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A STUDY ON RECYCLABILITY OF AlSi7Mg0.3 MACHINING WASTE

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Abstract: Aluminium products are widely used in the automotive industry. One of the important aluminium products in the automotive is wheel production. Turkish wheel production is expected to reach 360000 tons in 2025. The wheels are produced by Low-Pressure Die Casting at the first stage and the machining process in CNC machines is used to create the final form. A significant amount of machining waste (swarf, turnings, and chips) is created during the machining and the importance of secondary aluminium has been increasing due to environmental and economic concerns. This study focuses on the recycling of AlSi7Mg0.3 cast alloy machining waste. The turnings were sorted into two size fractions and remelted separately under a salt flux in a resistance heating furnace. Two different salt mixtures with different melting points and different salt factors were studied in this work. Metal yield and coagulation yield after remelting were discussed.

Keywords: Recycling, Aluminium, Machining waste, Remelting

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1. Introduction

Primary production of aluminium has been increasing over the last decades because of the increase in aluminium consumption in different sectors such as transportation, engineering, and packaging. Automotive industry ranks first in its usage areas. Kelly et al. (2018) reported in 2018 that the amount of aluminium used per vehicle will increase by 39% in the next 10 years in North America. This rate was predicted as 32% for Europe. Considering the amount of aluminium consumption, recycling has gained importance to reduce the cost and conserve primary resources. In addition, recycling reduces the energy consumption and environmental impact caused by the primary aluminium production.

Automobile wheels, produced from aluminium alloy, represent an important portion of aluminium usage in the automotive industry (Das et al., 2007; The European Aluminium Association, 2021). Steel and aluminium alloys are the most used alloys in the automobile wheel industry, though aluminium alloy wheels are the most preferred wheel type today due to their low weight, high strength/weight ratio, and high corrosion resistance. These characteristics have made the aluminium competitive for a variety of applications (Kara et al., 2017).

Gravity casting was prevalent to manufacture a wheel in the past. However, plenty of factories around the globe has been producing wheels for years by low-pressure die casting. It is made as a single component because it gives the wheel a functional level of safety (Kara et al., 2017). AlSi7Mg0.3 aluminium alloy, also named A356, is used mainly as a raw material in the manufacture of the wheels machining is an operation that carried out by CNC (Computer Aided Numerical Control) turning and milling to meet dimensional tolerances and final shaping the cast wheel. During this shaping process, chips are generated.

Recyclability of the aluminium gives several advantages upon process flow in mass production. Chips that formed during the machining, can be used in a foundry as well as ingots and scraps after preliminary treatments including degreasing. Recyclability and its efficiency have been studying consistently. Preparation and categorization of the scrap as well as the type of furnaces that melt the scrap must be taken into consideration to optimise the production chain. Because the quality and yield of molten scrap are essential factors that must be improved (Yan et al., 2005; Capuzzi et al., 2018). On top of that the waste form of trace elements such as titanium chip which uses generally for the purpose of decreasing the grain size in A356 alloy, can be added into the molten metal to alter transference efficiency (Ozer et al., 2021). The machining waste has usually a high specific surface area which might hinder both metal yield and coagulation efficiency. Thus, scrap melting in a specific salt can be an alternative to arise the recycling efficiency. Salt fluxes in the recycling of aluminium scrap decrease metal losses by preventing oxidation. In order to save energy, recycling takes place at a lower temperature with the help of a mixture of various salts. Majority of them are based on NaCl and KCl, but also fluorides such as cryolite or CaF_2 are commonly used to raise coagulation. Chloride-based salts do not react with molten metal (Tenerio et al., 2002; Milke et al., 2005; Capuzzi et al., 2018). Bolivar et al. (2009) investigated the feasibility of the salt melting method for the recovery of scrap aluminium as using less salt. Using 2% CaF_2 led to the highest recovery efficiency. Mixed salts at the ratios of 50-50% NaCl:KCl and 2% CaF_2 have used by salt melting and obtained 99.5% coagulation efficiency (Gökelma et al., 2019).

