2. General Considerations

2.1 Aluminum's Attributes

Aluminum has many attributes that make it a cost-effective structural material. Most applications make use of a favorable life cycle cost, which includes costs for material, fabrication, erection or installation, operation, maintenance, and disposal.

For example, aluminum is the principal material in aerospace structures, primarily because of its high strength-to-weight ratio. The density of aluminum is about 1/3 that of steel, and aluminum alloys have strengths similar to those of construction steels. Aluminum aerospace structures are cost effective because smaller engines and less fuel are needed during service compared to those required for heavier structures.

Aluminum structures generally weigh 1/3 to 1/2 those of steel (see Section 2.3). Light weight and corrosion resistance are the major factors for the selection of aluminum for trucks, automobiles, and rail cars.

Aluminum's excellent corrosion resistance (see Section 6) helps reduce maintenance costs. Aluminum's corrosion resistance and its appearance, bare or finished, are major factors in its use in buildings. Many aluminum structures, such as light poles, overhead sign trusses, latticed roofs, and bridges do not require painting because of aluminum's corrosion resistance.

2.2 Alloy Selection

Sheet, plate, extrusions, forgings, and castings are made of aluminum. Alloys and tempers with both good strength and corrosion resistance are available. Aerospace alloys are generally not used for other types of structures because their combination of specialized properties results in relatively higher costs than that of other alloys. Examples of some of the common alloys and tempers used for each product are given in the following table.

Product	Application	Alloys
Sheet and Plate	Building	3105-H25, 5052-H34, 3004-H16
	Heavy Duty Structures	5083-H116, 5086-H116, 6061-T6
Extrusions	Building	6063-T5, 6063-T6
	General Purpose	6061-T6
Forgings	Wheels	6061-T6
Castings	General Purpose	356.0-T6, A356.0-T6
	High Elongation	A444.0-T4

2.3 Comparing Aluminum and Steel

Aluminum structural design is very similar to that for steel and other metals. Because many engineers are more familiar with steel than aluminum, aluminum and steel are compared in Table 2-1, taken from Sharp (1993).

Because of the difference in properties (modulus, for example) an aluminum design should be different than that for steel in order to use material efficiently. Figure 2-1 shows the relative weights of aluminum and steel box beams with the same bending strength and deflection. The yield strength of the two materials is the same. The aluminum part weighs about 50% of the steel part when its size is about 1.4 times that of steel. Other configurations provide less weight savings. Where deflection and fatigue considerations control the design, such as in bridge girders, automotive frames and other transportation vehicles, aluminum

TABLE 2-1

COMPARING ALUMINUM AND STEEL

Property	Steel	Aluminum	Importance for Design
Modulus of elasticity	29,000 ksi 200,000 MPa	10,100 ksi 70,000 MPa	Deflection of members Vibration Buckling
Weight per volume	0.284 lb/in^3 7870 kg/m^3	0.10 lb/in^3 2770 kg/m^3	Weight of product, vibration
Thermal expansion	7 × 10^{-6} /^{o}F 12 x 10^{-6}/^{o}C	13 x 10^{-6}/^{o}F 23 x 10^{-6}/^{o}C	Thermal expansion Thermal stress
Stress-strain curves	Varies	Varies	Depends on alloys. Steel often has higher strength and elongation at room temperature. Aluminum has better performance at low temperatures
Fatigue strength	Varies	Varies	For joints, aluminum has about 1/3 to ½ the fatigue strength as steel for same detail
Corrosion resistance	Needs protection	Often used unpainted	Aluminum usually is maintenance free Aluminum is non-staining
Strain rate effects on mechanical properties	High strain rates increase properties—varies with type of steel	Much less change in properties compared to steel	Need to use dynamic properties for high-strain rate loadings

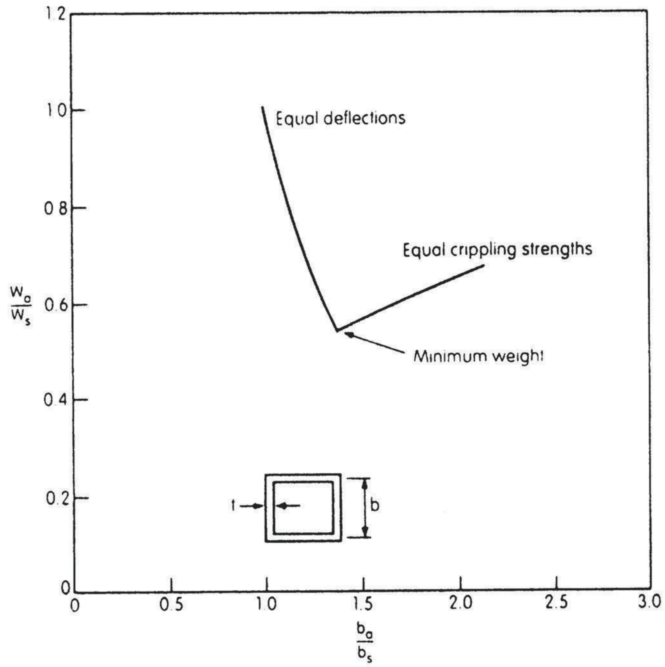

Figure 2-1
MINIMUM WEIGHT OF SQUARE TUBULAR SECTIONS

structures weigh about half that of steel structures. For structures controlled by static strength, such as automobile hoods and deck lids and some building components, aluminum structures weighing about 1/3 that of steel have been achieved. Such structures are designed for aluminum and do not have the same dimensions as the steel structure.

