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EFFECT OF SCRAP RATIO ON LIQUID METAL QUALITY OF LOW-PRESSURE DIE-CASTING (LPDC) ALLOY USING ROTARY DEGASSING

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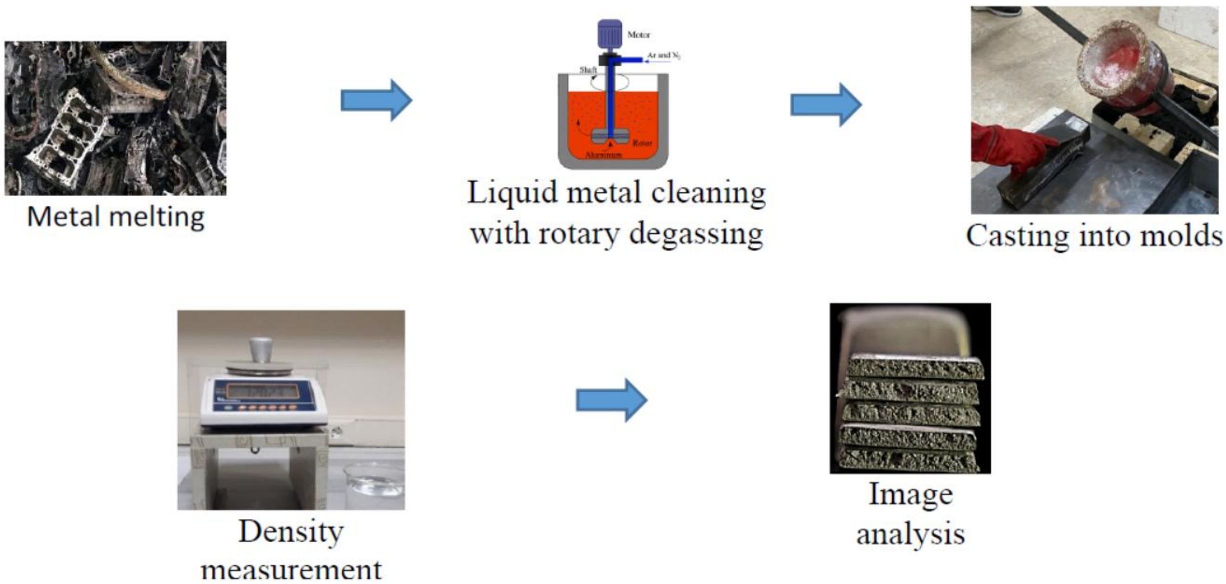
Highlights

- Melting with different ratios of scrap and ingots
- Liquid metal quality assessments
- Rafination with rotary degassing machine

Graphical Abstract



Flowchart of the experimental process

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ABSTRACT: Although various processes are used in aluminum liquid metal cleaning, environmentally friendly, economical and applicable methods should be preferred in industry. Among these methods, the Density Index test based on the reduced pressure test (RPT), which is widely used to measure the efficiency of the rotary degassing process, and the K-mold test method, which offers fast and practical results were carried out. The effects of rotary degassing method on the liquid metal quality of AlSi7Mg0.3 (A356) aluminum alloy charges prepared with different proportions of scrap and ingots were evaluated using a constant 5 l/min gas flow rate, a constant 5 min process time and a constant 300 rpm rotor rotation speed. The results show that the Density Index values can be reduced from 1.48% to around 0.74% with increasing scrap rate, while K-mold values can be reduced from 2.8 to 0.6. It was also shown that the rotary degassing method is effective in liquid metal cleaning, and the K-mold test can be used as a very practical control tool for evaluating liquid metal quality.

Keywords: *K-Mold, Density Index, Melt Quality, Rotary Degassing*

1. INTRODUCTION

One of the most important factors determining production quality in the aluminum casting industry is the quality of the liquid metal. The main defects observed in liquid metal include inclusions, oxides, and gases. Due to high affinity of aluminium for oxygen, bifilm structures form, which negatively affect the mechanical properties of the metal. The literature indicates that bifilms play a key-role in the formation of defects such as porosity and hot tearing. Additionally, bifilms have been reported to contribute to the heterogeneous nucleation of intermetallic phases and silicon particles in Al-Si alloys [1-3]. Various methods have been developed to improve liquid metal quality. These include the use of flux, rotary degassing, controlled solidification, electromagnetic degassing, spray, ultrasonic, and vacuum degassing methods. The rotary degassing process is widely used in both academic experiments and industry to remove impurities and inclusions from a bath by purging an inert gas into a molten material at a specific flow rate and time [4-6].

