Analysis of the extrusion process parameters of high strength aluminium alloys used in the aerospace industry

V Hotea and J Juhasz

Technical University of Cluj-Napoca, Faculty of Engineering, Department of Mineral Resource, Material and Environment Engineering, Baia Mare, Romania

E-mail: jozsef.juhasz@cunbm.utcluj.ro

Abstract. The paper approach some aspects of the most important parameters that influence the process of extrusion and the quality of material exiting from the die such as extrusion ratio, working temperature and speed of deformation. An important advantage gained by using extrusion of high strength aluminium alloys is that different microstructures may be obtained by varying process parameters, such that optimization of processing conditions leads to improved thermo-mechanical properties. Among the multiple process parameters in aluminium extrusion, the extrudate temperature is the most important because it determines the quality of the product and indicates the possibility of increasing extrusion speed.

1. Introduction

Aluminium alloys are the raw material for aircraft structural parts for over 80 years due to their well-known performance, well-established manufacturing design methods and reliable inspection techniques. The Aluminium Association maintains a widely recognized system for each category of aluminium alloys, as described in ANSI H35.1, Alloys and Temperatures for Aluminium [1]. This standard date back to 1957 (American Standard H35.1-1957) when only the names of deformable alloy systems that were developed by the Aluminium Association were considered. This standard was re-enacted in 1962 by adding names of temperamental systems as an effect. Good high-temperature strength is attained by the addition of copper (up to 4%) and/or nickel, manganese, or iron up to one percent each. Good chemical resistance is shown by alloys with additions of magnesium, manganese, or a combination of magnesium and silicon. Machinability is greatly improved by the addition of lead and bismuth up to 0.6% each. A fine-grained structure is obtained especially through the addition of titanium and boron (up to 0.1%) [2]. Also, the homogenization treatment given to the alloy further improves the distribution of alloying element in the aluminium alloy’s composition.

From the 7xxx series, there are Al-Zn-Mg-Cu alloy systems containing zinc, magnesium and copper, as well as additives such as chromium, manganese, or zirconium, and impurities such as iron and silicon. These alloys have a short hot-melt temperature due to a high deformation resistance and an early melting tendency at high processing temperatures [3, 4].

The extrudability, which can be measured by the maximum extrusion speed, is one of the most important factors influencing the cost and efficiency of the extrusion parameters of the process. The temperature and velocity as well as the state of stresses in the deformation zone, mainly in the die region, a significant role in improving the extrudability of a particular alloy. Various evaluations of the extrudability of high-strength aluminium alloys were studied by Zasadzinski and Misiolek who
presented the results of extrusion investigations of alloys that are difficult to deform by applying controllable container temperatures [5].

In a recent study, the extrudability of 7xxx series alloys was measured as the maximum extrusion speed before the hot break or the crack speed in the extrudate section. Their resins show that the extrudability of these alloys is strongly dependent on some alloying constituents such as Mg and only slightly dependent on the zinc content. Adding percentages of copper and zirconium also reduces extrusion speed [6].

Despite the fact that control systems and infrared thermometers are commonly used in the aluminium extrusion industry, the Temperature Process Control (TPC) System is the first to effectively merge these two technologies to deliver true automatic temperature-based control in a system that is easy to use [7].

2. Fundaments and principles of aluminium alloys extrusion

Extrusion is a plastic deformation process in which a block of metal (billet) is forced to flow by compression through the die opening of a smaller cross-sectional area than that of the original billet as shown in figure 1. Extrusion is an indirect-compression process. Indirect-compressive forces are developed by the reaction of the workpiece (billet) with the container and die; these forces reach high values. The reaction of the billet with the container and die results in high compressive stresses that are effective in reducing the cracking of the billet material during primary breakdown from the billet [8].

![Figure 1. Principle of direct extrusion](image)

The most important and common method used in aluminium extrusion is the direct process. Figure 1 show the principle of direct extrusion where the billet is placed in the container and pushed through the die by the ram pressure. These processes can be summarized as follow [9]:

- First billet or ingot (metal work piece of standard size) is produced. This billet is heated in hot extrusion or remains at room temperature and placed into a extrusion press (Extrusion press is like a piston cylinder device in which metal is placed in cylinder and pushed by a piston);
- Now a compressive force is applied to this part by a plunger fitted into the press which pushes the billet towards die;
- The die is small opening of required cross section. This high compressive force allows the work metal to flow through die and convert into desire shape;
- The extruded part removes from press and is heat treated for better mechanical properties.