Figure 2-2 shows fatigue strengths for aluminum and steel for groove welds (a Category C detail). For long lives the fatigue strength of aluminum groove welds is about 40% that for steel. The difference is smaller at shorter lives.

In efficient designs, aluminum components are different from steel components for the same loading. Aluminum beams should be deeper than steel beams. The spacing of stiffeners on aluminum elements should be smaller than for steel. These geometrical differences will help meet deflection requirements for aluminum components and reduce stresses, helping with fatigue requirements.

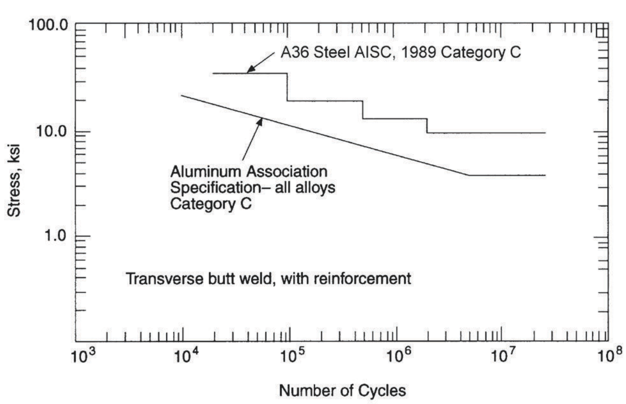

Figure 2-2
FATIGUE DESIGN CURVES FOR ALUMINUM AND STEEL

2.4 References

The following references are additional sources of information on aluminum structural design. References marked * are available from the Aluminum Association (www.aluminum.org/bookstore).

2.4.1 General

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2. Sharp, Maurice L., *Behavior and Design of Aluminum Structures*, McGraw-Hill, Inc., New York, NY, 1993.

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2.4.2 Fabrication

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2.AWS D1.2/D1.2M:2014 *Structural Welding Code-Aluminum*, American Welding Society, Miami, FL, 2014.

*3. *Welding Aluminum: Theory and Practice*, 4th ed., Aluminum Association, Washington, DC, 2002.

4. Minford, J. Dean, *Handbook of Aluminum Bonding Technology and Data*, Marcel Dekker, Inc., New York, NY, 1993.

5. AWS D17.3/D17.3M:2010, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*, American Welding Society, Miami, FL, 2010.

2.4.3 Alloys and Products

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*2. *Aluminum Standards and Data Metric SI 2013*, Aluminum Association, Arlington, VA, 2009.

*3. *Standards for Aluminum Sand and Permanent Mold Castings*, Aluminum Association, Arlington, VA, 2008.

4. AWS A5.10/A5.10M: 2012 *Welding Consumables – Wire Electrodes, Wires and Rods for Welding of Aluminum and Aluminum-Alloys*, American Welding Society, Miami, FL, 2012.

2.4.4 Bridges and Highway Structures

1. *AASHTO LRFD Bridge Design Specifications*, 6th ed., American Association of State Highway and Transportation Officials, Washington, DC, 2012. Section 7 addresses aluminum structures.

2. *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*, 6th edition, American Association of State Highway and Transportation Officials, Washington, DC, 2013.

3. CAN/CSA S6-06 (R2012) *Canadian Highway Bridge Design Code*, Canadian Standards Association, 2012.

2.4.5 Rail Cars

1. *Manual of Standards and Recommended Practices Section C, Part II, Design, Fabrication, and Construction of Freight Cars*, Association of American Railroads, Transportation Technology Center, Pueblo, CO.

2. AWS D15.1:2012 *Railroad Welding Specification for Cars and Locomotives*, American Welding Society, Miami, FL, 2012.

2.4.6 Ships

1. A*NSI/AWS D3.7-2004 Guide for Aluminum Hull Welding*, American Welding Society, Inc., Miami, FL, 2004.

2. *Rules for Building and Classing Aluminum Vessels*, American Bureau of Shipping, Houston, TX, 1996.

2.4.7 Storage Tanks, Pressure Vessels, and Pipe

1. *ASME B31.3-2012, Process Piping*, American Society of Mechanical Engineers, New York, NY, 2012.

2. *ASME Boiler and Pressure Vessel Code*, Section II, Materials, American Society of Mechanical Engineers, New York, NY, 2013.

3. *API Standard 620, Design and Construction of Large, Welded, Low-Pressure Storage Tanks*, 11th ed., American Petroleum Institute, Washington, DC, February 2008.

