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Investigation of the effect of liquid metal quality on feedability in the casting of A356 aluminum alloys

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ABSTRACT

The use of aluminum in the foundry industry is basically in two different ways, from ore and scrap materials. It is very advantageous to use aluminum as secondary ingots through recycling from scrap material due to the energy inputs generated in production. However, liquid metal quality is important in the use of secondary aluminum. Because, in order to produce quality parts, it is necessary to have it free from iron-containing intermetallic phases, bifilms such as dissolved hydrogen, and inclusions that may be present in aluminum. In cases where adequate cleaning cannot be performed, the casting properties affect the final product properties in many ways. In this study, the effect of changing scrap rate and liquid metal cleaning on the feedability of A356 aluminum casting alloy was investigated. The rotary degassing method was used in the liquid metal cleaning process. Castings were made into standardized permanent molds known as duck feet molds. It has been determined that the casting of the liquid metal with cleaning can be in high quality compared to without cleaning case. Additionaly, the increase in the amount of scrap in the castings without cleaning adversely affects the feedability.

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1. INTRODUCTION

Aluminum alloys are very important engineering materials due to their lightweight, high corrosion resistance, high electrical and thermal conductivity, high strength, and ductility. As a result, it is widely used in different applications in the automotive, aerospace, defense, aerospace industry, machinery manufacturing, and food industries [1]. The exploitation aluminum alloys is continuously increasing in automotive industry. Considering that the aluminum parts produced in Türkiye, predominantly for automotive sector, it has an important export revenue for Türkiye [2].

The raw materials required for aluminum production are basically supplied in two different ways. The first one is production from ore in which bauxite ore is mined and alumina is produced by Bayer Process. After this process, pure aluminum is obtained by applying an electrolysis process [3]. This method requires high energy input. In the second method based on recycling; the amount of energy required during recycling from scrap and aluminum production is comparatively low. The primary aluminum production process requires approximately 14500-17000 kWh of energy per ton of aluminum production. However, required energy amount during the production from scrap is almost 5% (~750 kWh) of the producing aluminum from ore [4]. Considering low energy consumption during scrap processing, the importance of recycling and secondary production increases even more [3-4]. However, the most important problem encountered in the use of secondary aluminum by recycling is the optimization of the liquid metal quality and the need for additional processes in the casting of scrap [5-7].

To produce high-quality aluminum castings, it is necessary to have it free from impurities such as hydrogen dissolved in liquid aluminum and its surface oxide from inclusions such as bifilm, which have various forms. Dissolved hydrogen in aluminum alloy, non-metallic oxide films, and some other inclusion elements such as C_l, and Fe can be classified as inclusions and impurities that negatively affect the liquid metal quality. The combination of hydrogen and non-metallic oxides has adverse effects on the microstructures and properties of the alloy. These impurities may cause the melt to lose its fluidity and create micro-porosity. They can adversely affect of part quality such as machinability, surface smoothness, mechanical, and particularly toughness and fatigue resistance [8-13]. Inappropriate liquid metal quality may cause the casting parts to be separated as scrap, as well as it adversely affect the loss of fluidity of the melt, the formation of micropores in the casting, cracks, machinability, and the mechanical properties of the casting [14-16]. Macro or microporosity defects that cannot be avoided in aluminum casting, can cause many negative effects on the product. It is

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known that these defects can yield low strength, decrease ductility, cause problems in leaking under pressure, and eventually cause restrictions in its use [11-17]. Thermal conditions, insufficient liquid metal cleaning, and hydrogen-induced casting defects are known to be the main sources of the low-quality problems in Al castings. Therefore, the removal of hydrogen and inclusions from the aluminum melt to increase the purity of the liquid metal, especially controlling the hydrogen content, is of great importance in the recycling and reuse of aluminum scrap castings and scrap parts [18-20]. On the other hand, it can greatly improve the performances and reliability of castings which is crucial for expanding recycling aluminum applications in aerospace structures and the automotive industry. In this context, studies and researches continue and many liquid metal cleaning processes are developed in the casting industry, from the use of inert gas to the use of tablets [5].

This study aims to examine the effect of liquid metal cleaning on feedability. In this context, the effect of cleaning on the feedability of A356 aluminum alloy was investigated experimentally by using a rotary-type degassing process at varying scrap rates.

2. EXPERIMENTAL

In the study, scrap with the same chemical composition of secondary alloy was used in varying proportions into the primary A356 aluminum ingot. The chemical composition of the A356 alloys used in the experiments is given in Table 1.

Table 1. Chemical composition of the alloys used in the current study (% wt.).

