Bulletin of Materials Science & Metallurgy

Periodical Scientific Journal of UCTEA Chamber of Metallurgical and Materials Engineers

Volume 1, Issue 3, 2024, Pages 16-19 Received: 06 December 2024 Accepted: 25 December 2024

https://doi.org/10.70342/UKTF5630

Research Article

Investigation of the Effect of Thermo-Mechanical Processing Orientation on the Final Material Performance in 6xxx Aluminium Alloys Produced With High Recycling Rates

Zeynep Tutku Ozen[a]*, Irem Yaren Siyah[a], Ilyas Artunc Sari[a], Melih Caylak[a], Gorkem Ozcelik[a], Burak Kardesler[a], Ibrahim Bat[a]

[a] ASAS Aluminyum A.S., Turkiye

*Corresponding author’s email: tutku.ozen@asastr.com

Abstract

Recycling of aluminium alloys is crucial due to its effects on environment, economy and social situations. It is also a popular research topic for aluminium producers and aluminium end users like automotive industry due to its tremendous effects on final carbon equivalent value and price. This scientific study emphasizes the critical importance of recycling in alloys used in the automotive sector, investigating the effects of thermo-mechanical processing orientation on the final material performance of 6XXX aluminium alloys with high recycling rates. Specifically, materials obtained using high recycling rates on 6063 and 6082 alloys produced for the automotive industry have been examined. The study aims to evaluate the mechanical properties of materials under thermal load through methods such as anisotropic strength correlations and bake-paint testing. The central focus of the study is to establish correlations between mechanical properties in different orientations based on thermal inputs. Data obtained through mechanical tests and bake paint tests conducted at 0, 45, and 90-degree orientations to extrusion direction play a crucial role in determining the material's performance. The findings contribute to our understanding of the impact of 6XXX aluminium alloys produced with high recycling rates on the final material performance in industrial applications.

Keywords

Recycling; Anisotropy; Aluminium Alloys, Thermo-Mechanical Properties

1. Introduction

Recycling of aluminium alloys has great importance due to its environmental, economic, and social impacts. Recycling conserves natural resources, saves energy, and lowers the carbon footprint. Consequently, advancing and implementing recycling techniques is a vital research focus for aluminium alloy producers and end users [1].

The automotive industry is one of the biggest industries that is in the use of recycled aluminium alloys due to its demand for lightweight and strong materials with low carbon footprint amounts. This demand both increases the performance of vehicles and provides environmental benefits by improving fuel efficiency. 6XXX series aluminium alloys, especially 6063 and 6082 aluminium alloys, are widely used in automotive applications due to their excellent mechanical properties and corrosion resistance [2]. However, studies are continuing to examine the effects of these alloys produced with high recycling rates on the final material performance [3].

Aluminium alloys produced with increased recycling content may not exhibit the same properties as alloys produced with primary contents even their similar nominal chemical compositions. This discrepancy arises from the mixing of scraps, the potential presence of impurity elements, and residual oxide inclusions. These inclusions can form intermetallic phases of varying nature, whose size, morphology, and distribution can significantly influence the alloy's physical and mechanical properties [4].

According to relevant studies such as [4,5], it can be noticed that recycling content increase both harm and benefit the final properties of the aluminium alloys. Bruschi et al. have studied machinability and mechanical properties of recycled and primary aluminium alloys. They have find that, increased recycling content may cause ductility decrease due to Fe-rich intermetallic [4]. Ouyang et al. have studied enhancing joining mechanical properties. They have come up with following correct strategy to recycle waste sheets to enhance the joining mechanical properties of aluminium alloys experimentally proven to be useful. In addition, it has the effect of reducing the joint bulge height and improving joint aesthetics [5].

This study aims to investigate the effects of 6XXX series aluminium alloys produced with high recycling rates on the final material performance depending on the thermo-mechanical processing orientation. Mainly, this research on 6063 and 6082 aluminium alloys produced for the automotive industry uses methods such as anisotropic strength correlations and bake-paint tests to evaluate the mechanical properties of the materials under thermal load.

Anisotropy behavior of the alloys are investigated to get an idea over the thermo-mechanical process effects with respect to process direction of the profiles. Different specimens are prepared and subjected to tensile testing with perpendicular, diagonal and parallel directions to extrusion. Bake-Paint test is performed to determine the changes in mechanical properties of parts produced in the automotive industry after post-painting process [6].

Mechanical tests and bake-paint tests at different orientations (0, 45, and 90 degrees) to determine the performance of the material are conducted.