4. A*PI Standard 650, Welded Tanks for Oil Storage*, 11th ed., American Petroleum Institute, Washington, DC, June 2007. Appendix AL addresses aluminum storage tanks.

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2.4.8 Material Properties

*1. Kaufman, J. Gilbert, *Fracture Resistance of Aluminum Alloys: Notch Toughness, Tear Resistance, and Fracture Toughness*, ASM International, Materials Park, OH, 2001.

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2.4.9 Foreign Codes

1. EN 1999-1-1:2007 *Eurocode 9 Design of Aluminium Structures Part 1-1: General structural rules*, European Committee for Standardization (CEN), Brussels, 2007.

2. CAN-CSAS157-05 (R2010) *Strength Design in Aluminum*, Canadian Standards Association, Mississauga, Ontario, Canada, 2005.

3. Structural Issues not Addressed in the Specification for Aluminum Structures

3.1 Ductility

The accepted measure of ductility of aluminum alloys is fracture toughness, and many high strength aluminum alloys used in aerospace applications have been evaluated as summarized by the Aluminum Association (1987). The ductility of alloys included in the *Specification* (non-aerospace alloys) is generally not a design issue for wrought products. The best proof of adequate ductility of alloys is the satisfactory service in buildings, bridges, automobiles, trucks, and rail cars. Menzemer (1992) showed that in laboratory fracture tests the normalized resistance curves (same fatigue strength) of parts made from 5456-H116 were higher than those of A36 steel at temperatures from -200 to +75 °F (-130 to 25°C). Sharp (1993) provides additional information on the toughness of aluminum alloys.

Welded strengths can be increased by welding in the solution heat-treated temper and then aging or by welding and then solution heat treating and aging. Light pole manufacturers typically use post-weld heat treatment. The ductility of transversely welded structures is usually reduced by post-weld heat treatment because the width of the zone of lower strength material is decreased (plastic deformation may be confined to a narrow zone). Post-weld heat treatments require careful evaluation of strength, ductility, and corrosion resistance implications.

3.2 Shear Diaphragms

Shear diaphragms are efficient in carrying shear loads. Corrugated panels can be used for a building's side or roof. The strength and stiffness of a corrugated panel subjected to shear depend on the alloy, configuration of the corrugation, size of the panel, and the type and configuration of the fastening to the framing members. Sharp presents the following design considerations:

1. Overall shear buckling of the panel may control strength. An equivalent slenderness ratio is defined for this mode of failure that is used with the buckling equations for shear.
2. Local buckling of the shear elements of the corrugations is given by the equations for unstiffened webs.
3. Failure of the corrugations and of the fastening at the supports must be calculated. Local failure of the corrugations at their attachment to supporting members can occur particularly if only part of the shape is connected.
4. Shear deflection of the panel is much larger than a flat panel of the same size. The major factors are size of panel, shape and thickness or corrugation, and the type and arrangement of the fastenings. Sharp (1993) provides equations of behavior for several standard corrugated shapes.

The Metal Construction Association's Primer on Diaphragm Design (2004) addresses aluminum diaphragms. Sooi and Peköz (1993) provide additional information on building diaphragms and their interaction with building frames.

3.3 Pipe Bursting Pressure

Sharp (1993) gives the bursting pressure of aluminum pipe as:

$$P = \frac{2tF_{tu}K}{D - 0.8t}$$

Where:
P = bursting pressure
t = pipe wall thickness
F_{tu} = tensile ultimate strength
$K = 0.73 + 0.33F_{ty}/F_{tu}$
D = pipe outside diameter
F_{ty} = tensile yield strength

Aluminum pipe applications may be governed by standards for that use. For example, aluminum pipe used in chemical plants and petroleum refineries is often designed in accordance with ASME B31.3, which provides a slightly different strength equation and safety factors appropriate to such applications.

3.4 Biaxial and Triaxial Stresses

The Aluminum *Specification* predates finite element analysis (FEA) and doesn't directly address all issues that arise from such analyses. For example, the *Specification* provides design stresses for prismatic members primarily under uniaxial stress, such as columns. FEA, on the other hand, can provide triaxial stresses by reporting, in addition to longitudinal stresses, through-thickness and transverse stresses. Many FEA programs calculate a von Mises stress (explained below) from the triaxial stresses at a given element.