Direct extrusion finds application in the manufacture of solid rods, bars, hollow tubes, and hollow and solid sections according to the design and shape of the die.

3. Study and analysis parameters of extrusion process

The most important parameters that influence the process of extrusion and the quality of material exiting from the die are as follows [10]:

- Extrusion ratio (E.R.);
- Working temperature (Tb);
• Speed of deformation (Ve);
• Alloy flow stress.
The correlation between these variables is shown in figure 2.

![Figure 2](image)

**Figure 2.** The main variables that influence the force required to produce extrusion and extruded quality [10]

3.1. **Extrusion speed**
The response of a metal to the extrusion processes can be influenced by the deformation velocity. Increasing the speed of the ram produces an increase in the extrusion pressure. The temperature developed at extrusion increases as the ram speed increases. This increase is due to the fact that the degree of stress is directly proportional to the speed of the piston and the magnitude of the heat generated is proportional to the stress rate. When the ram speed is lower, the more time will be available for the flow-generated heat energy. Heat conduction is more pronounced on aluminium due to its higher conductivity.

The start-up parameters are set from the Extrusion Speed Process Controller to Start, and its correction, as shown in figure 3.

![Figure 3](image)

**Figure 3.** Control panel of extrusion speed and temperatures at start-up [Source: UAC Europe SRL]

The most used alloys for small- and large-shaped extruded sections in the aircraft industry is 2024 and 7075, which offers a high strength-to-weight ratio.

The chemical composition, heat treatment and their extrudability are shown in table 1.

| Alloy | Heat treat       | Major Alloying elements | Extrudability (a) |
|-------|------------------|-------------------------|-------------------|
|       |                  | Mn          | Mg      | Cu       | Zn |      |
| 2024  | Natural aging    | 0.3-0.9     | 1.2-1.8 | 3.8-4.9  | 0.25| 15   |
| 7075  | Artificial aging | 0.30        | 2.1-2.9 | 1.2-2    | 5.1-6.1 | 10   |

Table 1. High strength aluminium alloys and extrudability
The starting parameters for the alloys in the 2xxx and 7xxx series are shown in tables 2 and 3.

Table 2. The starting parameters for alloys AA 2xxx series

| Extrusion Ratio (%) | Temp. billet (°C) | Temp. container (°C) | Extrusion speed (mm/min.) |
|---------------------|-------------------|----------------------|--------------------------|
| <60                 | 460               | 468                  | 1000                     |
| 40-60               | 430               | 450                  | 1000                     |
| 40-60               | 400               | 430                  | 1000                     |
| 20-40               | 380               | 430                  | 1000                     |
| <20                 | 380               | 410                  | 1000                     |

Table 3. The starting parameters for alloys AA 7xxx series

| Extrusion Ratio (%) | Temp. billet (°C) | Temp. container (°C) | Extrusion speed (mm/min.) |
|---------------------|-------------------|----------------------|--------------------------|
| <100                | 443               | 443                  | 1000                     |
| 70-100              | 420               | 440                  | 1000                     |
| 40-70               | 390               | 400                  | 1000                     |
| <40                 | 360               | 370                  | 1000                     |
| <40                 | 300               | 320                  | 1000                     |

As can be seen from Tables 2 and 3, the starting extrusion speed for the 2xxx and 7xxx series alloys is the same (1000 mm / min) as it's safe to avoid crack defects. The typical extrusion exit speeds achievable for different types of high strength aluminium alloys are shown in Table 4 [10], and are a direct indication of the extrudability of each alloy [11].

As can be seen from table 4, that the extrusion exit speed for several brands of high-strength aluminium alloys varies and is dependent on the cross-section shape and the extrusion ratio [12].

Table 4. Typical extrusion speed for high strength aluminium alloys [10]

| Alloy            | Heat treat or not | Temp. (°C) | Exit speed (mm/min.) |
|------------------|-------------------|------------|----------------------|
| 2014-2024        | Treat             | 420-450    | 1.5-3.5              |
| 7001             | Not treat         | 370-415    | 0.5-1.5              |
| 7075, 7079       | Not treat         | 300-460    | 0.8-2.0              |
| 7049, 7150, 7178 | Not treat         | 300-440    | 0.8-1.8              |

The extrusion outlet of the extrusion press is illustrated in figure 4.

Figure 4. Output extrudate from the extrusion press (Source: UAC Europe SRL)
3.2. Working Temperature
Temperature is one of the most important extrusion parameters. The flow demand is reduced if the temperature is increased and the deformation is therefore easier to achieve, but at the same time the maximum extrusion speed is reduced because the localized temperature can lead to the incipient melting temperature of the billet.