In this study effects on the final material performance of 6XXX series aluminium alloys produced with high recycling rates in industrial applications depend on the thermo-mechanical processing orientation have been discussed. The results obtained aim to increase the use potential of recycled aluminium alloys in various industrial applications, especially in the automotive sector.

2. Materials and Methods

In this paper, the experimental procedures illustrated on Figure 1 have been applied to investigate the effects of temperature and orientation effects on high recycling ratio 6063 and 6082 alloys. After profile production, tensile tests and bake paint tests have been applied to the samples.

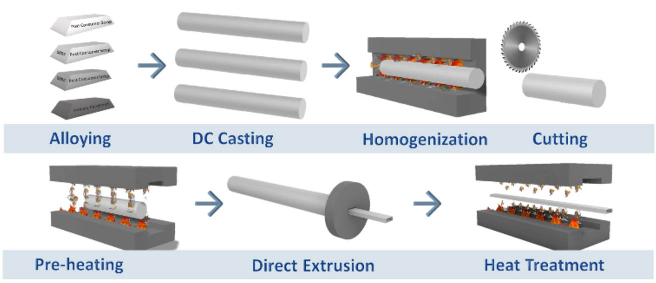

Figure 1. Experimental setup for analyzing high recycling ratio aluminium alloys.

2.1. Materials

To begin with the protype profile production with 6082 and 6063 alloys ASAS's prototype casting facility has been used with 500 kg capacity. Used materials ratios have been showed at Table 1.

Table 1. Composition of raw materials used in as-cast alloy production.

	6063	6082
Post-Consumer Scrap	16%	34%
6063 Post Consumer Scrap	54%	12%
6063 Post Consumer Scrap	-	44%
Primary Feedstock	30%	10%

After casting 14 inches extrusion billets they have been investigated by optical emission spectroscopy (OES) analysis to validate alloy composition according to the TS-EN 573-3 [7] chemical composition standard. Table 2 demonstrates the OES results after casting.

Table 2. OES results for the chemical composition of as-cast 6XXX alloys.

	Content wt. %						
	Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**
6063	0,55	0,23	0,02	0,06	0,55	0,01	0,05
6082	0,88	0,25	0,75	0,62	0,86	0,06	0

Casted billets have been tested by ultrasonic control in order to determine their suitability for extrusion with respect to ASTM 594-9 Class A [8]. Acceptable billets have been homogenized in ASAS's homogenization furnace. 6063 alloys have been homogenized by heating up to 570°C for 6 hours and keeping at 570°C for 6 hours. 6082 alloys have been homogenized by heating up to 555°C for 6 hours and keeping at 555°C for 6 hours. Homogenized billets have been extruded at ASAS's 62 MN extrusion press which is the biggest extrusion press in Turkey. 6063 billets have been extruded with 556°C exit temperature and 7,5 mm/s speed. 6082 billets have been extruded with 533°C exit temperature and 5,1 mm/s speed.

Extruded profiles have been cut to the length to get $A30_{mm}$ tensile test specimens. In order to carry out anisotropy analysis specimens that are parallel to extrusion direction (0°), specimens that are diagonal to the extrusion direction (45°) and specimens that are perpendicular to the extrusion direction (90°) have been prepared. Both anisotropy and bake paint tensile tests are carried out at 250 kN Zwick Tensile Testing Device with respect to EN ISO 6892-1:2020 [9] standard. Bake paint tests are applied to the specimens after exposing them to 180°C for 20 minutes.

3. Results and Discussion

In the analysis of anisotropy and bake paint tests, 5 samples have been tested. Their average values and standard deviations are stated as results. Anisotropy analysis results have been showed at the Table 3.

Table 3. Anisotropy analysis results at different orientations.

	Angle	Rp0,2 [MPa]	σ	Rm [MPa]	σ	A (%)	σ
6063	0°	244	4,4	270	4,3	13,6	4,1
	45°	238	4,2	257	4	9,66	4,1
	90°	222	3,4	258	3,2	11,23	3,3
6082	0°	267	4,3	293	4,1	15,3	4
	45°	264	2,7	287	2,6	9,1	2,8
	90°	276	2,4	300	2,4	9,25	2,3

According to the results yield strengths of 6063 alloys decrease from parallel to perpendicular direction. While yield strength of the 6082 alloys increases from the direction of 0° to 90° while it shows lowest value at 45°.

Tensile strength of the alloys showed similar behavior with yield strengths. When the testing direction is diagonal and perpendicular to the extrusion direction, tensile strengths of the 6063 alloys 4-5% lower than the 0°. This behavior is primarily due to the alignment of grains and precipitates along the extrusion direction. Highest tensile strength values are achieved with testing in 0° angle for 6063 alloys. 6082 alloys highest strength seen at 90° angle. The tensile strength of this alloys has decreased from 0° to 45°. The unexpected result of 6082 alloy can be explained by its high alloying rates and Cu elements has created Al_2Cu precipitates which caused directional strengthening [10].

