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Extrusion of Aluminum Alloys

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ALUMINUM AND ALUMINUM ALLOYS are very suitable for extrusion and many types of profiles can be produced from easily extrudable alloys (Fig. 1, Ref 1). Aluminum extrusion is a very competitive technology for creating profiles for new products with short lead times, a wide range of properties associated with various alloys, and design flexibility.

The widespread use of aluminum extrusions is due to the versatility of applications from the combination of the extruded product form and the material characteristics of aluminum. Applications may be linked to the advantages of extruded profiles, or both. The basic material characteristics of aluminum and its alloys include (Ref 1–7):

- Density approximately one-third that of steel, copper, brass, or nickel.
- High strength-to-weight ratios with tensile yield strength in excess of 550 MPa (80 ksi) for some aluminum alloys.
- Good electrical conductivity: Aluminum has two times the electrical conductance as copper on a weight basis, stemming from its lighter mass density and its electrical conductivity of 62% IACS (International Annealed Copper Standard) relative to copper.
- Good thermal conductivity.
- Corrosion resistance.
- Nonmagnetic face-centered cubic (fcc) crystal structure for electrical shielding and electronic applications and an excellent reflector of electromagnetic waves, including radio and radar.
- Light reflectivity of more than 80% and an excellent reflector of radiant energy across the full range of wavelengths, including ultraviolet and infrared.
- Good ductility and workability (due to the fcc structure) for fabrication by rolling, stamping, drawing, spinning, roll forming, forging, and extrusion.
- Cryogenic toughness, as the fcc structure does not become brittle at low temperatures.
- Variety of surface finishes ranging from clear to color anodized for functional or cosmetic applications, as well as painted or plated.
- Nontoxic for food storage, cookware, and food processing applications.
- Recyclable.

Aluminum Extrusion Alloys

The relatively inexpensive cost of producing aluminum extrusions, coupled with the ease of recycling aluminum, has expanded its many applications in industry, transportation, household, and everyday use. As modern technologically advanced materials, aluminum and its alloys are used in emerging applications as well as revitalizing older designs. Aluminum extrusions ranging from rod, bar, or tube to complex cross-sectional designs find applications in transportation, building and construction, electrical, medical, household, and sports products. The flexible alternatives of the extrusion process and vast array of cross-sectional geometries in many sizes offer many design possibilities and advantages such as:

Design feature	Design advantage
Near-net shape	Optimized cross-sectional design
Variable wall geometry	Place metal only where needed
Solid, open, and hollow profiles	Minimize overall weight
Multivoid hollow designs	Avoid secondary machining operations
Legs	Allow assembly or joining operations
Fins	Replacement of multiple parts
Slots and dovetails	Reduce component inventories
Screw bosses, hinges, slides, snap fit, thermal breaks	Provide attachment points

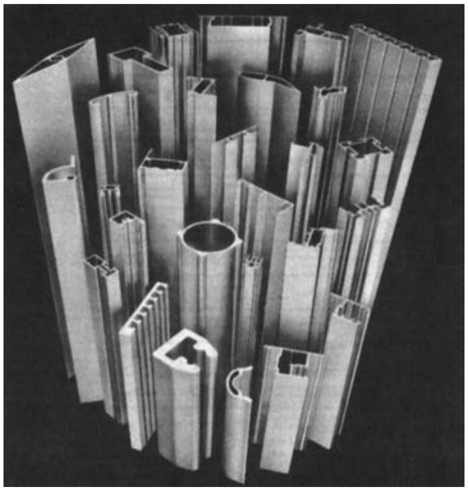

Fig. 1 Examples of extruded sections produced from easily extrudable aluminum alloys. Source: Ref 1

Table 1 lists some extrusion alloys by aluminum alloy series. Ranging from simple to complex cross sections, aluminum extrusions can be produced in many alloys including the 1*xxx* (99.00% minimum Al), 2*xxx* (with Cu), 3*xxx* (with Mn), 5*xxx* (with Mg), 6*xxx* (with Mg and Si), and 7*xxx* (with Zn) alloy series. Of these, the predominant alloy group by commercial volume is the 6*xxx* series alloys; the year of introduction for several key 6*xxx* alloys is listed in Table 1. Table 2 provides a general listing of some typical applications for aluminum extrusions using the 6*xxx* alloy series. Many newer applications, such as space frames for automobiles or in-line skate rails, are also aluminum extrusions from this

