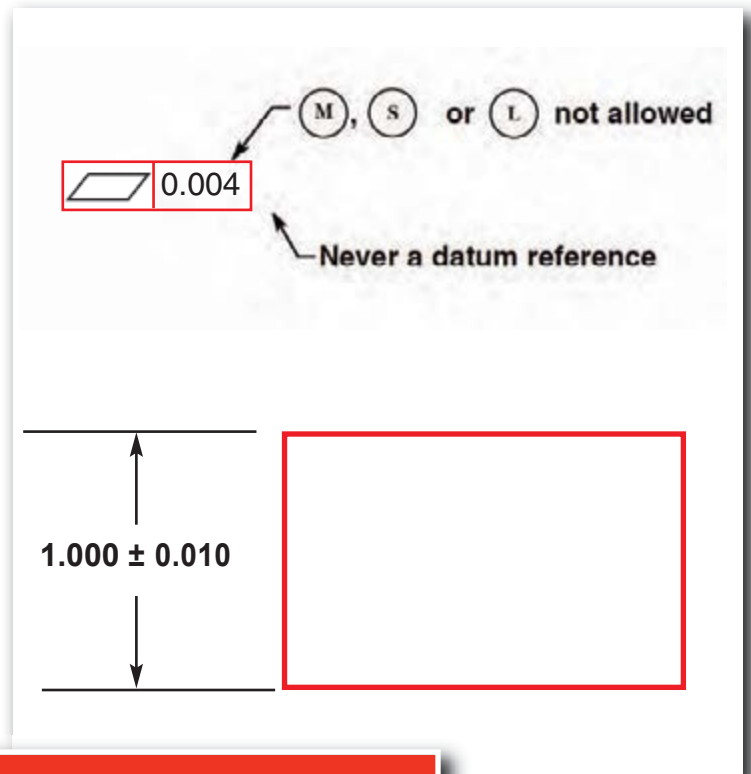
The straightness tolerance can be used whenever a straight line element, axis, or center plane can be identified on a part. The tolerance zones used for straightness can be either a pair of parallel lines or a cylinder. Each line element, axis, or center plane is compared to the tolerance zone. The tolerance for line elements is shown on the drawing in a view where the elements to be controlled are shown as straight lines.



Surface Straightness (on a flat surface, cylinder or cone)








Other tolerances that provide flatness control include:

- ▶ Any size tolerance on a feature comprised of two internal or external parallel opposed planes.



The straightness in this case would be 0.020.

- ▶ Any flat surface being controlled by:

Perpendicularity		0.008	A
Parallelism		0.008	A
Angularity		0.008	A
Profile of a Surface		0.010	A B
Total Runout		0.010	A
Flatness		0.006	
Cylindricity		0.006	

Circularity (roundness)

Circularity is the condition on a surface of revolution (cylinder, cone, sphere) where all points of the surface intersected by any plane (1) perpendicular to a common axis (cylinder, cone) or (2) passing through a common center (sphere) are equidistant from the center.

Other tolerances that provide circularity control include:

- ▶ Any size tolerance on a cylindrical feature or sphere.
- ▶ Any feature containing circular elements and being controlled by:

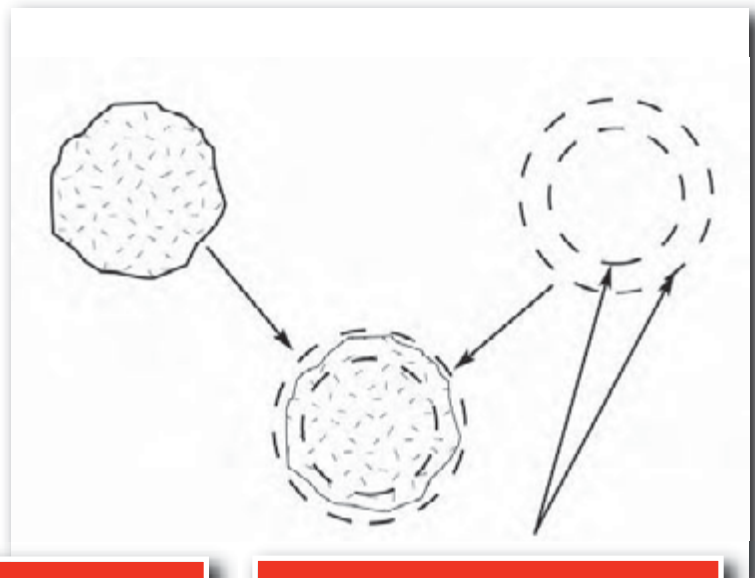
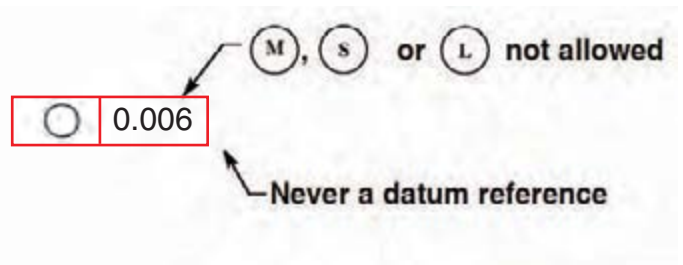
Circular Runout  0.006 A

Total Runout  0.010 A

Rule of thumb:
Runout tolerances are usually less expensive to verify and should be considered when circularity is desired.

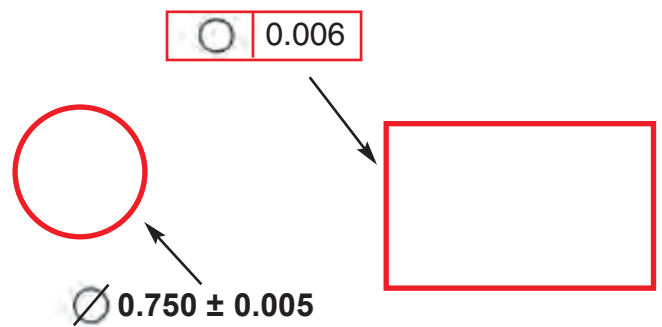
The tolerance will be a leader line, which points to the feature containing the circular element(s). Circularity is similar to straightness except that the tolerance zone is perfectly circular rather than perfectly straight.

Although the circularity tolerance floats within the limits of size, it is independent of size and should not be placed next to the size dimension.



Every circular element must be within the tolerance zone.

These two diameters can be of any diameters within the size limits of the feature, provided they remain concentric and their radial difference equals the circularity tolerance.



Cylindricity

Cylindricity is a condition of a surface of revolution in which all points of the surface are equidistant from a common axis.