Elongation percentage of the alloys have the highest ratios comparing the other directions for both alloys at 0°. In the 45° specimen for 6063 alloy, elongation decreased more than 30% comparing to 0°. The sharp decrease in elongation at 45° for 6063 alloy is attributed to the anisotropic distribution of second-phase particles, which act as stress concentrators and reduce plasticity. In the case of 6082 alloy, elongation values of 45° and 90° are very similar, reflecting a more uniform distribution of strengthening phases.

From the results of anisotropy analyses it can be discussed that, aluminium extrusion alloys should be designed with respect to their expected properties and extrusion directions should be arranged upon this theory. When high strength is crucial for final applications, 90° results are better for 6082 alloy while 0° better for 6063 alloy. When high elongation is important for final application, 0° results are better. According to this knowledge one can select or design aluminium extrusion profiles with respect to end users' criteria.

Table 4. Bake-paint test results for mechanical properties.

	Rp0,2 [MPa]	σ	Rm [MPa]	σ	A (%)	σ
6063	258	3,1	274	3	12,2	3,2
6082	279	2,9	306	2,9	15	3,1

According to bake paint results it can be noticed that yield and tensile strength of both 6063 and 6082 alloys have been increased. However, elongations of both alloys have been slightly decreased. This process promotes the formation of fine, coherent precipitates (e.g., Mg_2Si in 6063 and Al_2Cu in 6082), which impede dislocation motion and enhance strength. The more significant increase in 6082 alloy can be attributed to its higher alloying content, which provides a greater potential for precipitation strengthening. The decrease in elongation after the bake-paint test is a typical consequence of increased precipitation density. While the precipitates improve strength, they also reduce the material's ability to deform plastically, leading to lower elongation. According to these results it can be discussed that the thermal treatment applied before tensile test section of bake paint test has increased the strength of the alloys. As characteristics of aluminium alloys, one can notice that, these alloys have converged to the peak age aging condition.

4. Conclusion

This study demonstrates the critical influence of thermo-mechanical processing orientation on the performance of 6XXX series aluminium alloys with high recycling rates, particularly in automotive applications. The anisotropy analysis revealed that mechanical properties such as yield strength, tensile strength, and elongation vary significantly with orientation. For 6063 alloy, the highest yield and tensile strength were observed along the extrusion direction (0°), whereas the 6082 alloy exhibited superior properties at the perpendicular direction (90°). These variations are excepted to be caused from distinct alloying elements and their influence on precipitation behavior, particularly the formation of Al_2Cu precipitates in 6082 alloy.

The bake-paint tests confirmed a notable increase in yield and tensile strength post-thermal treatment, accompanied by a slight reduction in elongation. This is consistent with the alloys reaching peak age-hardening conditions. Yield strength increased by approximately 6% for both alloys after bake-paint testing. Tensile strength changes ranged between 4% and 7%, depending on the orientation and alloy type. Elongation decreased by 10%-15% after thermal treatment.

As a conclusion, material properties are highly related to their designs and processing. For automotive end users, 6082 alloys can be selected for high strength requirements such as battery box. However, 6063 alloy can be selected for moderate strength and elongation requirements. As engineering is highly related to optimization, investigating anisotropy behaviour of the metals serves best for this approach.

Authors' Contributions

Conceptualization: Zeynep Tutku Ozen, İrem Yaren Siyah, İbrahim Bat; Methodology: Zeynep Tutku Ozen, İlyas Artunç Sarı, Burak Kardeşler, Melih Çaylak; Investigation: İrem Yaren Siyah, Zeynep Tutku Özen, İbrahim Bat, İlyas Artunç Sarı, Burak Kardeşler, Melih Çaylak; Validation: Zeynep Tutku Özen, Görkem Özçelik, İrem Yaren Siyah, İlyas Artunç Sarı, İbrahim Bat, Burak Kardeşler; Writing—original draft preparation: Zeynep Tutku Özen, İrem Yaren Siyah, İlyas Artunç Sarı; Writing—review and editing: Zeynep Tutku Özen, İrem Yaren Siyah, İlyas Artunç Sarı; Supervision: Zeynep Tutku Özen, Görkem Özçelik.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This paper has been studied in a Horizon 2020 project called SALEMA with grant agreement number of 101003785. ASAS Aluminyum R&D department and SALEMA project partners are acknowledged due to their high effort and great contributions.

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