Table 1 Aluminum extrusion alloys by series

Series	Alloys
1*xxx*	1060, 1100, 1350
2*xxx*	2011, 2014, 2024, 2219
3*xxx*	3003, 3004
5*xxx*	5066, 5083, 5086, 5154, 5454, 5456
6*xxx*(a)	6005 (1962), 6005A, 6020, 6021, 6040, 6060 (1972), 6061 (1935), 6063 (1944), 6066, 6070, 6082 (1972), 6101 (1954), 6105 (1965), 6162, 6262, 6351 (1958), 6463 (1957)
7*xxx*	7001, 7003, 7004, 7005, 7029, 7046, 7050, 7075, 7079, 7116, 7129, 7146, 7178

(a) Year of introduction noted in parentheses for selected 6*xxx* series alloys alloy group due to its combination of material characteristics, ease of extrusion, and economical production.

Although the term extrudability (i.e., the material formability under conditions of the extrusion process) does not have a precise physical definition (see the section "Extrudability" in this article), the relative extrudability of aluminum alloys can be roughly ranked as measured by extrusion exit speed, as given in handbook references for several of the more important commercial extrusion alloys:

Alloy	Extrudability (% of rate for 6063)
1350	160
1060	135
1100	135
3003	120
6063	100
6061	60
2011	35
5086	25
2014	20
5083	20
2024	15
7075	9
7178	8

In general, the higher the alloy content and strength, the greater the difficulty of extrusion and the lower the extrusion rate. The easily extruded alloys can be economically extruded at speeds up to 100 m/min (330 ft/min) or faster. With a typical extrusion ratio of 40 to 1, exit speeds of the more difficult alloys are on the order of 0.6 to 1.2 m/min (2 to 4 ft/min).

Extrudability of the moderately difficult or very difficult alloys also cannot be significantly increased by hot extrusion technology, because of the narrow temperature interval between the extrusion load limiting temperature and the temperature of unacceptable surface quality. Billet temperatures generally range from approximately 300 to 595 °C (575 to 1100 °F), depending on the alloy. Typical billet temperatures for some of the harder aluminum alloys are listed in Table 3. This does not include variations in exit temperatures. For more information on hot extrusion of aluminum alloys, see the article "Conventional Hot Extrusion" in this Volume.

Cold Extrusion. Aluminum alloys are well adapted to cold (impact) extrusion. The lower-strength, more ductile alloys, such as 1100 and 3003, are the easiest to extrude. When higher mechanical properties are required in the final product, heat treatable grades are used. Although nearly all aluminum alloys can be cold extruded, the five alloys most commonly used are:

Alloy (annealed slug)	Cold extrusion pressure relative to that for 1100 aluminum
1100	1.0
3003	1.2
6061	1.6
2014	1.8
7075	2.3

For more information on cold extrusion of aluminum alloys, see the article "Cold Extrusion" in this Volume.

Profile Types

An extruded profile is defined as a product that is long in relation to its cross section other than extruded rod, wire, bar, tube, or pipe. Many custom or complex cross-sectional designs are possible with aluminum extrusion and, as such, three broad categories of profiles have been established:

- *Solid profiles:* Extruded cross sections that do not incorporate enclosed or partially enclosed voids (Some examples of solid profiles are I-beams or C-channels; refer to Table 4 and related information to discern solid from semihollow profiles.)
- *Hollow profiles:* Extruded cross sections that contain one or more completely enclosed voids in one or more portions of its overall shape geometry
- *Semihollow profiles:* Extruded cross sections that contain one or more partially enclosed voids in one or more portions of its overall shape geometry (see also Table 5)

Classes of Profiles

To further describe hollow and semihollow profiles and to provide greater distinction from solid type profiles, classes of profiles have been defined for producers and users and are listed in Table 4.

