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A REVIEW ON DEFORMATION BEHAVIOR OF EXTRUDED AA6060 AND AA6063 ALLOYS

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Abstract

The 6xxx series aluminium (Al) alloys are used for several applications in building, automobile, and aerospace industries. The alloys are generally processed using hot extrusion. The commercialized AA6060 alloy is suitable for various surface and heat treatments and exhibits excellent properties like formability, corrosion resistance etc. The temperature used for hot extrusion of AA6060 alloy lies typically in between 400-500 °C. It is a wrought alloy of Al-Mg-Si family and shares a close relationship with alloy AA6063 than to AA6061. The differently shaped profiles employed for diverse applications are fabricated by AA6063 alloy using extrusion. The chemical composition of AA6063 alloy comprises marginally higher Mg concentration than AA6060 alloy. Glazing bars, window frames, and windscreen sections are some typical applications of the AA6060 alloy. Various extrusion techniques are used for AA6060 and AA6063 alloys. No extrusion technique entirely utilizes the potential of strain hardening. Therefore, the present study is focused on the advantages and disadvantages of various extrusion techniques used for the alloys. A comparison of extrusion techniques suitable for AA6060 and AA6063 alloys was also focused. The comparison of the extrusion behaviour of AA6060 and AA6063 alloys with the results described in the literature was also accomplished.

***Keywords*:** Aluminium alloy, Extrusion, Strain hardening, Formability, Aging temperature.

1. Introduction

Aluminium is a third most commonly found material on the earth crust, or it is more recyclable than many other materials. It has properties like high specific strength, nonmagnetic behaviour, and rust or corrosion free nature. Apart from its lightweight, this property makes it an attractive material for several applications in aerospace, automotive and electronics industries. In the automotive and aerospace industry, flat sheets are used to fabricate intricate design and standalone profiles for several \ applications. Direct extrusion is a multitudinous process for making flat sheets or hollow profiles of aluminium alloys. Al-Mg-Si alloys are classified as 6xxx series alloys, and AA6060 and AA6063 alloys are most commonly used aluminium alloys of this series. These alloys are widely used because they have excellent strength to weight ratio, good formability, and good corrosion resistivity. Also, they can easily be welded and machined. The processing of 6xxx series is not usually done by casting thereby extrusion is an imperative processing method for 6xxx series alloys. As per the product requirement, various types of extrusion processes such as direct, indirect, cold, warm, hot and twist extrusion are employed for mechanical properties enhancement. This is a severe plastic deformation process and involves recrystallization, strain hardening, and grain refinement steps resulted in enhanced mechanical properties.

This article aims to provide recent development in the extrusion process for AA6060 and AA6063 alloys. The effect of various parametric variations was also included. This is an attempt to render a systematic review of the work carried out by several authors in the field of extrusion behaviour of AA6060 and AA6063 alloys.

2. Material Description

AA6060 is a wrought Al-Mg-Si alloy. Its chemical composition is closely related to AA6063 alloy. These two alloys are distinguishable because of the magnesium contents. As already mentioned in the previous section, the main forming techniques of the alloys are extrusion, forging and rolling. It is challenging to work hardened however it can be heat treatable to get good strength (Marks and Baumeister, 1923). The chemical compositions of these alloys are shown in Table 1.

3. Extrusion

The main reason for having plastic deformation in a metallic material is the creation and movement of dislocations. Extrusion is a process by which metallic materials are plastically deformed. In this process, a metal billet is pushed through a smaller die-opening. The cross-sectional area of die-opening is lower than the original billet size. This operation is carried out at a different temperature as per the necessity or applications. If the extrusion is performed at a temperature which is approximately 75% higher than the melting point of extruded metal, it is termed as hot extrusion. However, extrusion performed at ambient or slightly higher temperature than ambient is known as cold extrusion. Hot extrusion temperature for aluminium alloys is commonly lying in between 350-500°C. In the hot extrusion of Al alloys, a preheated billet is forced to move via a required shaped die. As the force is applied to the ram, a compression action will take place on the billet during the movement through the profile opening. The exiting speed from the profile cross-section is ranged in between 5-100 m/min. The extruded Al billet was cooled by air cooling or by water quenching. The quality of extruded Al predominantly depends on parameters like extrusion speed, room temperature, material type, billet size, wear of die and lubrication along with friction factors (Saha, 2000).