Gyarmati, et al. [7-11] conducted studies on the effect of different flux compositions on metal quality in various aluminum alloys. They achieved a reduction in oxide inclusions of up to 90% by adding CaF_2, MgF_2, and K_2SiF_6 to NaCl-KCl-based fluxes. Also, they used rotary degassing technology to improve melt quality and reported that pore formation is highly dependent on the oxide inclusions. Mostafaei, et al [12] concluded that tensile properties of the materials could be enhanced by rotary degassing process and if the technique could not be optimized, melt quality could be worse than original quality. Similarly, Taghiabadi and Jalali [13] demonstrated in their studies the quality index of machining chips that the

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primary cause of the decrease in mechanical properties was oxide inclusions, and that materials with fewer oxide inclusions exhibited higher mechanical properties. Sampone, et al. [14] also suggested that oxides formed during filling due to turbulence in gravity die casting cause cumulative casting defects in the final products and that prominent defects such as hot tearing actually originated from filling defects.

Various test methods have been developed to measure the success of these methods. In this study, the K-mold test method and Density Index, which are easy to apply and provide quick results, were used to assess the melt cleanliness and to evaluate the effects of scrap ratios on the liquid metals.

2. MATERIAL AND METHODS

The aluminium alloy AlSi7Mg0.3 (A356), used extensively in the low pressure die casting (LPDC) process and particularly well known as a wheel alloy, was obtained from both primary ingot and secondary chip scrap from CMS Wheel. The experiments were carried out in an electrically resistance furnace having a SiC crucible with 5000 g of charge material at a melt temperature of 730 °C by firstly melting the ingots, then gradually adding scrap (sawdust/chips), and according to three different charges having different scrap ratios as 5%, 10% and 15%, are expressed as secondary aluminium, that is, the proportions added entirely from their own chips of wheels. The raw materials were procured from CMS Jant ve Makine Sanayi A.Ş and their chemical compositions were given in Table 1.

Table 1. Chemical composition of ingot and scraps AlSi7Mg0.3 aluminium alloy

Element	**Fe**	**Si**	**Mg**	**Cu**	**Mn**	**Zn**	**Ni**	**Ti**	**Al**
Ingot	0.20	7.30	0,32	0,02	0,03	0,04	0,02	–	Balance
Scrap (Chips)	0.07	7.28	0.23	–	–	–	0.004	0.11	Balance

The liquid metal was melted in an electrically resistant furnace in a SiC crucible, and the parameters used for the degassing process —gas flow rate, rotor speed, and process time— were kept constant in order to observe the effect of scrap ratios on liquid metal quality. In this context, the degassing process was carried out for 5 minutes with a gas flow rate of 5 litres per minute and a rotor speed of 300 rpm. Nitrogen gas was used as cleaning gas due to its low cost and ease of availability. The molds were heated to 200 °C to cast. To evaluate the liquid metal quality, Density Index and K-mold techniques were performed

3. RESULTS AND DISCUSSION

3.1. Density Index (Reduced Pressure Test)

The RPT test (Figure 1) is practiced by pouring approximately 200 g of liquid aluminium into two preheated up to 200 °C thin-walled molds (tiny pots), one of them is under atmospheric pressure and the other one is under 80 mbar pressure having a 300 s solidification time. After solidification, the samples are evaluated for density and porosity. As the porosity decreases, the liquid metal is considered to be cleaner [15].

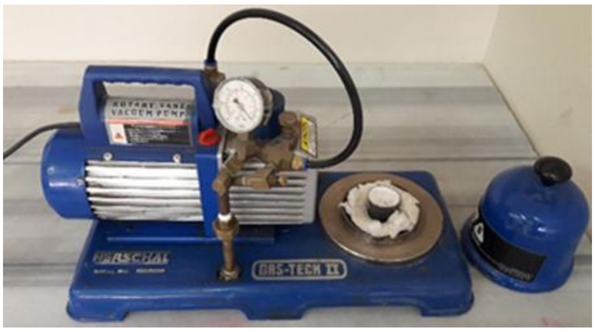

Figure 1. Setup of reduced pressure test (RPT) [4].

The samples, which were solidified for 300 seconds, were first weighed in air and then in pure water, and their densities were calculated according to Archimedes' principle. The formula used is shared below as Equation (1);

$$DI = [(D_{atm} - D_{vacuum}) / D_{atm}] \times 100\% \tag{1}$$

DI, density index value of the specimen, D_{atm} and D_{vacuum} are the densities of the specimen in one and vacuum atmospheres, respectively.

The samples were then cut and subjected to metallographic preparation processes, including grinding, after which their cross-sections were visually inspected to determine their oxide structure or porosity, and comparisons were made using the density index. These values were given as bar chart of the Density Indices in Figure 2.