Table 2 Typical applications for 6*xxx* series aluminum extrusions

Automobiles and other ground transportation	Air bag housings
	Automobile space frames
	Bumper components
	Engine mounts
	Fuel-injection rails
	Suspension components
	Truck trailer frames
Electrical and electronic components	Bus bar
	Cable trays
	Electrical connectors
	Electrical shielding
	Heat sinks
Household and architectural items	Appliance trim
	Fencing
	Furniture
	Hand rails
	Lighting reflectors
	Picture frames
	Shower curtain enclosures
	Swimming pool structures
	Window and door frames
Sporting goods and recreation equipment	Bicycle frames and wheels
	In-line skate rails
	Sailboat masts
	Tennis rackets
Other	Aircraft cargo containers
	Cargo and bicycle racks
	Heating elements
	Ladders and scaffolds
	Level bodies
	Pneumatic cylinders
	Railcar structures

Table 3 Typical values of billet temperature and extrusion speed of some harder aluminum alloys

		Billet Temperature		Exit speed	
Alloy	Type	°C	°F	m/min	ft/min
2014–2024	Heat treatable	420–450	788–842	1.5–3.5	5–11
5083, 5086, 5456	Non-heat-treatable	440–450	824–842	2–6	7–20
7001	Heat treatable	370–415	700–780	0.5–1.5	2–5
7075, 7079	Heat treatable	300–460	572–860	0.8–2	3–7
7049, 7150, 7178	Heat treatable	300–440	572–824	0.8–1.8	2.5–6

Note: Temperatures and extrusion speeds are dependent on the final shape and the extrusion ratio, and it may be necessary to start with lower billet temperatures than mentioned in the table. Source: Ref 1, 3

Table 4 Hollow and semihollow profile classes

Class	Description
Hollow profiles	
Class 1	Contains a single, round void that is equal to or greater than 25 mm (1 in.) in diameter and is symmetrical to its exterior geometry on two axes
Class 2	Contains a single, round void that is equal to or greater than 9.53 mm (0.375 in.) in diameter or a single, nonround void that is equal to or greater than 0.710 cm^2 (0.110 in.^2) in area and that does not exceed a 127 mm (5 in.) diam circumscribing circle of its exterior features and is other than a class 1 hollow
Class 3	Any hollow profile other than Class 1 or Class 2 hollow (Class 3 hollow would include multivoid hollow profiles.)
Semihollow profiles	
Class 1	Contains two or less partially enclosed voids in which the area of the void(s) and the area of the surrounding wall thickness are symmetrical to the centerline of the gap feature of the profile.
Class 2	Any semihollow profile other than class 1 semihollow. Class 2 semihollow would include nonsymmetrical void surrounded by symmetrical wall thickness, or symmetrical void surrounded by nonsymmetrical wall thickness.

The partially enclosed voids of semihollow profiles are classified in Table 5 and consider the ratio of the cross-sectional area of the partially enclosed void to the square of the gap dimension. This calculated ratio when greater than the value listed in Table 5 for the applicable semihollow class and alloy group confirm the classification as a semihollow profile; otherwise, it is deemed a solid-shape profile.

Extruded Tube and Pipe. Extruded tube is a specific form of hollow extrusion, though not termed as a hollow "profile," that is, long in comparison to its cross-sectional size. Extruded tube is symmetrical with uniform wall thickness and is either round, elliptical, square, rectangular, hexagonal, or octagonal. Square extruded tube, rectangular tube, hexagonal tube, and octagonal tube may have either sharp or rounded corners.

Extruded pipe is a specific form of hollow extrusion that meets the criteria for extruded tube and also meets certain standardized combinations of outside diameter and wall thickness.

Extruded Rod, Bar, and Wire. Extruded rod is a specific form of solid extrusion, though not termed as a solid "profile," that is, a round cross section of 9.53 mm (0.375 in.) or greater in diameter.

Extruded bar follows the criteria for extruded rod except rather than round in shape, extruded bar is either square, rectangular, hexagonal, or octagonal and has a width between parallel faces of 9.53 mm (0.375 in.) or greater. Square extruded bar, rectangular bar, hexagonal bar, and octagonal bar may have either sharp or rounded corners.