Alloy	*Fe*	*Si*	*Cu*	*Mn*	*Mg*	*Zn*	*Ni*	*Ti*	*Al*
Primary A356	0.20	6.60-7.40	0.02	0.03	0.30-0.45	0.04	0.02	-	Balance
Secondary Alloy	0.07	7.28	-	-	0.227	-	0.004	0.11	Balance

The melting process was carried out in an electric resistance furnace with a capacity of 8 kg of liquid aluminum and a power of 10 kW and in a SiC crucible. In melting, scrap A356 alloy was added to the primary A356 ingot at 5%, 10%, and 15% of the charge weight, respectively. In the casting experiments carried out without cleaning, the molten liquid metal was made ready for casting at 720 °C. In the casting experiments carried out upon cleaning, the rotary degassing process, whose schematic image is shown in Figure 1, was applied to the molten liquid metal for cleaning. In this process, nitrogen gas flow rate and rotor rotation speed parameters were adjusted to be 5 l/min and 300 rpm, respectively. The cleaned liquid metal was made ready for casting at 720 °C.

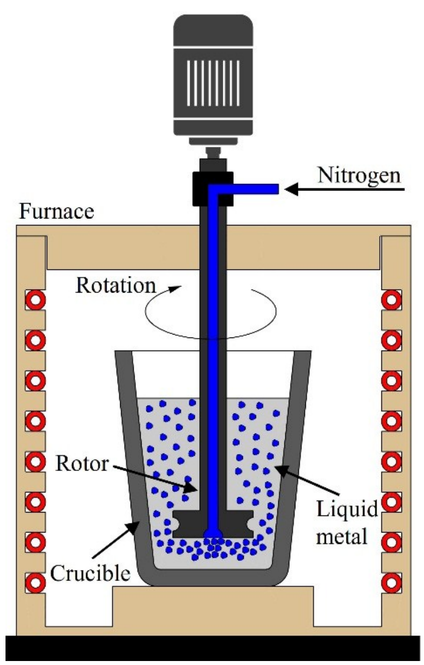

Fig. 1. Schematic view of the liquid metal cleaning process with rotary degassing.

After the melting process, the crucible filled with liquid metal was removed from the furnace, and slag was removed by scraping from the surface. After the A356 alloy was prepared in different scrap addition amounts, it was poured into the Duck foot permanent mold whose image and dimensions are given in Figure 2. The molds were heated up to 200 °C using a heating table before casting.

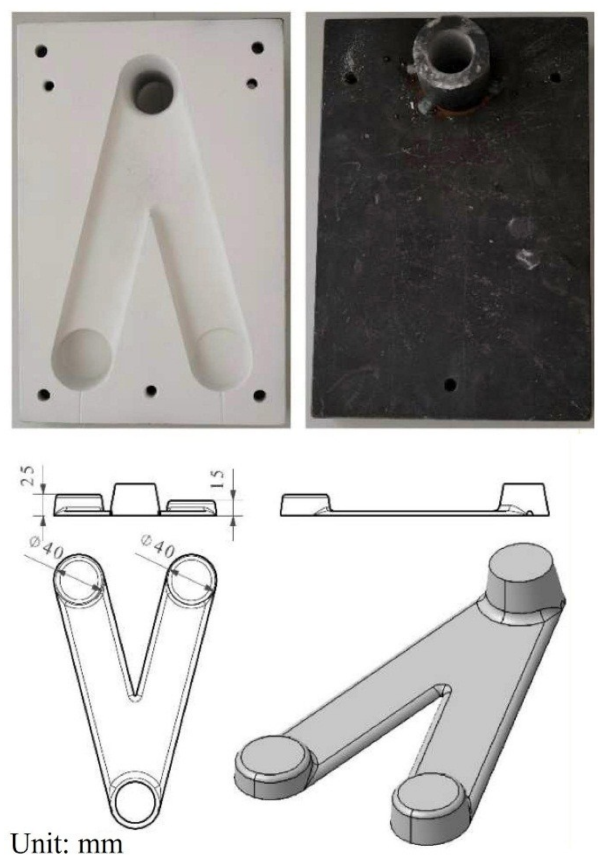

Fig. 2. Duck foot mold from different view, and its dimensions.

Using the % shrinkage mold with different section thicknesses shown in Figure 2, the relationship between the liquid metal quality and the % shrinkage was investigated. The relationship between % shrinkage and solidification time was also observed in mold cavities with 15 mm and 25 mm section thicknesses. Round pieces with a section thickness of 15 mm and 25 mm were cut from the cast sample ends as shown in Figure 3. After the solidified samples were cut vertically, they were prepared for metallographical examination. Afterward, an areal calculation of % shrinkage was performed using image analysis software.