Yielding occurs in ductile materials like aluminum when

$$(f_1 - f_2)^2 + (f_2 - f_3)^2 + (f_3 - f_1)^2 \geq 2\, F_{ty}^2$$

where f_1, f_2, f_3 = principal stresses (the normal stress on each of three orthogonal surfaces such that the shear stresses on the surfaces are zero)
F_{ty} = tensile yield stress

This equation is called the von Mises criterion or distortion energy criterion. It predicts that yielding will occur when the distortion energy equals the distortion energy in an axially loaded member at yield. The above equation is for the general triaxial stress state. If stresses are biaxial, $f_3 = 0$, and the equation above predicts yielding when

$$(f_1 - f_2)^2 + f_2^{\ 2} + f_1^2 \geq 2\ F_{ty}^{\ 2}$$

For convenience, the von Mises stress is defined from the von Mises criterion as

$$\sqrt{\frac{(f_1 - f_2)^2 + (f_2 - f_3)^2 + (f_3 - f_1)^2}{2}}$$

so that it may be compared directly to the yield stress to determine if yielding will occur. In the biaxial stress state, the von Mises stress becomes

$$\sqrt{f_1^{\ 2} - f_1 f_2 + f_2^{\ 2}}$$

The von Mises criterion is used in the Aluminum *Specification* to determine the shear yield strength of aluminum alloys, since there is no established test method to measure shear yield strength. In the case of pure shear, the shear stresses in a biaxial stress element are τ and $-\tau$. Mohr's circle can be used to show that the principal stresses f_1 and f_2 are, then, also τ and $-\tau$, so the von Mises stress is

$$\sqrt{\tau^2 - \tau(-\tau) + \tau^2} = \tau\sqrt{3}$$

When the von Mises stress equals F_{ty}, yielding occurs, so shear yield τ_y is

$$\tau_y = \frac{F_{ty}}{\sqrt{3}}$$

Local yielding in a member may not limit its usefulness if the amount of material that yields is small or positioned so as to have only a negligible effect on the shape and load-carrying capacity of the member. Where yielding is a limit state, the von Mises stress should be limited to the yield strength of the material.

3.5 Aluminum Composite Material (ACM)

The 2012 *International Building Code* (IBC) Section 1402.1 defines metal composite material (MCM) as "a factory-manufactured panel consisting of metal skins bonded to both faces of a plastic core". Panels with aluminum skins are called aluminum composite material (ACM) (see Figure 3-1). The IBC also defines a metal composite material system as "an exterior wall covering fabricated using MCM in a specific assembly including joints, seams, attachments, substrate, framing and other details as appropriate to a particular design." However, ACMs are not limited to exterior applications.

IBC Section 1407 provides requirements for two uses of MCM: one as exterior wall finish, and the other as architectural trim. Section 1407.4 requires that MCM exterior walls be designed for IBC Chapter 16 wind loads for components and cladding. Section 1407.5 requires that test results or engineering analysis be submitted to the building official to demonstrate this. IBC also specifies fire-resistance requirements that apply to both MCM uses.

ACM panels must be designed to meet deflection limits as well as provide sufficient strength for wind loads.

Typical ACM properties

Property	Value	Units
coefficient of thermal expansion	13×10^{-6} 23×10^{-6}	/°F /°C
available thicknesses	3, 4, and 6 0.118, 0.157, and 0.236	mm in.
skin thickness	0.020 0.50	in. mm

Manufacturers provide additional information on load-span-deflection, dimensional tolerances, section modulus, stiffness, weight, thermal resistance, sound transmission, and fire resistance.

In a similar product, an aluminum-elastomer sandwich beam, the components comprising the structural elements also act together creating a combined strength and other characteristics that are greater than the sum of the parts. The composite beam may have to resist stresses due to a temperature gradient through the section as well as stresses from wind and dead loads. The amount of composite action can be determined by analysis (AAMA (1990)) or testing.

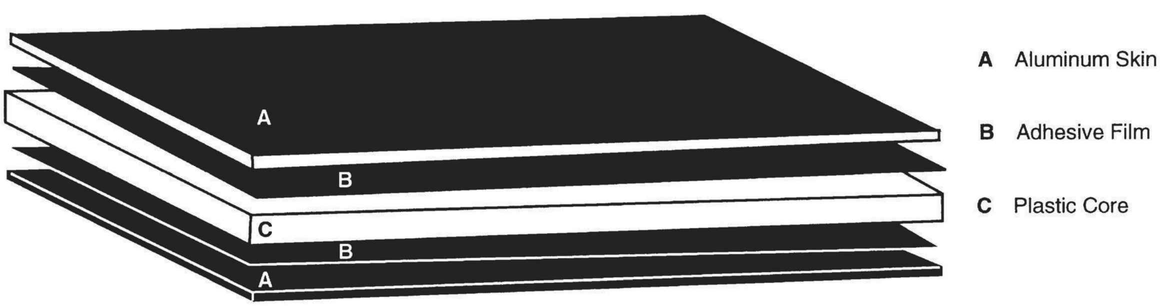


Figure 3-1
SANDWICH PANEL

4. Adhesive Bonded Joints

An adhesive can be defined as a substance capable of holding materials, similar and dissimilar, together by surface attachment. The critical substrate surfaces can be held together by chemical and/or mechanical adhesion at the interfacial layer of contact between surfaces (D.A.T.A. (1986)).