Extruded wire is extruded rod or bar where the dimension across the shape is less than 9.53 mm (0.375 in.).

Extrusion Profile Design. The varied array of extruded products already in use also represents the large diversity of designs that are possible with extruded profiles. Once again, the combination of multiple advantages that can arise from the design geometry of the profile and the multiple advantages that stem from the material characteristics of aluminum alloys offer great potential for many new applications or redesign of existing ones.

Whether a solid, hollow, or semihollow profile type, the overall size of the cross section is a basic consideration. The circumscribing circle size, or the diameter of minimum circle that can contain the extremities of the cross section of the profile, is a parameter that is useful in determining the best match to press production equipment, overall economics of manufacture, and opportunities for multihole tooling where more than one lineal extrusion can be produced simultaneously.

The circumscribing circle size, together with the profile type and class, are considered with the parameters of extrusion tolerances, the extruded surface finish, and alloy, when developing an extrusion design and its tooling. It is common to select an alloy for extrusion based on more than one material performance characteristic. The following parameters are often considered in profile design and product performance:

- Ease of extrusion
- Control of tolerances
- Length of extruded lineal (not alloy dependent)
- Mill finish (or as-extruded) appearance
- Response to subsequent finishing (anodizing)
- Temper and tensile strength
- Electrical conductivity
- Corrosion resistance
- Weldability
- Machinability
- Recyclability

Multipurpose Profile Design. Extrusion profiles can be designed to handle multiple purposes within the same part. An extruded heat sink, for example, may also include screw bosses or dovetails in its design for attachment purposes. As another example, a hollow profile extrusion may have multiple voids for carrying different fluid media, as well as external cooling fins, attachment features, and stiffening ribs.

Alternatively or additionally to multiple function features, extruded profile design can also combine designs and functions of multiple parts into a single, one-piece aluminum extrusion. An integral extruded design that replaces multiple components can eliminate assembly and joining steps, associated jigs and fixtures, fasteners, and multiple part inventories, resulting in a more cost-competitive approach overall. Often, final product reliability and performance are also improved with one-piece, integral extrusion designs.

Connection Features of Extruded Profiles. Aluminum extrusions can be designed with connection features or appendages to simplify assembly with other components and materials. Mating surfaces, snap-fits and interlocking joints, dovetails, screw boss slots, nested or tongue-and-groove joints for fasteners or welding, and key-locked joints can be used alone or in combination with other product components or with other extrusions. Rotational joints, such as hinges, are also possible to incorporate into the cross-sectional design of the extruded profile.

Finishes. Extruded profiles, rod, bar, pipe, and tube may be subsequently finished for cosmetic and/or functional purposes. Opaque films such as paint or plating can be applied to aluminum extrusions as well as integral anodized coatings that are either transparent or semitransparent. Most industrial methods of application can also be used, including spray, dip, or powder coating, and electrodeposition.

Mechanical pretreatments, such as scratch brushing or polishing, may precede anodizing or may be applied as the final surface finish. Chemical pretreatments, such as etching or bright dipping, may precede anodizing either alone or in combination with mechanical treatments. Other chemical pretreatments, such as conversation coating, can also be employed to improve film adhesion of paints.

As anodizing is an electrolytic process and its resultant coating is integral with the aluminum surface, the response in appearance from anodizing is alloy dependent. Further, the preceding chemical prefinishes, if used, can also respond differently to different aluminum alloys. Hardcoat anodizing can be applied to aluminum extrusions to provide wear-resistant surfaces.

To assist in the handling of extrusions that have aesthetic applications, portions of the extruded profile that will be exposed in use or areas whose surface condition is critical are usually identified. This information on exposed surface(s) is communicated to both extrusion production and finishing operations and is used to select handling procedures, protective packaging, and shipping methods.