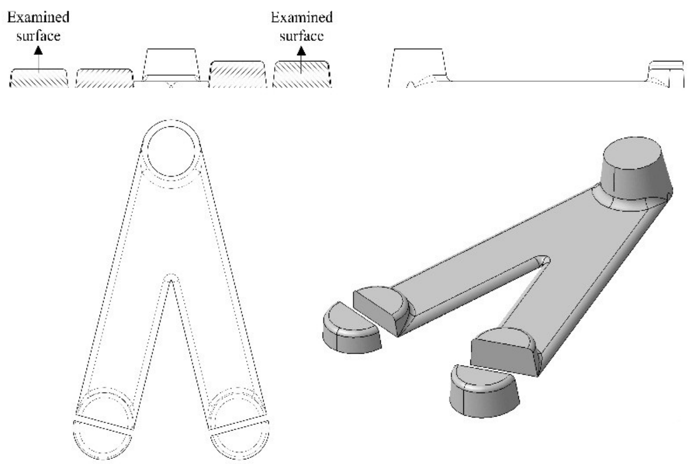

Fig. 3. Schematic views of the cut parts of the cast samples for examination.

After the metallographic processes, the shrinkage part in the original picture was processed and the % shrinkage amount in the total area was determined. An example image from the image analysis process is given in Figure 4.

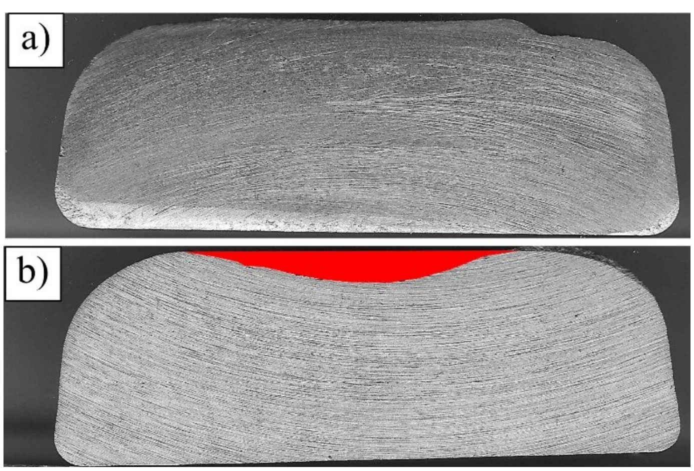

Fig. 4. Shrinkage of duck foot; a) without cleaning, b) after cleaning.

3. RESULTS AND DISCUSSION

Casting samples were obtained according to the casting methods specified in the test parameters of the mold shown in Figure 2. Figure 5 shows a sample obtained from the castings made with the duck foot mold.

Fig. 5. Duck foot mold casting sample.

In Figure 6, cross-sectional images of duck foot mold samples obtained from all experimental conditions are given. In the figure, 15 mm thick samples are given at the top while 25 mm thick samples are given at the bottom in each subfigure.

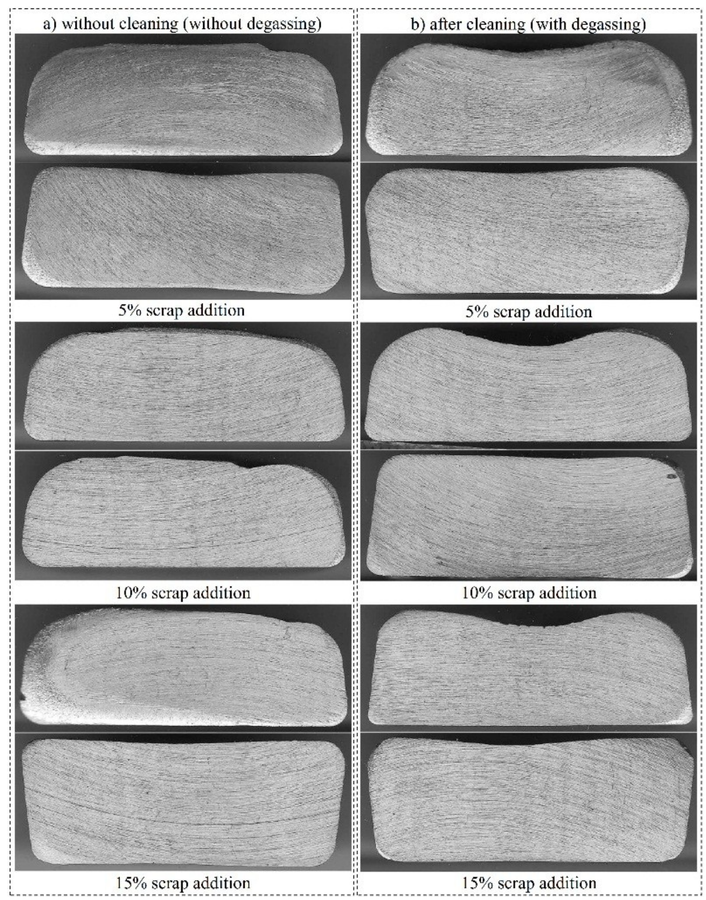

Fig. 6. Display of shrinkage amount of duck foot small and large pieces a) without cleaning, b) after cleaning.