This study focuses to assess the recyclability of the aluminium alloy wheel chips, generated by machining, experimentally by remelting in different salt fluxes. The effects of size fraction, salt composition, and stirring on the recovery rate of AlSi7Mg0.3 alloy chips were investigated.

2. Materials and Methods

The machining waste of AlSi7Mg0.3 alloy, provided by "Cevher Alloy Wheels Co." was used for the experiments. CaF_2 (Sigma Aldrich), NaCl, and KCl (Isolab) salts with >99.5% of purity were used for the re-melting. A Sample Divider (Loyka, LNB 1613) was used for representative sampling. The scrap was divided into two size fractions (Figure 1.) namely -2 and +2 mm to study the effect of the surface area on remelting. The remelting experiments were performed in a chamber furnace (Protherm) in clay-bonded graphite crucibles coated with boron nitride. After remelting, metal and salt were separated by washing out the salt over a sieve and collected metal pieces were dried and weighed.

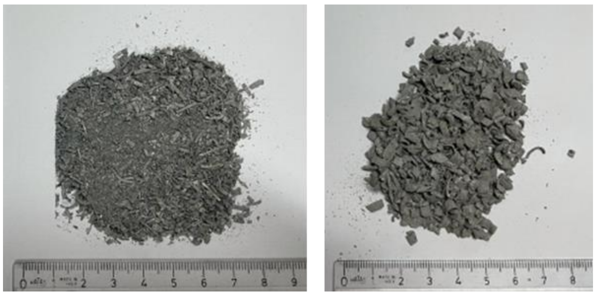

Figure 1. Machining waste of AlSi7Mg0.3 alloy in +2 and -2 mm size fractions.

Table 1 presents the parameters applied for all trials. Chloride (KCl/NaCl) ratio was changed as 30/70 and 50/50 as well as CaF_2 addition was varied as 2 and 3 wt.% to observe the effects on the yield and coagulation. Stirring was applied to some trials to observe the effect of mixing on the coalescence. Salt to scrap mass ratio was changed as 1 and 2 to study the amount of salt on the yield and coagulation. Coalescence efficiency (CE, Equation 1) was calculated by the ratio of biggest droplet to the entire metal collected after remelting. The metal yield (Equation 2) was calculated by the ratio of recovered metal amount to the amount of the scrap. The equations of coalescence efficiency and metal yield are given below:

$$\mathrm{CE} = \frac{m_{largest\ droplet}}{m_{total\ recovered\ Al}} \times 100 \quad (1)$$

$$\mathrm{Yield} = \frac{m_{total\ recovered\ Al}}{m_{scrap\ charge}} \times 100 \quad (2)$$

Thermo Gravimetric Analysis (TGA) was performed on +2 mm and -2 mm samples under pure oxygen to observe the oxidation behaviour as a function of temperature. The mass change was measured from 25 °C to 810 °C with a heating rate of 10K/min.

Table 1. Experimental parameters

Exp. #	Size of the Chips (mm)	Chloride mix		CaF_2 (wt.% in the flux)	mSalt/mAl	Stirring
1	2	30% KCl	70% NaCl	2	1	No
2					1	
3	-2				1	
4					2	
5				3	2	
6				2	1	Yes
7					2	
8		50% KCl	50% NaCl		1	
9					2	
10				3	1	No
11				2	1	
12					2	

3. Results and Discussion

Figure 2 presents the mass change of the samples as a function of temperature increased by 10 K/min. Approximately 3.5 mg of sample was used for both analyses. Both fractions showed approximately 1 wt.% of mass loss until 300 °C which might be due to the combustion of the lubricant rest on the samples. The oxidation started to increase clearly at around 360 °C and 410 °C and the total mass gain (after combustion of the lubrications) was 4.5 wt.% and 2.5 wt.% for – and + fractions respectively. Although the sample composition is the same the oxidation rate is affected by the surface area.