Table 5 Semihollow profile classification

	Ratio(a)			
	Class 1(b)		Class 2(b)	
Gap width, in.	Alloy group A	Alloy group B	Alloy group A	Alloy group B
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
$\geq$ 2.000	3.0	2.5	3.0	2.0

(a) Ratio = void area (sq. in.)/gap width^2 (in.). (b) Alloy Group A: 6061, 6063, 5454, 3003, 1100, 1060; Alloy Group B: 7079, 7178, 7075, 7001, 6066, 5066, 5456, 5086, 5083, 2024, 2014, 2011. Use void-gap combination that yields the largest calculated ratio, whether the innermost void and gap of the profile or the entire void and gap features

Process of Aluminum Extrusion

The typical sequence of production steps for aluminum extrusion aluminum from a billet includes:

1. Preheat billets
2. Extrude
3. Quench
4. Stretch
5. Cut into mill lengths
6. Artificially age
7. Quality control

Some design-for-manufacturing considerations for aluminum extrusions depend on the difficulty of extruding through small complex die openings. Hollow sections are quite feasible, though they cost more per pound produced. The added cost is often compensated for by the additional torsional stiffness that the hollow shape provides. It is best if hollow sections can have a longitudinal plane of symmetry. "Semihollow" features should be avoided, as semihollow features require the die to contain a very thin—and hence relatively weak—neck. Sections with both thick and thin sections are to be avoided. Metal tends to flow faster where thicker sections occur, giving rise to distortions in the extruded shape.

The direct extrusion process (Fig. 2a) is the most popular among extrusion processes. A metal billet is forced through the die orifice in the same direction as the applied force to the billet. The major advantage of this process is its high productivity due to the fact that the total length of the extrudate is generally limited by the size of the metal billet. The disadvantage of the process is associated with the presence of friction at the billet/container interface. Due to the large surface area of this frictional interface, a high extrusion force is required to initiate the process. Additionally, the billet/container interface is a source of frictional heating resulting in a temperature gradient within the billet during the process.

The temperature gradients are generally not desired; however, due to characteristics of the aluminum alloys in some specific cases they can be introduced intentionally. In order to maintain constant extrusion process parameters, it is necessary to balance changing process parameters such as extrusion speed and temperature. These process parameters are not constant due to the fact that friction is decreasing during the process cycle, temperature is increasing, and process speeds could be allowed to change. Changes to increase process speeds result in higher extrudate temperature and eventual surface tearing. In order to maximize process productivity, a temperature profile can be introduced in the billet prior to extrusion. The billet can be prepared to have a selected optimal deformation temperature at its front end, with the temperature dropping toward the back of the billet. This billet taper can be calculated for the specific process, press, shape, and alloy, allowing deformation and friction heating to equilibrate the billet temperature in the deformation zone for the entire process (Ref 9, 10).

In the indirect extrusion process (Fig. 2b), the ram forces the extrusion die into the billet and deforms it, with the extrudate flowing through the die orifice in the direction opposite to applied force. The major difference between direct and indirect process is an absence of billet/container interface friction with the indirect process, which therefore has a much more uniform temperature gradient during deformation. However, limitations of the length of the hollow stem, due to mechanical instability, in turn limit the length of the extrudate produced.

Extrudability. The term extrudability (i.e., the material formability under conditions of the extrusion process) does not have a precise physical definition. Very often extrusion is presented as a process that is taking place under hydrostatic stress. This is a correct statement describing conditions in the main deformation zone in front of the die orifice(s). However, the state of stress in the extrusion itself is more complicated because friction along billet-to-container, billet-to-die, deformation zone-to-dead metal zone, and extrudate-to-bearing land (part of the extrusion die) interfaces creates other stresses, which are responsible for material formability.

There are several methods proposed for extrudability evaluation (Ref 11); however, no specific method has been adopted as a single, accepted test. The ideal solution would be to base material evaluation on more traditional laboratory formability tests, such as tensile, compression, or torsion. The difficulty in interpreting laboratory test results comes from the fact that very different states of stress, as well as gradient of strain, strain rate, and temperature are present during the laboratory tests versus the actual extrusion process. In practice, laboratory tests can be used as screening methods, allowing establishment of a window of processing parameters for the tested material. This information can then be applied to a more practical approach where optimum extrusion process parameters can be established (Ref 13). These approaches are based on plotting the relationship between maximum extrusion exit speeds and preheat billet temperature (Fig. 3) for a particular profile or industrial shape (Ref 11–19). The maximum exit speed ($V_{\max}$ in Fig. 4), which ensures obtaining a product without surface tearing, has been frequently suggested (Ref 11, 12, 15, 16). An additional advantage of selecting maximum exit speed as a measure of extrudability is the fact that this parameter is both a metallurgical and productivity measurement. Flow stress and extrudability (expressed as exit speed) are plotted in Fig. 5 for several types of aluminum alloys.