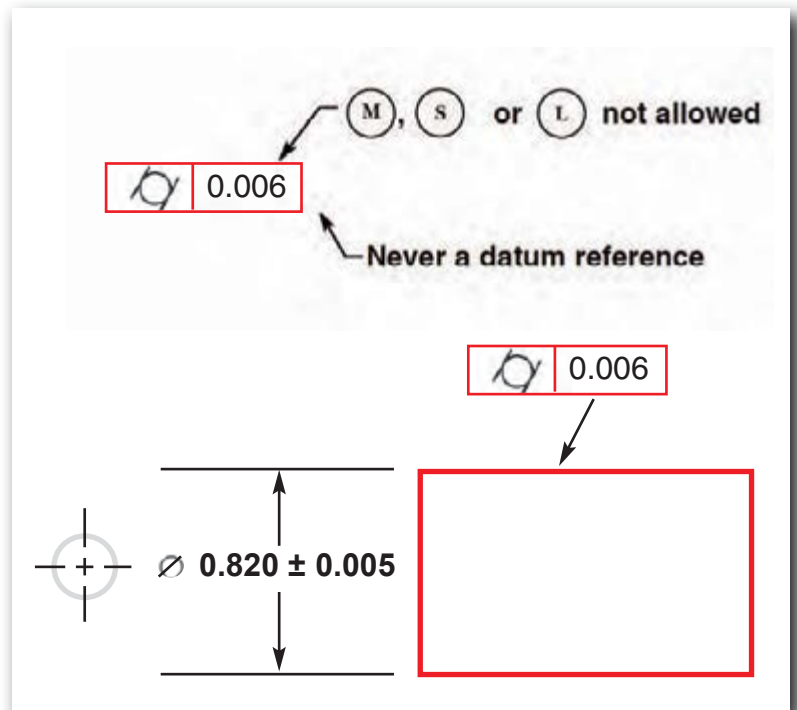
Other tolerances that provide the control of cylindricity include:

- ▶ Any size tolerance on a cylindrical feature.
- ▶ Any feature containing cylindrical features being controlled by:

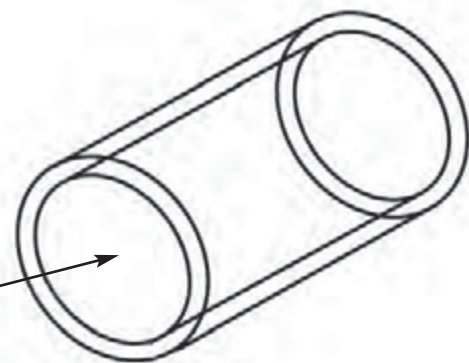
Total Runout  0.010 A

Rule of thumb:
Total runout is usually more cost effective to verify and should be considered when cylindricity is desired.

- No datum reference
- Independent of size
- May not be modified
- Does not locate or orient.



Width of Cylindricity Tolerance Zone



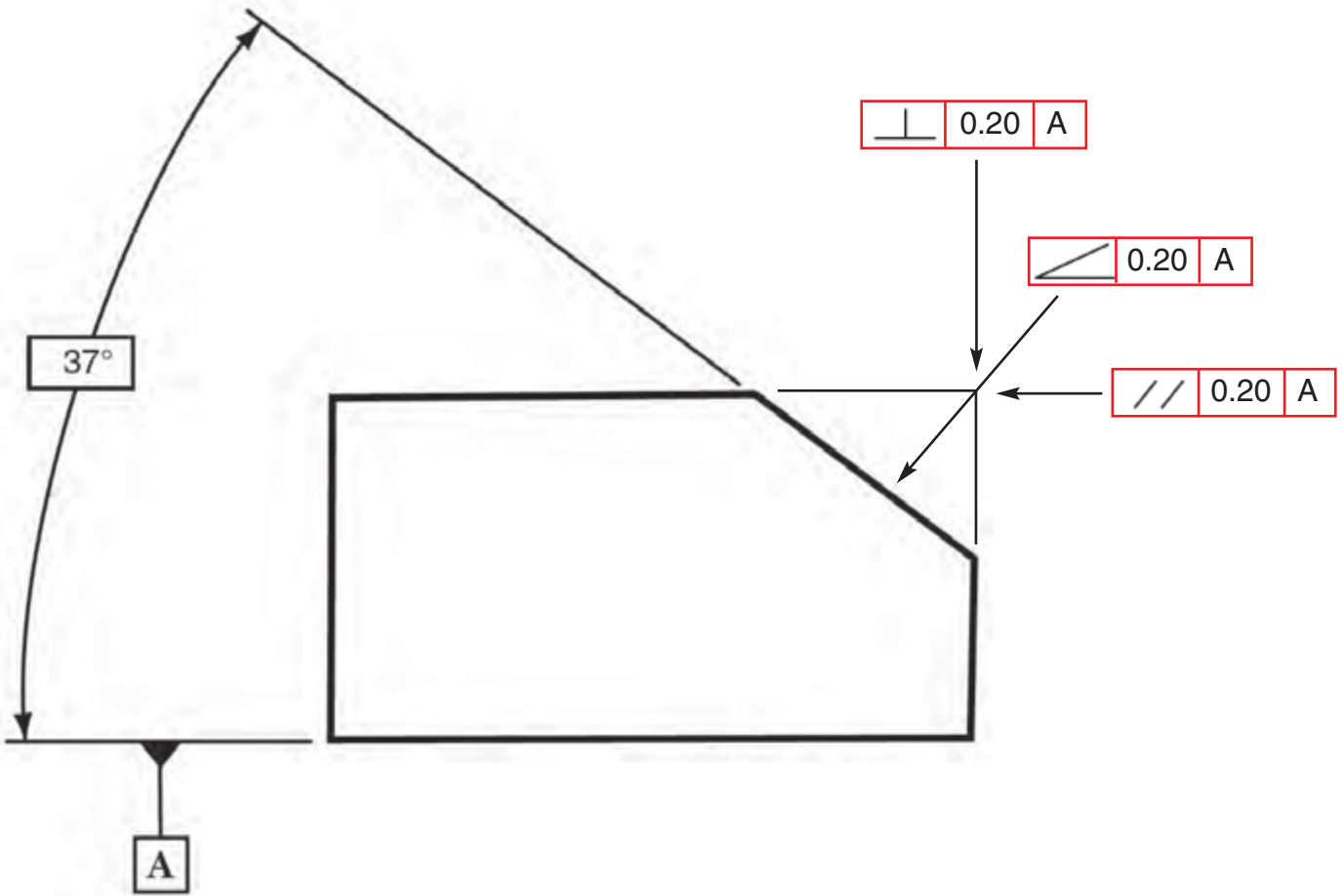
Tolerance Zone is created by two concentric cylinders

Orientation Tolerances

Orientation tolerances are applicable to related features, where one feature is selected as a datum feature and the other related to it. Orientation tolerances are perpendicularity, angularity, and parallelism.