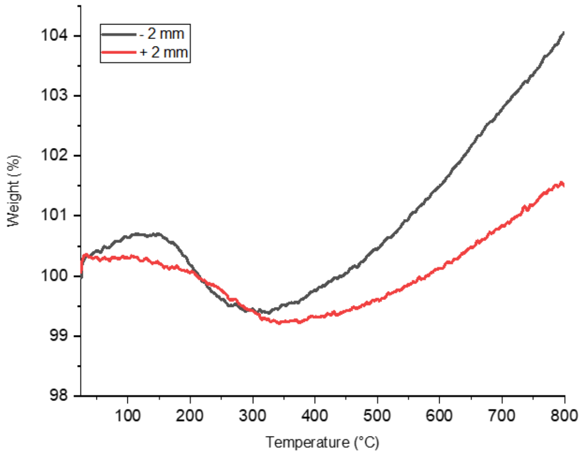

Figure 2. Thermo-gravimetric analysis -2 and +2 mm AlSi7Mg0.3 machining waste under pure O_2.

Two pre-trials were conducted without a salt flux to observe the remelting behaviour of the machining waste in the absence of salt. No melt was obtained at 800 °C for both fractions. This indicates that the high specific surface area of the samples hinders the molten aluminium to break the oxide layer and coagulate. Therefore, the rest of the trials were performed under a salt flux (NaCl, KCl, and CaF_2).

Figure 3. presents the metal yield and coagulation results after remelting the machining waste under the salt fluxes. The first seven trials were remelted by using a chloride mix 70:30 NaCl:KCl and CaF_2 as the coagulation agent. The results of +2 mm fraction are shown as 1st and 2nd trials in the diagram. The metal yield and coagulation results were 98.4% ±0.4 and 9.7% ±0.3 respectively. These results indicate that the low oxide/metal ratio allows the salt flux to remove the oxide layer easily even without any stirring. In addition, the salt amount used in the trials was enough to avoid further oxidation during remelting.

The parameters of the third trial were same as the 1st and 2nd trials except the size of the chips. -2 mm fraction was used in this trial which showed almost 20% of metal loss and no coagulation. To investigate the effect of the salt, the salt amount was doubled in the fourth trial which did not change the metal yield but increased the coagulation to 10.3%. The amount of CaF_2 was increased to 3% in the fifth trial to observe the effect of fluoride in comparison with the 4th trial where CaF_2 was only 2%. With this increase, the metal losses increased to 30% and 4.6% of coagulation was observed. The lower yield might be caused by the increasing melting point of the salt flux with increasing CaF_2 content as shown in the calculation of Milke et al. (2005) (Figure 4.) which was in line with the measurements of Bukhalova and Bergman (1955).

A manual stirring was applied for the sixth and seventh trials and the salt/scrap ratio was increased from one to two in the seventh trial. Stirring increased both the metal yield and coagulation significantly and increasing the salt/metal ratio served an additional 2-4% increase which promoted the protection of the melt and the metal-salt interactions. Only the NaCl:KCl ratio was changed in the eighth and ninth trials and 50:50 ratio was applied. The change in the chloride mix increased the metal yield and coagulation. Coleman and Lacy reported that the binary melting point of 50:50 mix is 645 °C and the melting point increased to 700 °C when NaCl concentration increases to 70wt.%.