Deformation and Metal Flow. Each material has a range of optimum deformation parameters defined by strain, strain rate, and temperature conditions. The actual challenge in industrial practice is the changing of process parameters during the extrusion cycle, making optimization very complicated. Therefore, it is difficult to directly apply to industrial practice

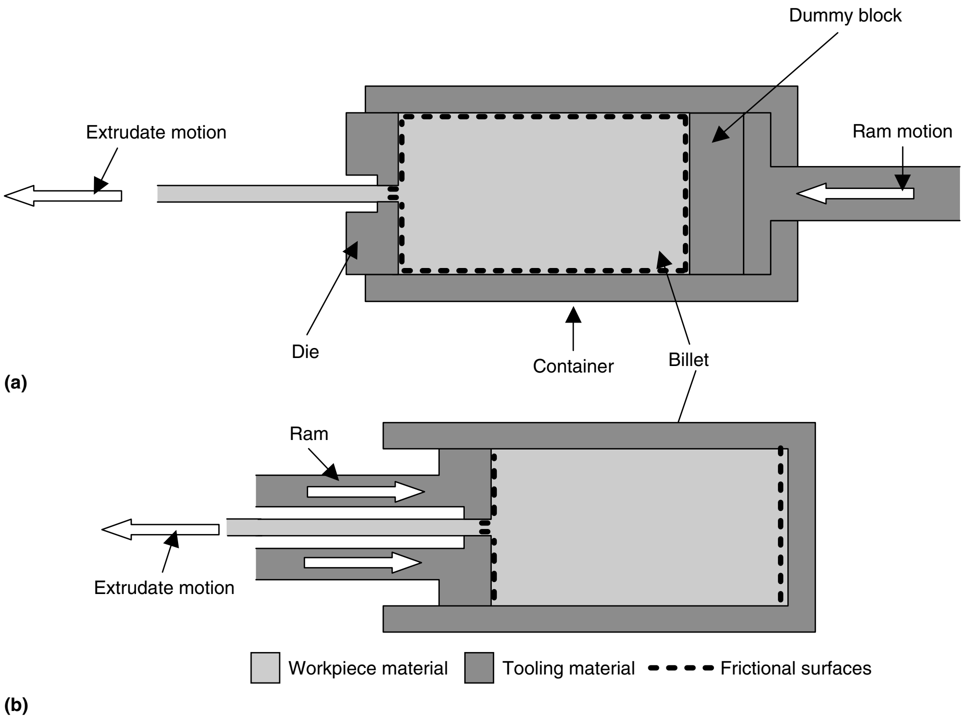

Fig. 2 Direct (a) and indirect (b) extrusion process. Source: Ref 9

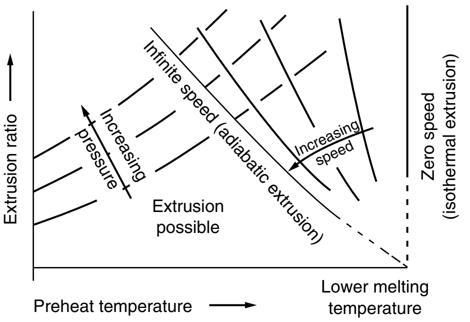

Fig. 3 Extrusion exit speed as a function of temperature. Source: Ref 11, 12, 13

the results of laboratory deformation optimization studies for a given alloy. Due to the bulk nature of deformation, an extrusion billet experiences a range of strain, strain rate, and temperature values based on inhomogeneous deformation inherent in extrusion. The presence of both the friction on the billet/container interface and temperature gradient within the billet as a result of preheating process combine to contribute to the final metal flow pattern. Extrusion processing parameters have very different values in the main deformation zone, dead metal zone, and the shear zone. Valberg (Ref 20) has expanded existing classification of metal flow patterns proposed by Duerrschnabel (Ref 21) to include characteristic examples for direct and indirect extrusion for various aluminum alloys (Fig. 6).