Orientation tolerances control the orientation of a feature with respect to a datum that is established by a different part feature (the datum feature). For that reason, the tolerance will always include at least one datum reference. Orientation tolerances are considered on a

“regardless of feature size” basis unless the maximum material condition modifier is added. The important thing to remember about orientation tolerances is that they do not locate features. Because of that, with the exception of perpendicularity on a secondary datum feature or a plane surface, orientation tolerances should not be the only geometric control on a feature. They should, instead, be used as a refinement of a tolerance that locates the feature.



Perpendicularity

Perpendicularity is the condition of a surface, axis, or line which is 90 degrees from a datum plane or a datum axis.

Perpendicularity is used on a secondary datum feature, relative to the primary datum.

It may be used to a tertiary datum feature not requiring location.

Other tolerances that may provide perpendicularity include:

Position 

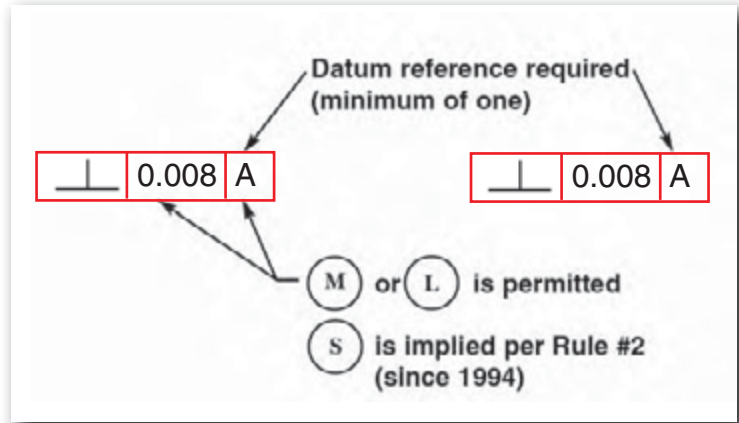
Profile of a Surface 

Total Runout 

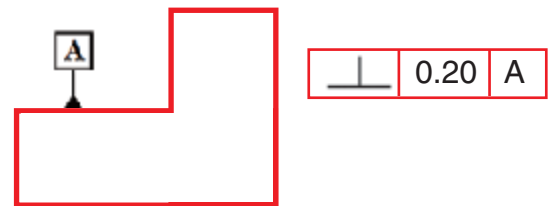
Therefore, perpendicularity should usually be used as a



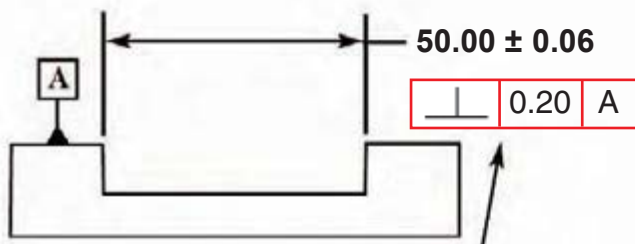




The perpendicularity tolerance is specified by being placed on an extension line. The tolerance zone is defined by a pair of parallel planes 0.2 mm apart. The tolerance zone is perfectly perpendicular to the datum plane -A-. The tolerance zone may be thought of as a flatness tolerance zone that is oriented at exactly 90 degrees to the datum.



The perpendicularity of features of size may also be controlled. The tolerance will be associated with the size dimension. When the size dimension applies to a pair of parallel planes (a slot or tab), the median or center plane is controlled by the tolerance.



Could be modified (M) or (L)
RFS is implied



Parallelism

When parallelism is applied to a flat surface, parallelism automatically provides flatness control and is usually easier to measure.

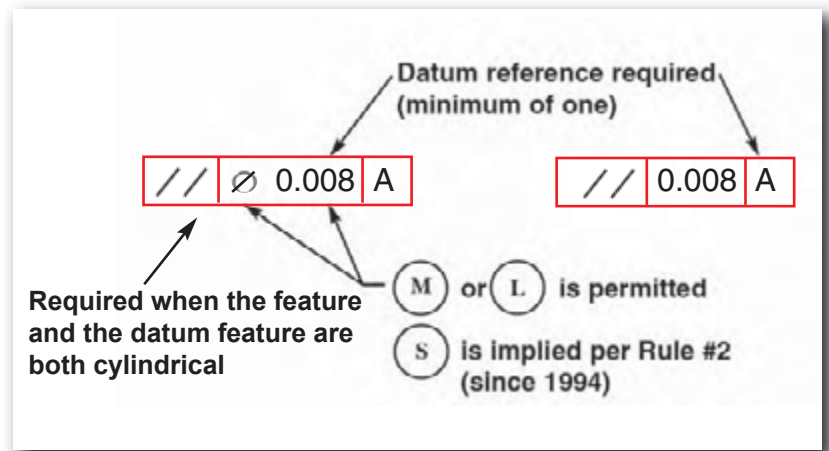
Other tolerances that may provide parallelism include:

Any size tolerance on a feature composed of two internal or external parallel planes.

Features are considered parallel when the distance between them remains constant. Two lines, two surfaces, or a surface and a line may be parallel. The parallelism of features on a part is controlled by making one a datum feature and specifying a parallelism tolerance with respect to it.

When parallelism is applied to a plane that is part of a feature of size and the other plane of that feature is the referenced datum feature, the parallelism tolerance cannot be greater than or equal to the total size tolerance or it would be meaningless since the plane's parallelism is automatically controlled by the size dimension.

Parallelism can also be specified on an MMC basis. The MMC modifier can be on the feature tolerance, the datum feature, or both. As the feature deviates from its maximum material condition, the parallelism tolerance is increased.