When the pictures given in Figure 6 are examined, it is understood that there is more shrinkage in the samples obtained after cleaning, regardless of the amount of scrap. This confirms the liquid metal's cleanliness. From the existing literature, it is known that cleaning liquid metal reduces the risk of micro-porosity in the cast part, and accordingly, there is more precipitation on the surface [21]. In addition, when the shrinkage amounts in the small and large samples that occur in the mold under the same casting conditions are compared, more depressions appear in the 25 mm high sample. This is thought to be related to the solidification time and modulus criterion [22, 23]. Table 2 gives the measurement results of the cross-sectional images made with the image analysis software.

Table 2. The results of the % shrinkage image analysis of the shrinkage samples obtained from the duck foot mold.

Alloy Scrap Addition Rate	*Shrinkage (%)*			
	Without Cleaning		*After Cleaning*	
	Small specimen (15 mm)	*Large specimen (25 mm)*	*Small specimen (15 mm)*	*Large specimen (25 mm)*
5%	0.64%	1.62%	1.12%	2.23%
10%	0.42%	1.34%	1.26%	2.34%
15%	0.34%	1.10%	1.62%	2.54%

When the duck foot mold image results given in Table 2 are examined, the shrinkage amount of 0.64% in the small sample and 1.62% in the large sample was obtained without cleaning in the castings with 5% scrap addition. With the same alloy after liquid metal cleaning process, shrinkages in the small sample and in the large samples were acquired as 1.12%, and 2.23%, respectively. Shrinkage on the surface is due to cleaning solely, and, excessive shrinkage amount confirms the cleanliness of the liquid metal. When similar studies on the subject are considered, it is known that the amount of shrinkage on the surface is less since the microporosity in the sample is dispersed in the structure in the castings made without cleaning due to the impurities in the liquid metal [24]. However, this does not mean that the mechanical properties and density of the alloy are higher. Another point that draws attention when examining the results is that the alloys have surface depression after cleaning, regardless of the amount of scrap, and the resulting shrinkage values are close to each other. This is an indication that the liquid metal quality after cleaning is almost same, and at acceptable levels. With the increase in the amount of scrap in the alloy casting without cleaning, a decrease in the shrinkage amounts in the samples is observed. It is thought that this situation is caused by the liquid metal impurity and the increase in the amount of scrap may cause more microporosity to swell and prevent shrinkage on the surface.

4. CONCLUSION

In this study, the effect of changing scrap rate and liquid metal cleaning on the feedability of A356 aluminum casting alloy was investigated. In this context, duck foot mold and rotary degassing methods were used. The results obtained from the experiments carried out within the scope of the study are listed below:

- % shrinkage values were evaluated in samples in different modules under changing casting conditions in which castings were made into duck foot molds. It was observed that more shrinkage occurred independent of the scrap amount after the cleaning process of the alloys.
- When the effect of section modulus change is evaluated, more depressions were encountered in the 25 mm high sample with a large section modulus, and this was attributed to the longer solidification time.
- In the same alloy, shrinkage on the surface is only due to cleanliness, and accordingly, excessive shrinkage confirms the cleanliness of the liquid metal.
- It has been determined that there is a depression on the surface of the alloys after cleaning, independent from the amount of scrap, in the cast samples made into the duck foot mold, and the resulting values are close to each other, between 2.23 - 2.54 % in the large section modulus sample and 1.12 - 1.62% in the small section modulus sample.
- By obtaining quality parts from scrap aluminum alloy using the rotary degassing process, the need for primary aluminum has been reduced and thus energy savings have been achieved.

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Biographies

Mehmet Tokatlı was born in Konya. He graduated from Fırat University Metallurgical and Materials Engineering in 2009. He completed his master's degree at Atatürk University, Metallurgy and Materials Engineering, Department of Production Metallurgy. He worked as a production engineer in various private-sector institutions operating in the foundry industry between 2009-2011. He started to work as a lecturer at Bayburt University in 2019 and is still working there.

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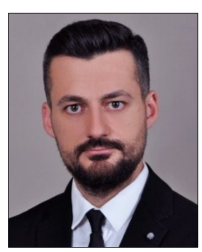

Çağlar Yüksel obtained his BSc and MSc at the Department of Metallurgical and Materials Engineering. He got his Ph.D degree from Yildiz Technical University in 2016 in the field of increasing the liquid metal quality of aluminum and its alloys. He currently works at Atatürk University as an associate professor. His research interests are mainly light alloys, metal matrix composites, casting, and solidification.

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