Many solid-type aluminum profiles are generally extruded through 90° semicone angle die, also known as a flat-face die. Despite the fact that die geometry (die angle) can significantly influence metal flow, industrial conditions and process productivity favor the flat-face design in many cases. In this situation, metal flow can be corrected only by proper design of the bearing land of the die itself or the addition of feeder plates (Ref 22) used to control the material flow in front of the die orifice. This concept has been developed even further into single bearing land die where whole metal control takes place in front of the die orifice (Ref 23). A majority of extrusion analysis available in literature is focused on a classic round-to-round process, while in industrial practice multihole dies are preferred due to their higher productivity. The metal flow for these multihole dies and for more complex profiles is much more complicated (Ref 22).

Die Design. The major role for an extrusion die is to produce high-tolerance products in a repeatable way and to have a long service life. Since productivity is always a major concern, a typical extrusion die design considers the opportunity for multihole tool applications. In order to produce a high-quality product, the extrusion die has to create conditions for uniform metal flow within the die orifice for a vast range of extruded profiles with different geometries. The difficulty of this requirement is proportional to the number of the die orifices and complexity of the extruded shape. A die design, which requires from a die designer good experience and high engineering skills, considers attaining uniform metal flow in each of the profile segments that may have different wall thickness, screw bosses, or a host of other varying features. There are several ways of controlling metal flow within the die:

- Adjust the length and angle of the bearing land as a function of the distance of the die orifice from the geometrical center of the die and the wall thickness of the extrudate.
- Introduce weld pockets in front of the die, which enable billet-to-billet extrusion as well as redirect the metal flow before it reaches the die orifice. This method is especially efficient while extruding sections of very different wall thickness, and it yields high dimensional tolerances of the extrudate.

Tubular products are commonly extruded through the porthole dies. The design of the porthole die is much more complex since metal flow is divided into ports first and then it is welded around a short mandrel, which is responsible for inside geometry of the tube. The outside geometry is formed by the die itself, and in this way a structure with multiholes can be formed. In order to guarantee a sound weld integrity, the deformation measured by the extrusion ratio needs to be high enough to provide necessary stress resulting in a sound weld. The extrusion ratio, defined as the ratio between cross section of the container divided by the cross section of the extrudate(s), needs to be 14 or greater (Ref 3).

During the design process of the extrusion dies, it is necessary to take into account die deflections under pressure at elevated temperatures. This potential die deflection directly affects the dimensional tolerances of the extrudate, and compensations are considered in the die design stage. The calculations need to be performed for the die, and support tooling, such as die backers and die bolsters, provides a die set with acceptable performance.

The most popular method of prolonging die life and protecting it from wear during service is nitriding. The protective layer is built up as a result of nitrogen diffusing into the surface layers of the tool steel producing hard and wear-resistant nitride layer.

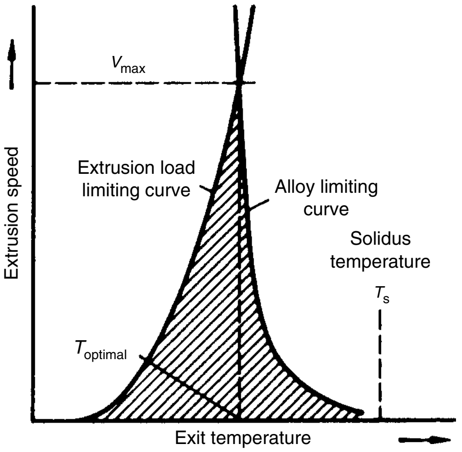

Fig. 4 Limit diagram of extrusion speed, V, versus temperature for a given extrusion load and the alloy limit for surface cracking (hot shortness). Note: This optimal temperature only refers to extrusion speed and not metallurgical development of properties. Adapted from Ref 1