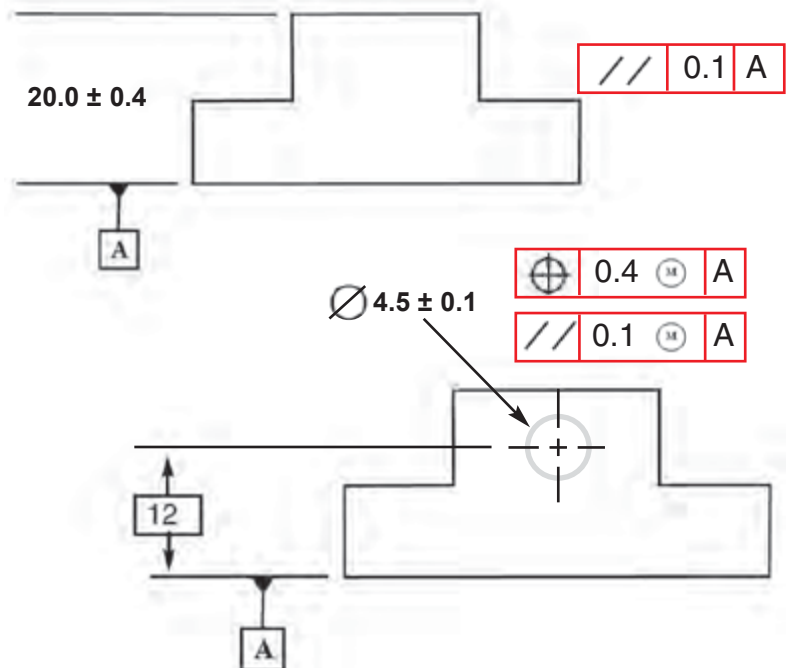
Position $\oplus \ \varnothing \ 0.020 \ (M) \ A \ B \ (M)$

Profile of a Surface $\frown \ 0.010 \ A \ B$

Total Runout $\nearrow \ 0.010 \ A \ B$

If the primary datum is a plane

Therefore, parallelism should easily be used as a refinement of Position Profile of a Surface.



Angularity

Angularity is the condition of a surface, axis, or center plane which is at a specified angle (other than 90 degrees) from a datum plane or axis.

Angularity, as a tolerance, always requires a BASIC angle.




Other tolerances that may provide angular control of features include:


- ▶ A tolerance in degrees applied to an angular dimension (not BASIC), provided there is a general note on the drawing relating toleranced dimensions to a datum reference frame.

Position  \varnothing 0.020  A B 

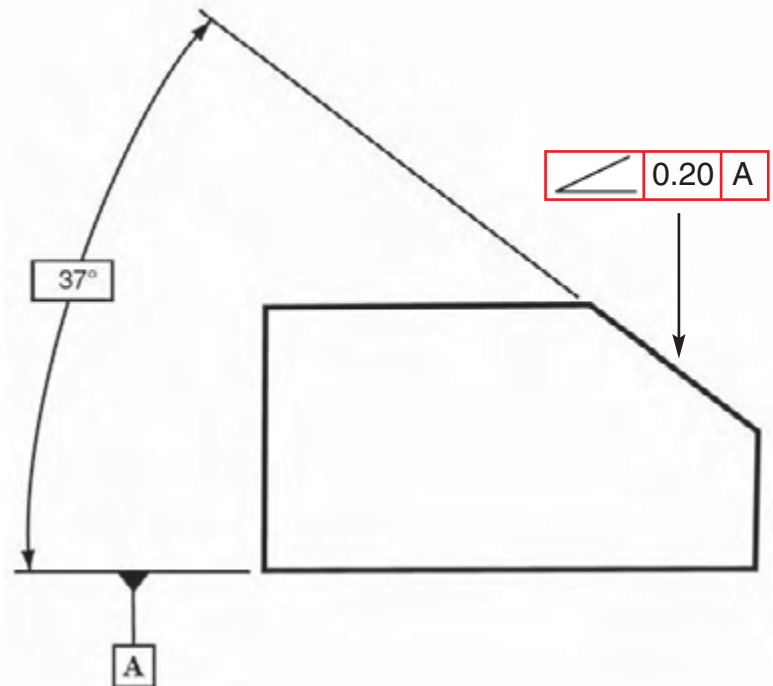
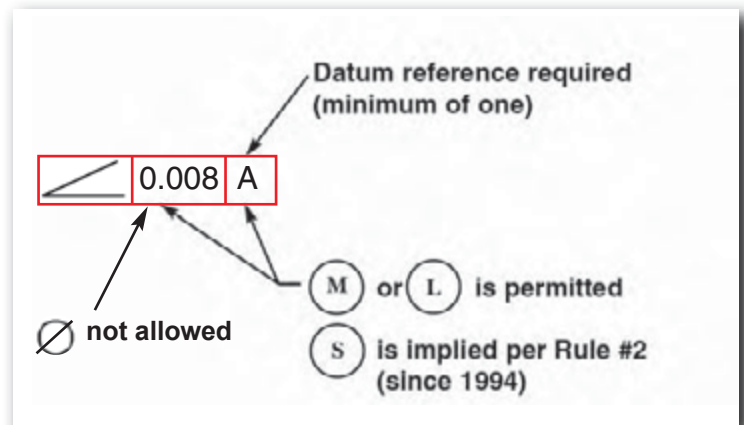
Profile of a Surface  0.010 A B

Therefore, angularity should usually be used as a refinement of one of the above:

 \varnothing 0.020  A B 

 0.008 A

Angularity is used to control the orientation of features to a datum axis or datum plane when they are at some angle other than 0 or 90 degrees. Since angularity does not locate features, it should only be considered after the feature is located. Usually a locating tolerance such as position or profile will do an adequate job of controlling the angularity and further refinement will not be necessary. A Basic Angle must always be applied to the feature from the referenced datum.