4.1 Advantages and Disadvantages

Shields (1970) and Thrall (1984) address advantages and disadvantages of adhesives. Some advantages of adhesive bonding are:

- Ability to bond a variety of materials that may exhibit differing coefficients of thermal expansion, moduli, thickness, etc., with proper joint design and material selection.
- Improved cosmetics of the finished product by the elimination of protruding mechanical fasteners, such as rivets or bolts.
- Excellent strength to weight ratio in comparison to other joining methods.
- Good joint stiffness and fatigue performance, with appropriate choice of adhesive.
- Elimination of stress concentrations inherent to mechanical fastening methods, and a more uniform stress distribution over the bonded surface area.
- Adaptable to many production processes because of the variety of forms (pastes, films, emulsions, etc.) and methods of application of adhesives.

The advantages of adhesive bonding are most evident when joining relatively thin materials and components. The cost advantages and joint efficiencies decrease as the members become thicker.

Some disadvantages of adhesive bonding are:

- Expert joint design is critical in order to minimize peel and/or cleavage stresses.
- Temperature limitations may restrict the use of many adhesives from high temperature applications.
- Adhesives require surface pretreatment of the aluminum unless the adhesive manufacturer recommends that no pretreatment is necessary. Even with this recommendation, the durability required for the application should be verified.
- Difficulties in inspecting for initial bond integrity and an insufficient understanding of the effects of in-service damage on subsequent bond performance limit confidence in adhesive bonding as a primary structural joining method.

4.2 Adhesive Selection

Literally thousands of commercial adhesives are available. In order to select the proper adhesive for a particular application the user needs a systematic approach to adhesive selection. Major areas to address are:

- Substrates
- Pretreatment
- Application of adhesive
- Fabrication process
- Service environments
- Design

4.3 Types of Adhesives

Kinloch (1987) identified two groups of adhesives: thermoplastics and thermosets. Thermoplastics are materials which can be repeatedly softened by heat and hardened by cooling to ambient temperature. Thermosets are materials that undergo chemical reactions initiated by heat, catalyst, UV light, etc. Thermosets are generally more durable than thermoplastics.

From the two groups of adhesives extend several classes of adhesives, which include anaerobic, contact, cyanoacrylate, film, hot melt, one-part and two-part. Anaerobic adhesives are generally esters or acrylics in which, upon the restriction/lack of air/oxygen, curing of the adhesive initiates. Anaerobic adhesives can also be cured by UV exposure. Contact adhesives are coated to both substrate surfaces, and a solvent is allowed to evaporate before assembly of the substrates. Cyanoacrylates are known as instant cure adhesives. They are derivatives of unsaturated acrylates which cure at room temperature without the aid of a catalyst. Films are uniform layers of adhesives that are generally rolled onto coils. Films can be supported (with reinforcing fibers), unsupported, heat-activated, or pressure-sensitive. Hot melts are generally solvent-free thermoplastics, which are solids at room temperature but soften and flow at heat activation temperature. Upon cooling the hot melt regains its structural strength. One-part adhesives are usually 99-100% solid systems. This class of adhesives includes epoxies, moisture activated silicones, and polyimides which can be waterborne or organic solvent based. Two-part epoxies and acrylics are generally cured at room temperature or accelerated with heat.

4.4 Surface Pretreatments

A surface pretreatment prior to bonding is usually necessary in order to achieve long-term bond strength of aluminum substrates, although in some cases an adhesive manufacturer may state that their adhesive requires no surface pretreatment or that their adhesive is chemically incompatible with the proposed pretreatment. Many aluminum surface pretreatments have been examined to determine the best adhesive substrates for bonding. It is commonly accepted that chemically pretreating the surface yields more durable bond strength than mechanically abrading the aluminum surface. Some of the most popular chemical pretreatment systems to improve the adhesion of aluminum are degreasing, acid etching, and phosphoric acid anodizing. The adhesive manufacturer's recommendations for surface preparation should be followed.

4.5 Joint Design

The decision to use adhesive bonding must consider joint geometry, the nature and magnitude of loading, the properties of the adhesive and the members to be joined, failure modes, and ease and reliability of manufacturing. Adapting a joint design intended for other joining methods often results in ineffective designs. The design must also consider the assembly scheme including needs for surface pretreatment, part tolerances, and fixturing.

The stresses present in adhesive-bonded joints are classified based on loading: normal, shear, peel, and cleavage (Figure 4-1). Cleavage and peel conditions describe a combination of normal and shear stresses specific to these two loading conditions. Cleavage stresses are concentrated on one side of the joint, while peel loads can occur with flexible members (Kinloch (1987)). Though technically different, tensile stresses normal to the bond line are also referred to as peel stresses in the literature. Because adhesives perform best when subjected to compressive and shear loads, joint design should distribute the loads in the adhesive layer as a combination of compressive and shear stresses to avoid tensile, cleavage and peel loadings.

There are four basic types of joints: angle, tee, butt, and surface or lap joints (Figure 4-2). In service, these joints may be subjected to the types of stresses mentioned in the previous paragraph. Most practical adhesive joint designs can be classified as variations of lap joints. Lap joint configurations are usually preferred because they require little or no machining. The use of overly complex configurations for low loads results in unnecessarily expensive designs. On the other hand, simple configurations are unacceptable if smooth uninterrupted surfaces are required, if high stresses are present in the bond, or if high loads must be sustained.