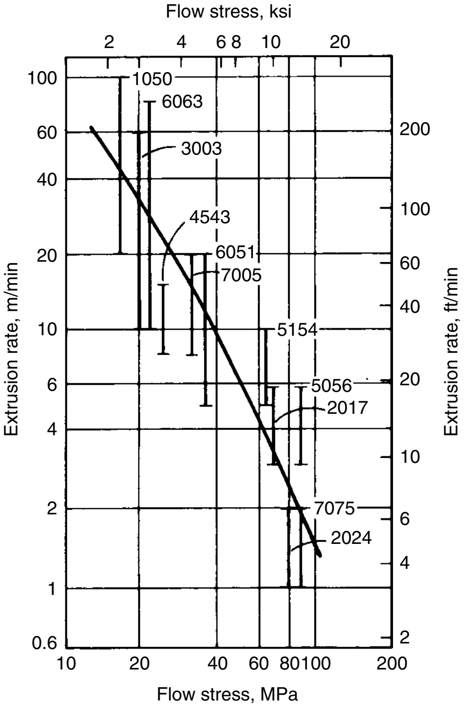

Fig. 5 Extrusion rate versus flow stress for various aluminum alloys. Adapted from Ref 16

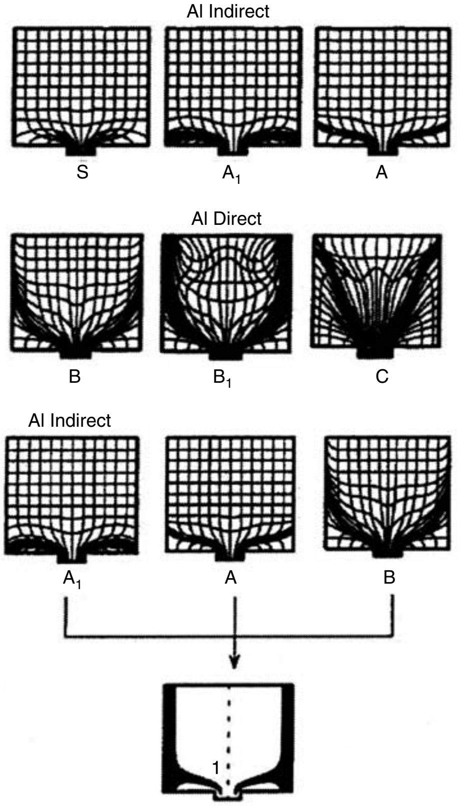

Fig. 6 Modified metal flow patterns for extrusion. S, homogeneous deformation with very low friction on billet/container interface; A, homogeneous deformation with low friction on billet/container interface; B, homogeneous deformation with moderate friction on billet/container interface; C, homogeneous or nonhomogeneous deformation with high friction on billet/container interface; A_1, aluminum in indirect process; B_1, aluminum in direct process. Source: Ref 20

Heat Treatment or Precipitation Hardening. Extrusions made of the heat treatable alloys (2*xxx*, 6*xxx*, 7*xxx*) are strengthened in a two-step process involving solution heat treatment and precipitation hardening also known as aging or age hardening. After solution treatment above the solid solution temperature of the alloy, the extrudate is quenched to room temperature to ensure presence of the supersaturated metastable solid-solution phase. Subsequently, extrusions after being stretched for straightening and releasing internal stresses from quenching are placed into an aging furnace for controlled precipitate of the second phase (e.g., Mg_2Si in 6*xxx* alloys) to yield a high number of fine precipitates. The presence and size as well as the distribution of these precipitates is responsible for the final mechanical properties of the extrudates.

Since deformation of 6*xxx* alloys can take place in the temperature range for the solid-solution treatment, the extrusions can be quenched on the press immediately after leaving the die orifice. Depending on the alloy chemistry and the shape, size, and wall thickness of the extrusion, different cooling techniques are implemented. These techniques range from forced air, through water mist, to complete immersion in water. It is critical to ensure required cooling rate to avoid any uncontrolled precipitation from the supersaturated solid-solution phase.

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