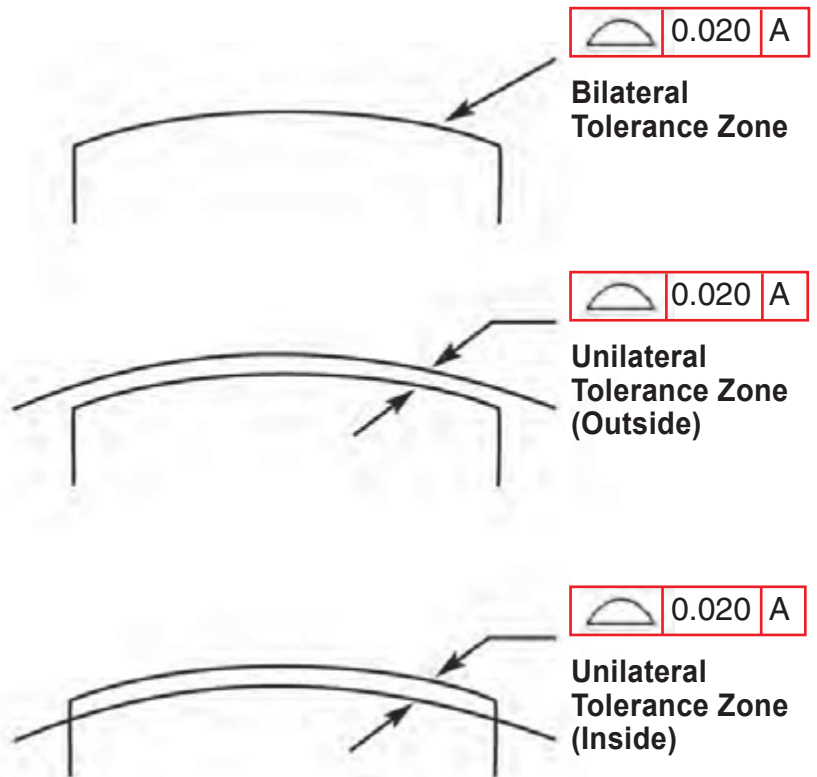
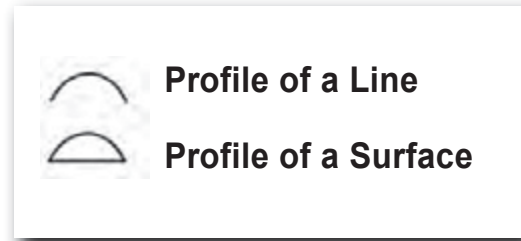
Angularity

- Must always have a datum reference
- May be modified when controlling a feature of size
- Does not locate features
- Requires a basic angle.

Profile

Profile is one of the least used--and yet most useful--geometric tolerances available. There are two types of profile tolerance: profile of a line and profile of a surface. The profile tolerances are the only geometric tolerances that may have a datum reference or may not. Without a datum reference in the feature control frame, the profile tolerance is controlling form. Profile of a line is very similar to the control seen with straightness or circularity. Profile of a surface is similar to the flatness or cylindricity tolerance. Care should be exercised in using profile without a datum. It usually makes the inspection of the part more difficult.

With a datum reference, the profile tolerance may control form, orientation, and location. Under certain conditions, profile may also control size. When a profile tolerance is used on the drawing, the tolerance is implied to be centered on the surface of the feature that has been defined by basic dimensions. If it is desired that the profile tolerance apply only in one direction, this can be illustrated on the drawing using a phantom line to indicate the side of the surface to which the tolerance should apply. This method of specifying the tolerance in only one direction is extremely useful for applications such as a punch and die in tooling or a cover on a housing where the internal and external features have an irregular shape. The basic shape of the object being controlled with profile must be dimensioned or defined using basic dimensions.



The tolerance zone is implied to be centered on the basic surface unless shown otherwise on the drawing.

Profile of a Surface

Profile of a surface is the condition permitting a uniform amount of a profile variation, either unilaterally or bilaterally, on a surface. (Profile tolerances are the only geometric tolerances where datum referencing is optional.)

Without a datum reference, profile of a surface controls the form of the surface (similar to straightness or circularity).

Form, orientation, and location may be controlled through datum referencing.

If a size dimension is made basic, profile of a surface may also control size.

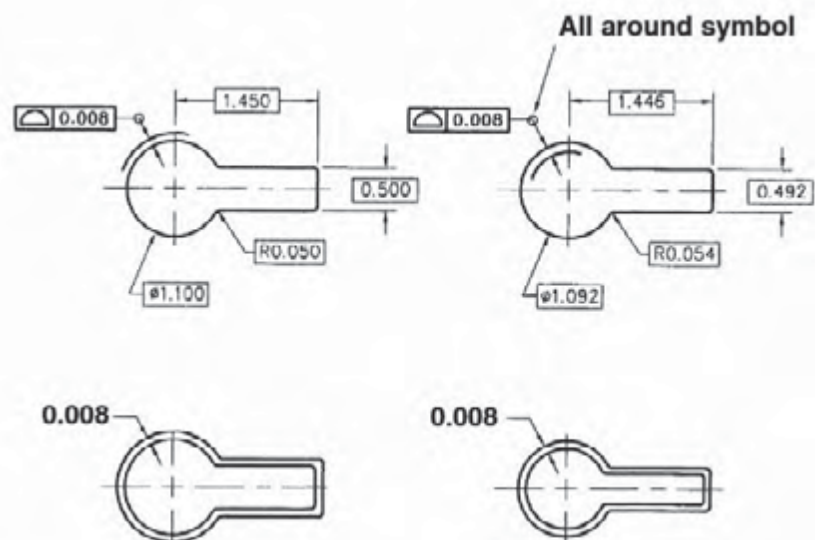
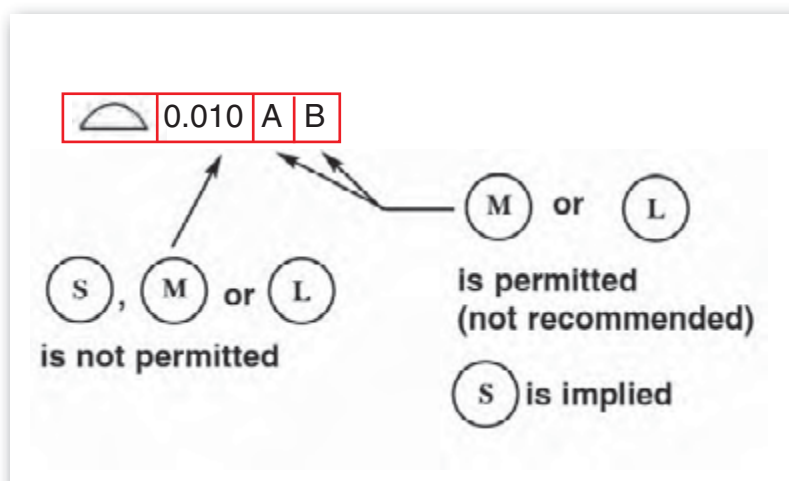
The shape of the feature must be described using basic dimensions.

The best application of profile of a surface is to locate plane and contoured surfaces.

When irregular parts must fit together, the use of unilateral profile tolerancing makes tolerance analysis easy for the designer. This approach may make manufacturing and inspection more difficult since many computer numerically controlled (CNC) machine tools and inspection machines now use the CAD file, which should usually be created at the goal or middle values.



Without a datum reference, profile of a surface controls the form of the surface (similar to straightness or circularity).



Profile of a Line

Profile of a line is the condition permitting a uniform amount of profile variation, either unilaterally or bilaterally, along a line element of a feature. (Profile tolerances are the only geometric tolerances where datum referencing is optional.)