Despite the fact that control systems and infrared thermometers are commonly used in the aluminium extrusion industry, the Temperature Process Control (TPC) System is the first to effectively merge these two technologies to deliver true automatic temperature-based control in a system that is easy to use. Williamson Corporation and SAI Automation have partnered to develop this innovative system which integrates Best Practices Standards with simple and effective closed loop controls to effectively optimize press performance and enable a process for continuous improvement.

Unique TPC features include [7]:
- Real-time temperature-based closed loop control;
- Continuous optimization of profile temperatures at the platen exit for isothermal control;
- Continuous optimization of billet feed temperatures;
- Automatic compensation for varying operating conditions;
- Recipe and order management modules that organize and apply Best Practices Standards for each die and order;
- Advanced Utilities and Reports to automatically capture critical process data;
- Flexible design to integrate with existing control systems;
- Advanced options to optimize tapered billet heating, nitrogen die cooling, and quench rates;
- Installation and training in less than one week with little or no downtime.

3.3. Extrusion ratio
The extrusion ratio (ER) for a multi-hole die is defined by the relationship:

\[
ER = \frac{A_C}{n(A_E)}
\]  

in which: \( A_C \) - the area of container, \( n \) - the number of symmetrical holes in the die, \( A_E \) - the area of extrudate shape.

The extrusion ratio of a extruded form is a clear indication of the amount of mechanical work that will take place as the extrudate form.

Actual demand is a function of the extrusion ratio and, finally, the extrusion pressure required for extrusion is a function upon request. If the extrusion ratio of the profile is low, the amount of plastic deformation is also low. As a result, the amount of work done during extrusion will be less. In extruded aluminium with a low extrusion ratio, the structure will be similar to the cast aluminium casting (thicker grains). This structure will be mechanically weak and, as a result, extruded dies with an extrusion ratio of less than 10 to 1, which cannot be guaranteed to satisfy the mechanical and physical properties of the material specifications.

4. Conclusions
An important advantage gained by using extrusion of high strength aluminium alloys is that different microstructures may be obtained by varying process parameters, such that optimization of processing conditions leads to improved thermo-mechanical properties.

The most important process variables affecting both the quality of the extruded and the productivity of the extrusion process is working temperature and extrusion speed. Among the multiple process parameters in aluminium extrusion, the extrudate temperature is the most important because it determines the quality of the product and indicates the possibility of increasing extrusion speed.
The extrudability, which can be measured by the maximum extrusion speed, is one of the most important factors influencing the efficiency of process extrusion parameters. The temperature and velocity as well as the state of stresses in the deformation zone, mainly in the mould region, play a role significant in improving the extrudability of a certain type of high strength aluminium alloy.

References
[1] Aluminum Association Secretariat 1997 *ANSI H35.1 Alloy and Temper Designation Systems for Aluminum* Aluminum Association Washington DC
[2] http://docplayer.net/21620621-Chapter-2-production-and-processing-of-aluminum.html
[3] Strawbridge D J, Hume-Rothey W, Little A 1948 *J. Inst. Met.* Vol 191 (No. 74) 1947-1948
[4] Hatch J.Ed. 1984 *Aluminum: Properties and Physical Metallurgy* ASM International pp.424
[5] Zasadzinski J and Misiolek W 1988 *Estimating Optimal Speed/ Temperatures to Maximize Hot Extrusion Exit Speed* Proc Fourth International Aluminum Extrusion Technology Seminar Vol 1 Aluminum Association and Aluminum Extruders Council
[6] Asboell K, Jensrud O, Reiso O and Jacobsen D 1996 *Extrudability and Mechanical Properties of Some 7xxx-Series Alloys* Proc. Sixth International Aluminum Extrusion Technology Seminar Vol 2 Aluminum Association and Aluminum Extruders Council
[7] https://www.williamsonir.com/wp-content/uploads/2018/
[8] http://www.mech4study.com/2017/04/extrusion-process
[9] https://www.williamsonir.com/wp-content/uploads/2018/04/Aluminum_Extrusion-Application
[10] Saha P K 2000 *Aluminum Extrusion Technology* http://www.asm-intl.org ISBN 0-87170-644-X pp.153
[11] Wilm A 1911 *Metall* Vol 225 (No. 8)
[12] Dix E H 1945 *Trans. AIME* Vol 130 (No. 35)