Table 1. Chemical compositions of AA6060 and AA6063

Alloy	Fe	Cu (max)	Si	Mn (max)	Mg	Zn)	Ti (max)	Cr	Al
AA 6060	0.1-0.03	0.1	0.3-0.6	0.1	0.35-0.6	0.15	0.1	0.05	Balance
AA 6063	0.35	0.1	0.2-0.6	0.1	0.45-0.9	0.1	0.1	0.1	Balance

4. Effect of Extrusion in AA6060 Alloy

AA6060 alloy is a heat treatable aluminium alloy which possesses adequate strength, corrosion resistance, weldability and formability. For AA6060 aluminium alloy, hot extrusion is a well-established industrial forming process by which complex shapes can be produced. Berndt et al. (Berndt et al., 2017) performed a cold (at ambient temperature), and warm (at 170 °C) extrusion on age hardened AA6060 Al alloy. In both the processes, the centre region of the extrudates consists of coarse and elongated grains whereas, surface layers comprise ultrafine grains. Despite this microstructural variation from the surface to centre, the reported mechanical properties are almost homogeneous. Table 2 consists of average values (surface to center) of mechanical properties taken from reference (Berndt et al., 2017; Westermann et al., 2016)

Table 2. Mechanical properties of extruded AA6060 alloys

Extrusion Type	Condition	Average Hardness	Average UTS (MPa)	Average % Elongation	Ref
Cold Extrusion	Extruded at Room Temperature	90.8 ±3.6	306.7±11.7	2.7±0.16	(Berndt et al., 2017)
Warm Extrusion	Extruded at 170 °C	109.1±2.5	356.6±13.4	4.3±0.29	(Berndt et al., 2017)
Hot Extrusion	Extruded at 475 °C	-	354.6	89.0	(Westermann et al., 2016)

From the Table 2, it can be easily noticed that the mechanical properties of warm extruded specimens are better than the cold extruded specimens. The extrusion at an ageing temperature ensures the homogeneous and dense distribution of fine particles resulted in improved strength and hardness (Kolar et al., 2012). The ageing temperature of AA6060 alloy is 170 °C. That is why the warm extrusion of AA6060 is exhibiting better mechanical properties than the cold extrusion. Westermann et al. (Westermann et al., 2016) studied the work hardening behaviour of as-cast, hot extruded (at 475 °C), and cold rolled AA6060 alloy. At larger strains, extruded material presented lower work hardening than other two due to the presence of prominent cube texture. Owing to the breakdown and redistribution of primary particles, high ductility was discovered in extruded AA6060 alloy.

Sanabria et al. (Sanabria et al., 2014) studied the behaviour of a friction boundary layer of the AA6060 alloy under extrusion conditions. They put a special emphasis on grain growth and hardness evolution in the surface layer under elevated temperature and severe shear deformation. Sliding speed and temperature were the input parameters during the study. Authors measured the axial friction force under sticking conditions on the specimen of initial diameter 7.8 mm and 10.5 mm length. High and low shear zones were created as a result of sticking friction. There was a transition of highly deformed and non-deformed grain due to which low shear zones was difficult to delimit. Due to successive compression and tension, plastic deformation occurred on the surface of the extrudate specimen. Sliding speed was found to be responsible for high shear zone and increases with the increment in sliding speed. The grain size evolution in the shear zone indicated that the grains were finer when sliding speed was high whereas, bigger grains at high temperature. Schikorra et al. (Schikorra et al., 2007) investigated the flow and friction behaviour of AA6060 billet towards container wall. The extrusion process was carried out at 430 °C. A perfect sticking condition was observed until a force was not applied on the billet. Ram speed had almost no effect on the wall friction. A calibrated frictional index diagram was proposed. As per the diagram, the total sticking of the billet would take place if the frictional index is 1. Sliding will be started when the frictional index is below 1.

Schikkora et al. (Schikorra et al., 2008) in their another study proposed a model to predict the extruded microstructure of AA6060 aluminium alloy. The results obtained from the model were also correlated with the experimentally obtained extruded microstructure. They observed an excellent agreement between simulated as well as experimental extruded microstructure of AA6060 alloy.

6. Effect of Extrusion in AA6063 Alloy

AA6063 alloy is another popular aluminium alloy which is frequently used to fabricate shaped profile using extrusion. Aydi et al. (Aydi et al., 2015) performed hot extrusion on AA6063-T5 alloy at 480 °C temperature. After extrusion, the air-cooled profile was aged at 185 °C. All the aged specimens were exhibited better mechanical properties than the quenched samples. They also observed negligible anisotropy in extruded AA6063-T5 alloy. They found that the strength and hardness of the aged sample of AA6063 alloys were high, while ductility in the quenched sample was better than the aged one. Pinter and El Mehtedi (Pinter and El Mehtedi, 2012) worked on hot workability of AA6063, AA6005 and AA7020 alloys using hot torsion tests (twist extrusion). They found improved ductility in AA6063 alloy in all investigated parameters. Zhao et al. (Zhao et al., 2013) studied the effect of deformation speed on the properties of extruded AA6063 alloy. A continuous extrusion process was adopted, and the extruded parts were subjected to water quenching and artificial ageing. They observed the best mechanical properties when extrusion wheel was rotating at a speed of 1.04 rad/s. At this speed the grain size of the extruded AA6063 alloy was the smallest, resulting in excellent mechanical properties. Karaby et al. (Karabay et al., 2003, p. 6063) studied the influence of extrusion ratio (ER) on mechanical properties of AA6063 alloy. They observed that with the increase of ER hardness and UTS was increasing, whereas, percentage elongation decreasing. Jayaseelan et al. (Jayaseelan and Kalaichelvan, 2014) studied the effect of lubrication on the extrusion process for AA6063 alloy. Using graphite as a lubricant, friction factor was found lower compared to other lubricants, which resulted in reduced extrusion load. This is because the graphite has self-lubricating properties and it can last up to 1000°C temperature (Bakhshi-Jooybari, 2002; Li et al., 2001). Lee et al. (Lee et al., 2006) studied the effect of various parameters on the deformation behaviour of AA6063 alloy in radial-forward extrusion technique. The parameters considered by them are the diameter of the mandrel, the radius of the punch nose/deflection corner, width of annular direction gap, and frictional forces. Among all the parameters, the value of deflection corner radius is affecting the requirement of maximum force predominantly.