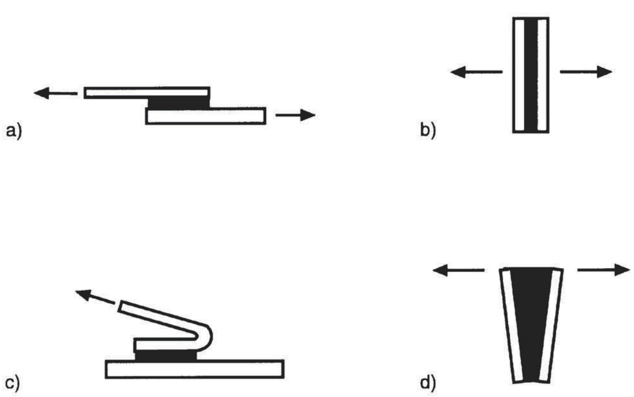


Figure 4-1
TYPES OF STRESSES: A) SHEAR; B) TENSION; C) PEEL; D) CLEAVAGE

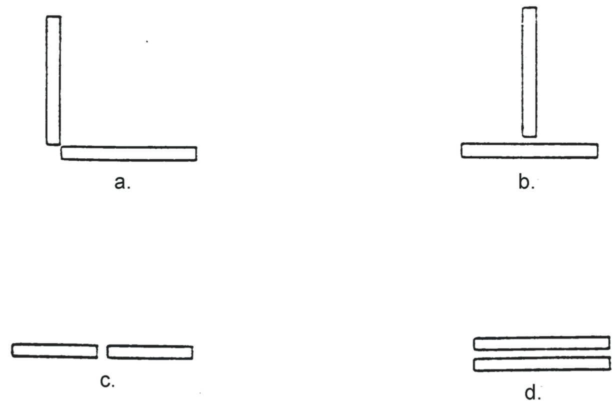


Figure 4-2
TYPES OF JOINTS: A) ANGLE; B) TEE; C) BUTT; D) SURFACE

In single lap joints that are not supported or restrained against joint rotation, bending within the joint and at the ends of the overlap causes locally high transverse tensile stresses in the bond. In joints that are designed to prevent or minimize joint rotation, the bond strength can exceed the full nominal strength of the members.

Although adhesive bonding has benefits in joining dissimilar materials, the application imposes additional design considerations. Using materials with different moduli may result in reduced joint efficiencies. If the materials do not have similar thermal expansion coefficients, temperature changes during elevated temperature cures and in service can increase stresses in adhesive bonds and lower joint strengths (Hart-Smith (1987)). If member materials are not identical, the design should equalize the in-plane and bending stiffnesses and the materials should have similar thermal expansion coefficients.

The identification of possible failure modes is crucial to effective joint design and satisfactory performance. For joints consisting of ductile isotropic materials such as aluminum alloys, four common failure modes are:

1) tensile or buckling failure of the member outside the joint area,
2) shear failure of the adhesive,
3) tensile cracking in the adhesive layer due to tensile or cleavage forces in the joint, and
4) adhesion failure at the adhesive/member interface.

Adhesion failures are least desirable because such interfacial failures typically result in low, inconsistent joint strengths. If the adhesive fails to adhere to the aluminum, this indicates incompatibility of the surface oxide of the aluminum with that particular adhesive. If the aluminum is pretreated and failure occurs at that interface between the pretreatment and the adhesive, this indicates adhesive/pretreatment incompatibility.

The adhesive properties for joint designs may be obtained from mechanical tests. Tensile properties can be obtained using cast adhesive specimens as described in ASTM D 638 (ASTM (2009a)). Adhesive shear properties can be generated using thick adherend tests (Dreiger (1985)) or a torsion test described in ASTM E 229 (ASTM (2009b)). Properties should be obtained for temperatures throughout the range expected in service. Temperature can affect adhesive properties, ductility and toughness, which will affect joint design and performance, including stiffness and failure loads and modes. The adequacy of the design should be checked for the range of service temperatures. Summaries of technology and data are provided by Minford (1993).

For critical applications in complex structures, a complete analysis of the stress components is recommended along with the identification of the potential failure modes. Nonlinear behavior of the adhesive and members should be accounted for in the most effective method of conducting such analysis. Mechanical tests to simulate typical service conditions of adhesive-bonded joints should be performed to verify the predicted failure location and modes.