Without a datum reference, profile of a line controls the form of lines independently within a surface (similar to straightness or circularity).

Both form and orientation are controlled through datum referencing.

Unless dealing with thin parts, profile of a surface is a better choice for location.

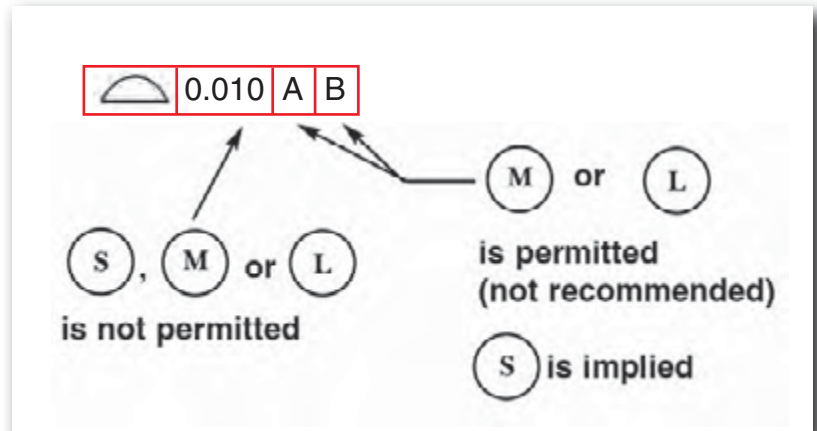
The shape of the feature must be described using basic dimensions.

Tangent Plane

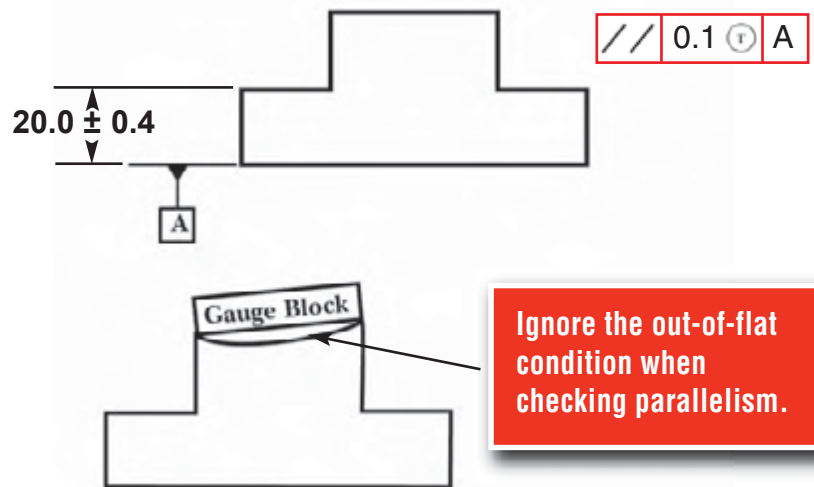
Tangent plane is a new concept/symbol, introduced in the 1994 Standard. Normally when a surface is inspected for Perpendicularity, Parallelism, Angularity, Profile of a Surface, or Total Runout, the flatness must also fall within the aforementioned geometric tolerance or the part would fail. Tangent Plane exempts the flatness requirement. The gauge block is intended to simulate the mating part.



Without a datum reference, profile of a line controls the form of lines independently within a surface (similar to straightness or circularity).



Since profile of a surface also controls the lines within the surface, profile of a line is often used to refine profile of a surface.



Concentricity

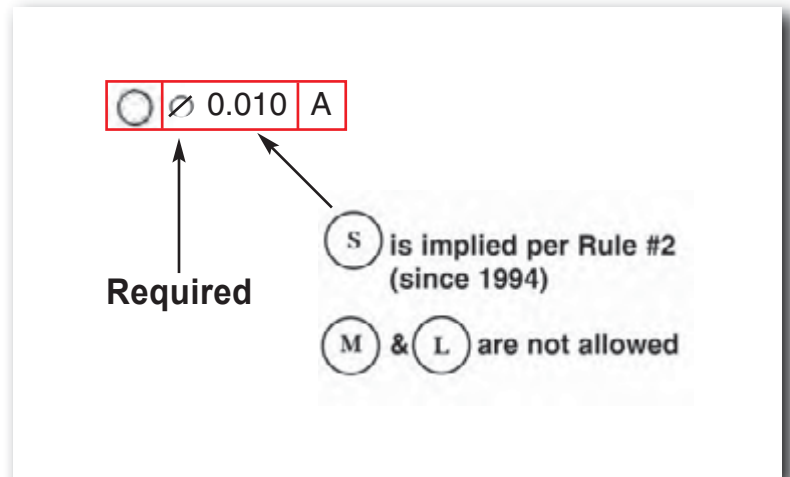
Concentricity is a condition in which two or more features (cylinders, cones, spheres, hexagons, etc.) in any combination have a common axis.

The datum(s) referenced must establish an axis.

Consider circular runout instead of concentricity:

- ▶ Runout is easier to verify
- ▶ Runout also controls the form of the feature.

Concentricity is a static attempt to control dynamic balance.



APPENDIX to Section 8

Basic Terminology for Geometric Tolerancing

actual size — An actual size is the measured size of the feature.

angularity — Angularity is the condition of a surface, axis, or center plane, which is at a specified angle (other than 90 degrees) from a datum plane or axis.

basic dimension — A dimension specified on a drawing as Basic (or abbreviated BSC) is a theoretical value used to describe the exact size, shape, or location of a feature. It is used as the basis from which permissible variations are established by tolerances on other dimensions or notes.

basic size — The basic size is that size from which limits of size are derived by the application of allowances and tolerances.

bilateral tolerancing — A bilateral tolerance is a tolerance in which variation is permitted in both directions from the specified dimension.

center plane — Center plane is the middle or median plane of a feature.

circular runout — Circular runout is the composite control of circular elements of a surface independently at any circular measuring position as the part is rotated through 360 degrees.

circularity — Circularity is the condition on a surface of revolution (cylinder, cone, sphere) where all points of the surface intersected by any plane (1) perpendicular to a common axis (cylinder, cone) or (2) passing through a common center (sphere) are equidistant from the center.

clearance fit — A clearance fit is one having limits of size so prescribed that a clearance always results when mating parts are assembled.

coaxiality — Coaxiality of features exists when two or more features have coincident axes, i.e., a feature axis and a datum feature axis.

concentricity — Concentricity is a condition in which two or more features (cylinders, cones, spheres, hexagons, etc.) in any combination have a common axis.