Table 3. Mechanical properties of extruded AA6063 alloys

Extrusion Type	Condition	Average Hardness	Average UTS (MPa)	Average % Elongation	Ref
Cold Extrusion	Extruded at Room Temperature	79.5 HB	224	13.1	(Zhao et al., 2013)
Hot Extrusion	Extruded at 480 °C	70.3± 0.9 HV	219.0± 4.0	13.0	(Aydi et al., 2015)

Die lines are a serious surface defect usually noticed on the extruded aluminium alloys especially in AA6063 alloy. They appeared on the surface when the die operates in a choked condition. These die-lines not only hamper the aesthetic look of the part but also alter its mechanical properties to some extent. Clode and Sheppard (Clode and Sheppard, 1990) studied the appearance of die lines on the extruded AA6063 alloy surface and suggested optimum parameters to minimize the defect.

5. Use of Hot Extrusion for Recycling of Aluminium Alloy Scrap

In the manufacturing industry, the highest energy is consumed in the metal extraction and metal recycling process. Excessive energy consumption leads to higher emission of harmful gases, and the problem of global warming begins to take a vivid form. It is difficult to control the energy used in the process of metal extraction, but using innovative methods can reduce the energy consumption in metal recycling. Using hot extrusion, aluminium chips can be recycled using less power. Tekkaya et al. (Tekkaya et al., 2009) worked on the reusability of AA6060 scraps (milling and turning chips) using direct hot extrusion method. This method is useful when chips of the same kind of alloy, e.g. AA6060 alloy are employed. Chip geometries and production history have minimal impact on final quality of extrudate. They also suggested that the process will be beneficial for composite production as well. Surface quality, yield strength, cutting and machining properties of the extrudates is comparable with the as-cast billets. Seam weld lines were observed in the extruded AA6060 alloy. However, pores and inclusions at grain boundaries were absent. Güley et al. (Güley et al., 2013) also used hot extrusion method to recycle the AA6060 chips. This solid-state recycling of aluminium alloy scraps needed lower energy consumption than the conventional recycling methods (remelting). They used two different die design, i.e. flat-faced and porthole die for producing solid aluminium alloy profiles from chips. The temperature used for the hot extrusion was 500 °C. They found that the chips were welded flawlessly in porthole die than the flat-faced die. Solid state welding of the chips occurs when the imposed shear deformation is able to demolish the brittle oxide layer on the surface of the chips. Owing to that 80% higher ductility was reported for the porthole die extrudate than the flat-faced die. Haase and Tekkaya (Haase and Tekkaya, 2015) investigate the conversion possibility of machining scrap into a finished product using stepwise hot and cold extrusion. Fat-face and integrated-equal channel angular pressing (iECAP die) die were used for the extrusion purpose. They found excellent mechanical properties of the material extruded by iECAP die.

7. Conclusion

In this article, a review on the research state of extruded AA6060 and AA6063 alloys is presented. From the study, the following conclusions are made.

In AA6060 alloy, improved hardness and strength were reported for warm extrusion technique. This was imperative due to break up and homogeneous redistribution of primary particles. High shear zones were created owing to high sliding speed. Finer grains were noticed when sliding speed was higher. On the other hand, high temperature leads to bigger grains. Friction index diagram is a powerful tool to decide frictional index for extrusion. Sliding will take place only when the frictional index is below 1. In case of AA6063 alloy, strength and hardness of the aged AA6063 alloy were better than quenched specimens. It is also reported that the extrusion ratio has a greater impact on the hardness and strength on extruded AA6063 alloy. Higher ER leads to higher hardness and strength but lower ductility. Hot extrusion is also considered as a prominent technique to recycle the chips and scraps of aluminium alloys. It was reported that the chip geometries has minimal impact on final quality of extrudate. Different die designs have a different effect on the welding tendency of chips. Porthole and iECAP type die greatly stimulate the solid state welding of the chips resulted in better mechanical properties.

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