4.6 Current Adhesive Applications

Adhesives are gaining popularity as a viable structural means of joining aluminum. Today, aluminum adhesive bonding is being used in the transportation, construction, marine, aerospace, and electronic industries. Examples in each category are:

- Transportation: buses, trains, and trailers; automotive seats, hoods, and air bag containers
- Construction: architectural panels
- Marine: boats, ships, and desalination plants
- Aerospace: space vehicles, planes, and helicopters
- Electronics: antennas, computer boards, and cable wires

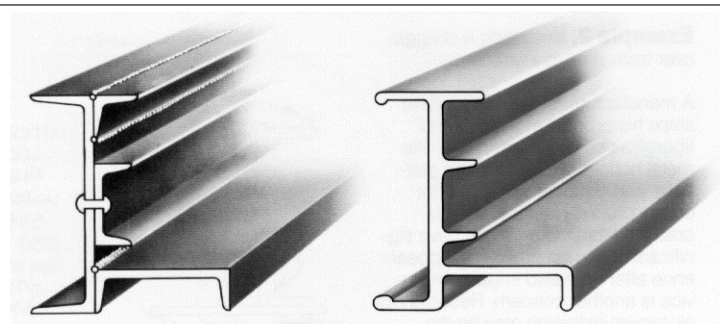
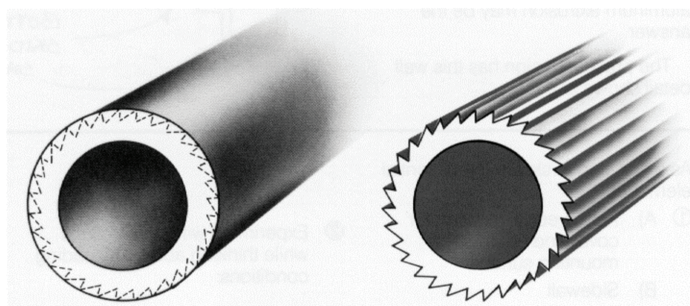
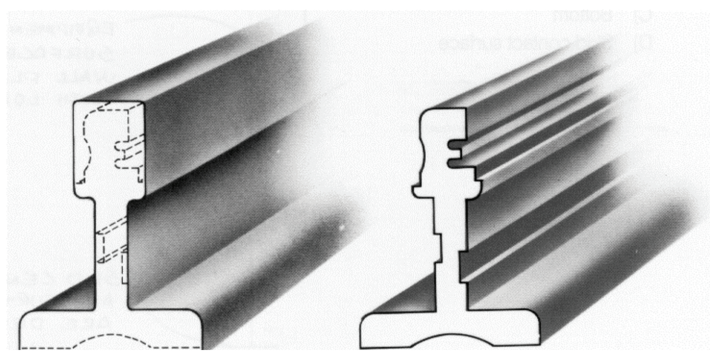
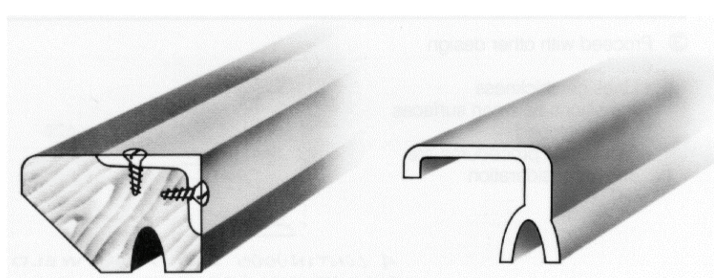
5. Extrusion Design

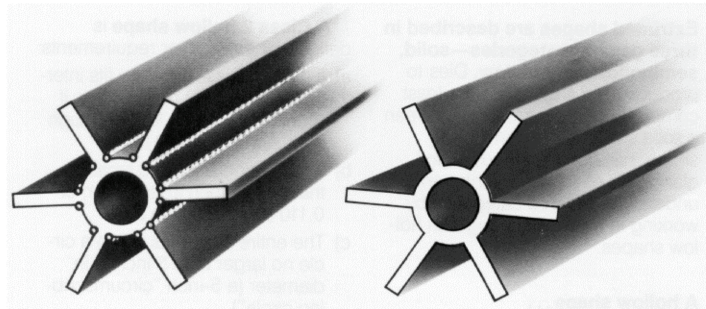
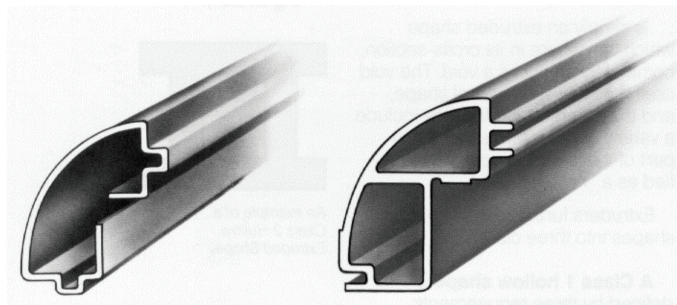
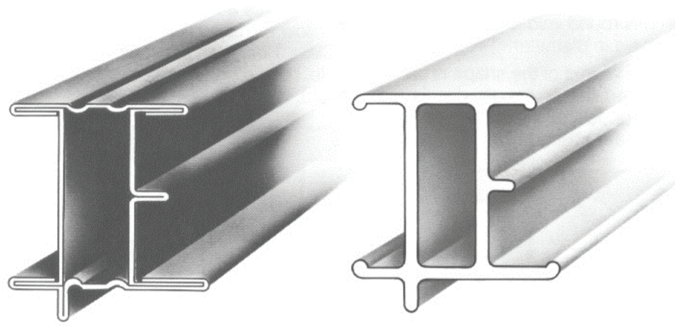
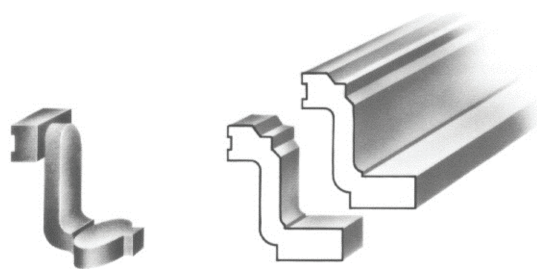
Aluminum can be easily extruded, unlike steel. The extrusion process consists of pushing hot aluminum through a die, likened to pushing tooth paste out of the tube. Custom shapes can be created that place the material where it is most effective.