contour tolerancing — See profile of a line or profile of a surface.

cylindricity — Cylindricity is a condition of a surface of revolution in which all points of the surface are equidistant from a common axis.

datum — A datum is a theoretically exact point, axis, or plane derived from the true geometric counterpart of a specified datum feature. A datum is the origin from which the location or geometric characteristics of features of a part are established.

datum axis — The datum axis is the theoretically exact center line of the datum cylinder as established by the extremities or contacting points of the actual datum feature cylindrical surface, or the axis formed at the intersection of two datum planes.

datum feature — A datum feature is an actual feature of a part which is used to establish a datum.

datum feature symbol — The datum feature symbol contains the datum reference letter in a rectangular box.

datum line — A datum line is that which has length but no breadth or depth such as the intersection line of two planes, center line or axis of holes or cylinders, reference line for functional, tooling, or gauging purposes. A datum line is derived from the true geometric counterpart of a specified datum feature when applied in geometric tolerancing.

datum plane — A datum plane is a theoretically exact plane established by the extremities or contacting points of the datum feature (surface) with a simulated datum plane (surface plate or other checking device). A datum plane is derived from the true geometric counterpart of a specified datum feature when applied in geometric tolerancing.

datum point — A datum point is that which has position but no extent such as the apex of a pyramid or cone, center point of a sphere, or reference point on a surface for functional, tooling, or gauging purposes. A datum point is derived from a specified datum target on a part feature when applied in geometric tolerancing.

datum reference — A datum reference is a datum feature as specified on a drawing.

datum reference frame — A datum reference frame is a system of three mutually perpendicular datum planes or axes established from datum features as a basis for dimensions for design, manufacture, and verification. It provides complete orientation for the feature involved.

datum surface — A datum surface or feature (hole, slot, diameter, etc.) refers to the actual part surface or feature coincidental with, relative to, and/or used to establish a datum.

datum target — A datum target is a specified datum point, line, or area (identified on the drawing with a datum target symbol) used to establish datum points, lines, planes, or areas for special function, or manufacturing and inspection repeatability.

dimension — A dimension is a numerical value expressed in appropriate units of measure and indicated on a drawing.

feature — Feature is the general term applied to a physical portion of a part, such as a surface, hole, pin, slot, tab, etc.

feature of size — A feature of size may be one cylindrical or spherical surface, or a set of two plane parallel surfaces, each of which is associated with a dimension; it may be a feature such as hole, shaft, pin, slot, etc. which has an axis, centerline, or centerplane when related to geometric tolerances.

feature control frame — The feature control frame is a rectangular box containing the geometric characteristic symbol and the form, orientation, profile, runout, or location tolerance. If necessary, datum references and modifiers applicable to the feature of the datums are also contained in the frame.

fit — Fit is the general term used to signify the range of tightness or looseness which may result from the application of a specific combination of allowances and tolerance on the design of mating part features. Fits are of four general types: clearance, interference, transition, and line.

flatness — Flatness is the condition of a surface having all elements in one plane.

form tolerance — A form tolerance states how far an actual surface or feature is permitted to vary from the desired form implied by the drawing. Expressions of these tolerances refer to flatness, straightness, circularity, and cylindricity.

full indicator movement (FIM) (see also FIR and TIR) — Full indicator movement is the total movement observed with the dial indicator (or comparable measuring device) in contact with the part feature surface during one full revolution of the part about its datum axis. Full indicator movement (FIM) is the term used internationally. United States terms FIR, and TIR, used in the past, have the same meaning as FIM. Full indicator movement also refers to the total indicator movement observed while in traverse over a fixed noncircular shape.

full indicator reading (FIR) — Full indicator reading is the total indicator movement reading observed with the dial indicator in contact with the part feature surface during one full revolution of the part about its datum axis. Use of the international term, FIM (which, see), is recommended. Full indicator reading also refers to the full indicator reading observed while in traverse over a fixed noncircular shape.

geometric characteristics — Geometric characteristics refer to the basic elements or building blocks which form the language of geometric dimensioning and tolerancing. Generally, the term refers to all the symbols used in form, orientation, profile, runout, and location tolerancing.

implied datum — An implied datum is an unspecified datum whose influence on the application is implied by the dimensional arrangement on the drawing—e.g., the primary dimensions are tied to an edge surface; this edge is implied as a datum surface and plane.

interference fit — An interference fit is one having limits of size so prescribed that an interference always results when mating parts are assembled. 8-53 Aluminum Extrusion Manual

interrelated datum reference frame — An interrelated datum reference frame is one which has one or more common datums with another datum reference frame.

least material condition (LMC) — This term implies that condition of a part feature wherein it contains the least (minimum) amount of material, e.g., maximum hole diameter and minimum shaft diameter. It is opposite to maximum material condition (MMC).

limits of size — The limits of size are the specified maximum and minimum sizes of a feature.

limit dimensions (tolerancing) — In limit dimensioning only the maximum and minimum dimensions are specified. When used with dimension lines, the maximum value is placed above the minimum value, e.g., .300 - .295. When used with leader or note on a single line, the minimum limit is placed first, e.g., .295 - .300.

line fit — The limits of size are the specified maximum and minimum sizes of a feature.

location tolerance — A location tolerance states how far an actual feature may vary from the perfect location implied by the drawing as related to datums or other features. Expressions of these tolerances refer to the category of geometric characteristics containing position and concentricity (formerly also symmetry).

maximum material condition (MMC) — Maximum material condition is that condition where a feature of size contains the maximum amount of material within the stated limits of size, e.g., minimum hole diameter and maximum shaft diameter. It is opposite to least material condition.

maximum dimension — A maximum dimension represents the acceptable upper limit. The lower limit may be considered any value less than the maximum specified.

minimum material condition — See least material condition.

modifier (material condition symbol) — A modifier is the term sometimes used to describe the application of the “maximum material condition,” “regardless of feature size,” or “least material condition” principles. The modifiers are maximum material condition (MMC), regardless of feature size (RFS), and least material condition (LMC).

multiple datum reference frames — Multiple datum reference frames are more than one datum reference frame on one part.

nominal size — The nominal size is the stated designation which is used for the purpose of general identification, e.g., 1.400, .060, etc.

normality — See perpendicularity.

orientation tolerance — Orientation tolerances are applicable to related features, where one feature is selected as a datum feature and the other related to it. Orientation tolerances are perpendicularity, angularity, and parallelism.

parallelepiped — This refers to the shape of the tolerance zone. The term is used where total width is required and to describe geometrically a square or rectangular prism, or a solid with six faces, each of which is a parallelogram.