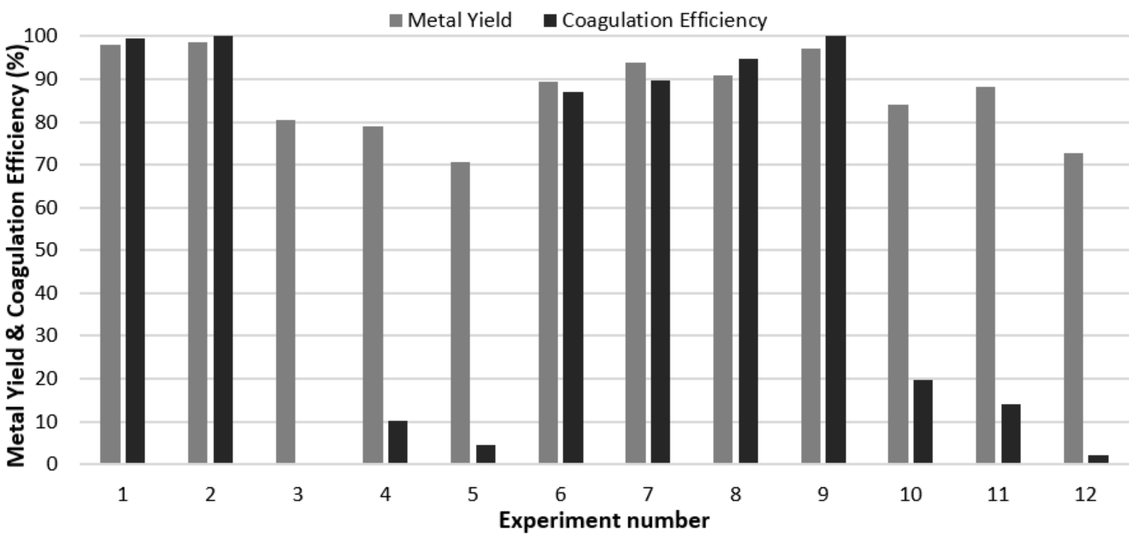

Figure 3. Metal yield and coagulation efficiency results of the machining waste of AlSi7Mg0.3 alloy.

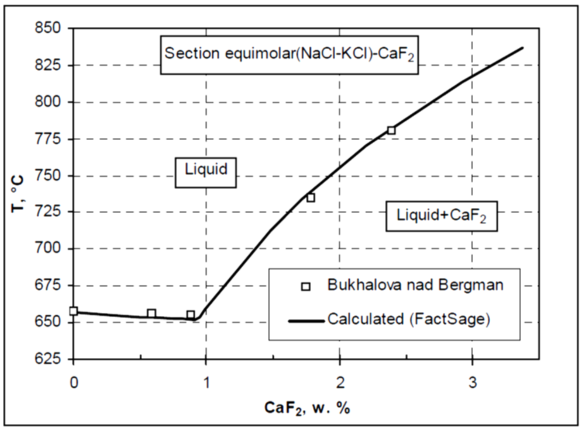

Figure 4. The ternary system NaCl.KCl-CaF_2 calculated by Milke et al. (2005).

The melting point difference is one of the positive influences on recycling which decreases the oxidation of the scrap since liquid salt forms in lower temperature before aluminium oxidizes too much. In addition, Bolivar and Friedrich reported that 50:50 ratio has a higher CaF_2 solubility than the 70:30. This solubility difference might have promoted the removal of oxides and coagulation. As observed in all trials, increasing the salt/scrap ratio increased both the metal yield and coagulation (Coleman et al., 1967; Bolivar et al., 2009).

In the last trials no stirring was applied and CaF_2 was changed as 2 and 3wt.%. A significant decrease in coagulation was observed without stirring. Although the coagulation was very low, 2 wt.% CaF_2 resulted in spherical droplets while 3 wt.% resulted in irregular droplets.

4. Conclusion

Scraps with low surface area needs to be stirred for an acceptable coagulation rate which points out the necessity of rotary furnaces.

50:50 NaCl:KCl ratio promotes the coagulation scraps with high surface area better due to the higher CaF_2 dissolution.

For a higher recycling efficiency and saving the resources, large and fine size fractions of machining wastes should be treated separately.

Author Contributions

The percentage of the author contributions is present below. The author reviewed and approved final version of the manuscript.

	M.G.	R.Ö.T	A.Y.K	O.Ö.
C	100			
D	100			
S	100			
DCP	25	25	25	25
DAI	25	25	25	25
L		50	50	
W	50	10	30	10
CR	50			50
SR	50		50	
PM	100			
FA	100			

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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