Cross sections must be constant along their length but they may be intricate. Often fabrication costs can be lowered by consolidating parts or incorporating assembly aids by using extrusions. Extrusions that fit within a circle up to about 30 in. in diameter are possible, but the more common ones fit within a diameter of about18 inches.

The following information in this section is from the *Aluminum Extrusion Manual* (1998).

5.1 Replacing Fabrications with Extrusions

As shown at right, several rolled and riveted structural shapes (left) can be combined into a single aluminum extrusion, thus eliminating all joining costs.	
Machined and stamped sections can be replaced by aluminum sections extruded to exact size and shape.	
As another example, the machining cost and weight of a framing member is reduced by redesigning the member as an extruded section.	
Aluminum extrusions may also replace wood sections. They can be made lighter, stiffer, and stronger, thus eliminating steel reinforcement.	

Welded assemblies are frequently redesigned into extruded sections. Not only is cost reduced, but accuracy and strength are increased.	
Because extrusions permit infinite changes in cross sectional design, they can be produced more readily to meet specific design requirements than rolled sheet sections.	
Crimped tubular sections frequently permit redesign in extruded shapes, with gains in both stiffness and strength. Cost of manufacture is also reduced.	
Small castings, forgings, and parts machined from bar stock may also permit redesign as an extrusion, as long as the cross section is symmetrical in at least one plane.	

5.2 Design Parameters

Five major factors should be considered in the detailed development of an aluminum extrusion design:

- Shape configuration
- Tolerances
- Surface finish
- Alloy
- Circumscribing circle size

These parameters are interrelated in their effect on the extrusion design and its application.

Shape Configuration

The designer's first priority is to satisfy a specific need, and aluminum extrusion allows you to design the shape that best meets your structural and aesthetics requirements. Since extrusion dies are relatively inexpensive, designers can afford to use several different shapes, if that's the best way to achieve their objectives.

Extrusions can be designed to aid in assembly, improve product appearance, reduce or eliminate forming and welding operations, and achieve many other purposes.

Extruded shapes are described in three general categories—solid, semihollow, and hollow. Dies to produce solid shapes are the least complex. The difference between a solid shape and a semihollow shape may not be obvious at first glance. It's easier to describe and understand all three categories by working in reverse, starting with hollow shapes.

A hollow shape is simply an extruded shape 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."

Tube and Pipe are specific forms of hollow shapes.

"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 drawing through a die.

"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."

A semihollow shape is one that partially encloses a void – for example, a circle or rectangle with a gap in one side; but a solid shape 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 size of the gap (actually, to the mathematical square of the gap size). If that ratio is larger than a certain number, the shape is classified as semihollow; if the ratio is smaller, the shape is considered a solid.

The dies required to make semihollow shapes are moderately more expensive than solid shape dies, and the output of those dies tends to approach tolerance limits. Tooling life and productivity are both improved with decreasing ratios, thus reducing cost.

A solid extruded shape is any shape that is not a hollow or a 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 void area/gap^2 ratios are too low for the semihollow-class.

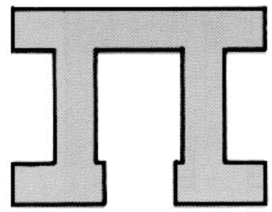


Figure 5-1
EXAMPLE OF A SOLID SHAPE

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

Extruded bar is a solid shape whose cross-section is square, rectangular, hexagonal or octagonal, and whose width between parallel faces is a least 0.375 inches.

If the dimension across any of these rod- or bar-type shapes is less than 0.375 in., it is classified as wire.

Tolerances

In many applications in which the extrusion will be part of an assembly of components, 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. Both standard and precision tolerances for extrusions are given in *Aluminum Standards and Data,* Section 11.

Aluminum extrusions are often designed to minimize or eliminate the need for machining. If desired, many extrusions can be produced to the recently introduced "precision tolerances" or to closer-than-standard custom tolerances, generating cost savings in secondary operations; such savings may range from modest to very large, depending on circumstances. The designer should consider his requirements carefully and order 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 tolerances will provide a proper fit.