perpendicularity — Perpendicularity is the condition of a surface, axis, or line which is 90 degrees from a datum plane or a datum axis.

position tolerance — A position tolerance (formerly called true position tolerance) defines a zone within which the axis or center plane of a feature is permitted to vary from true (theoretically exact) position.

profile tolerance — Profile tolerance controls the outline or shape of a part as a total surface or at planes through a part.

profile of line — Profile of line is the condition permitting a uniform amount of profile variation, either unilaterally or bilaterally, along a line element of a feature.

profile of surface — Profile of a surface is the condition permitting a uniform amount of profile variation, either unilaterally or bilaterally, on a surface.

projected tolerance zone — A projected tolerance zone is a tolerance zone applied to a hole in which a pin, stud, screw, or bolt, etc. is to be inserted. It controls the perpendicularity of the hole to the extent of the projection from the hole and as it relates to the mating part clearance. The projected tolerance zone extends above the surface of the part to the functional length of the pin, screw, etc., relative to its assembly with the mating part.

regardless of feature size (RFS) — This is the condition where the tolerance of form, runout, or location must be met irrespective of where the feature lies within its size tolerance.

roundness — See circularity.

runout — Runout is the composite deviation from the desired form of a part surface of revolution during full rotation (360 degrees) of the part on a datum axis. Runout tolerance may be circular or total.

runout tolerance — Runout tolerance states how far an actual surface or feature is permitted to deviate from the desired form implied by the drawing during full rotation of the part on a datum axis. There are two types of runout: circular runout and total runout.

size tolerance — A size tolerance states how far individual features may vary from the desired size. Size tolerances are specified with either unilateral, bilateral, or limit tolerancing methods.

specified datum — A specified datum is a surface or feature identified with a datum feature symbol.

squareness — See perpendicularity.

straightness — Straightness is a condition where an element of a surface or an axis is a straight line.

symmetry — Symmetry is a condition in which a feature (or features) is (are) symmetrically disposed about the center plane of a datum feature.

tolerance — A tolerance is the total amount by which a specific dimension may vary; thus, the tolerance is the difference between limits.

transition fit — A transition fit is one having limits of size so prescribed that either a clearance or an interference may result when mating parts are assembled.

true position — True position is a term used to describe the perfect (exact) location of a point, line, or plane of a feature in relationship with a datum reference or other feature.

total indicator reading (TIR) (see also FIR and FIM) — Total indicator reading is the full indicator reading observed with the dial indicator in contact with the part feature surface during one full revolution of the part about its datum axis. Total indicator reading also refers to the total indicator reading observed while in traverse over a fixed noncircular shape. Use of the international term, FIM (which, see), is recommended.

total runout — Total runout is the simultaneous composite control of all elements of a surface at all circular and profile measuring positions as the part is rotated through 360 degrees.

unilateral tolerance — A unilateral tolerance is a tolerance in which variation is permitted only in one direction from the specified dimension, e.g., $1.400 + .000 - .005$.

virtual condition — Virtual condition of a feature is the collective effect of size, form, and location error that must be considered in determining the fit or clearance between mating parts or features. It is a derived size generated from the profile variation permitted by the specified tolerances. It represents the most extreme condition of assembly at MMC.

Section

9

Terms and Definitions



ALUMINUM
EXTRUDERS
COUNCIL

Aluminum Extrusion
Manual
4.2 Edition

Section 9



Terms and Definitions

Every technical specialty has its own specialized language. Terminology employed in the context of aluminum extrusion carries specific meaning. Clear communication requires an understanding of the words used to describe products and processes associated with the aluminum extrusion industry.

With the further understanding that the sphere of commerce and industry is truly international in scope, a Global Advisory Group formed to develop a universal set of terms and definitions for aluminum interests. The Aluminum Extruders Council has chosen to adopt these Terms and Definitions developed to facilitate communication and foster understanding among aluminum interests worldwide.

As noted in the Introduction found within the Terms and Definitions document, “Especially it is intended to be a source for terms and definitions to be used in standards. By using identical terms and definitions, as far as possible, in standards of different countries or continents, a better alignment of such standards is possible.”

It is worth noting that the terms are grouped according to categories that include Products, Processing, Sampling/Testing and Product Characteristics, and Visual Quality Characteristics. An alphabetical index, here called a Glossary, appears at the end of the document for convenient reference.

The Terms and Definitions can be found [HERE](#).

Photo courtesy of Werner Co.



ALUMINUM
EXTRUDERS
COUNCIL

Additional Resources

The Aluminum Extruders Council (AEC) provides a wealth of information and resources about aluminum and extrusions on the website at www.AEC.org. In addition, there are other resources that may be of value for designers and engineers.

Webinars

AEC regularly conducts educational webinars on a variety of topics. From the extrusion process, (including aluminum standards, alloy finishing, fabrication and sustainability) to applications and design hints, AEC has a wealth of information to share in the form of webinar presentations. Visit www.AEC.org/Webinars for upcoming webinars, as well as archived presentations to view on demand.



the design phase, as they will often suggest ways to improve or enhance your component design to save money and time.

Released yearly, the Buyers' Guide contains the latest contact and capabilities information AEC member extruders. You'll find essential information on press sizes, plant locations, types of profiles produced, finishing and mechanical capabilities, and much more. The Buyers' Guide also serves as a directory that provides contact information for AEC Supplier and Producer members.

Aluminum Joining Manual



To assist automotive designers and engineers in effectively applying aluminum components in their lightweighting programs, as well as engineers in other markets, three leading aluminum organizations—European Aluminium, The

Aluminum Association and the Aluminum Extruders Council—have released the **Aluminum Automotive Manual - Joining**. The manual provides technical details on multiple welding technologies, mechanical joining and adhesive joining. Visit www.AEC.org/JoiningManual to view and download the manual.

AEC Buyers' Guide

When you are ready to move forward with your design, be sure to consult the AEC Buyers' Guide to find the right aluminum extruder for your project. It is important to get an extruder involved early in



Visit www.AECguide.org to view the latest version of the AEC Buyers' Guide.



ALUMINUM
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Find a Member/Find an Extruder

The AEC website also includes a handy "Find a Member" search tool! This search feature provides a valuable resource for your aluminum extrusion project. Search for an extruder by geographical location, by manufacturing capabilities, including press circle size, forms produced, finishing and fabrication and more.

Are you an extruder looking for equipment or services? Use the Find a Member search function to locate a supplier or aluminum billet producer.

Visit www.AEC.org and choose "Find a Member" from the navigation bar.