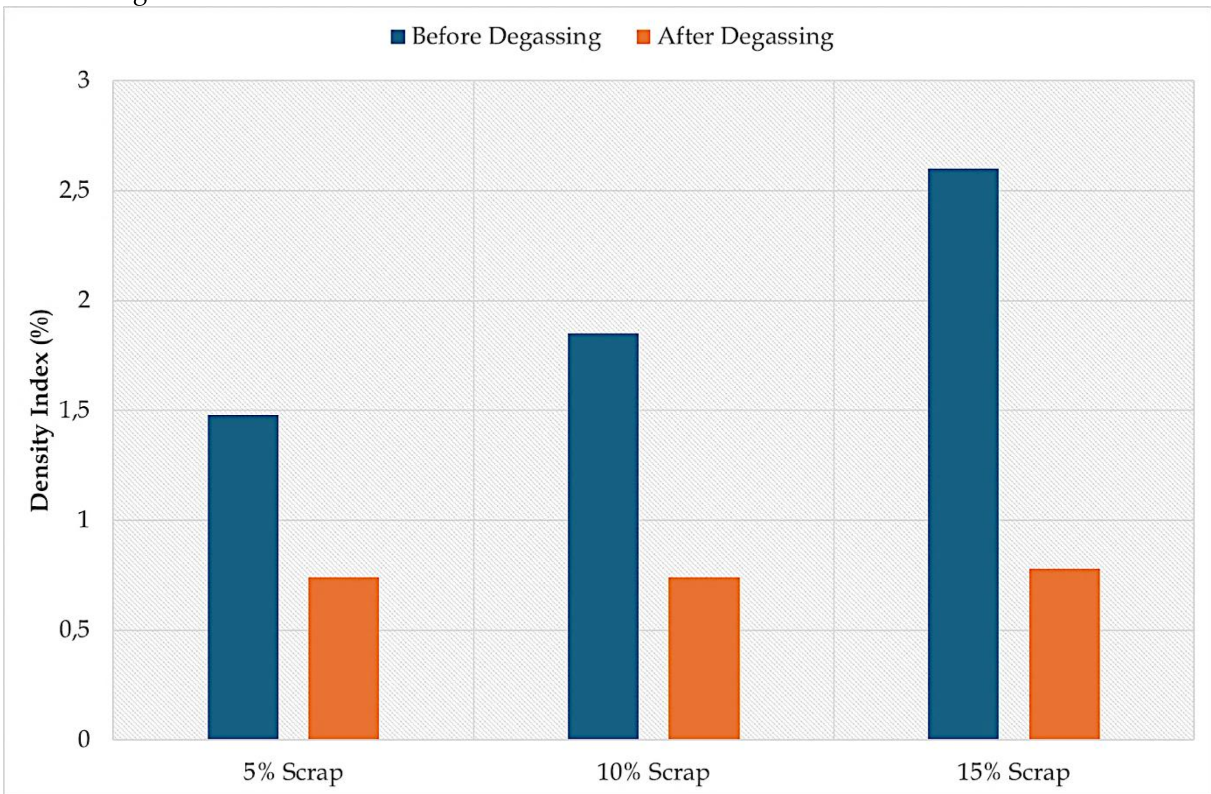

Figure 2. Density Indices of the castings having different scrap ratios.

As can be seen in Figure 2, the initial Density Index value of the melt tends to increase with the increasing amount of scrap and the initial Density Index values of the charges with 5%, 10%, and 15% scrap additions are 1.48%, 1.85%, and 2.60%, respectively. Although these values are most foundries aim to achieve after the degassing process, this study was conducted with the motivation to go beyond these targets. As a result, the values of Density Index were successfully reduced to 0.74% after degassing of liquid metals, which is significantly below the targeted values. Wu et al. [16] also conducted extensive literature research and examined many processes in practice and demonstrating that the degassing process significantly removes inclusions in the melt, thereby refining the metal and reducing density index.

Similarly, when Figure 3 is examined, it can be clearly seen that with the proper application of the degassing process, there is a reduction of at least 50% in the Density Index value. This reduction is achieved in a charge with 5% scrap content and a density index of 1.48%, while the Density Indices in charges with 10% and 15% scrap content decrease to 0.74% and 0.78%, respectively, from 1.85% and 2.60%. By calculating the percentage ratio of the before and after degassing process, it is observed that the highest efficiency is achieved in the charge containing 15% scrap, with a 70% improvement. The main reason for this efficiency could be the higher number of suspended inclusions encountered during the gas removal process compared to the other two charges. Liu et al. [17] reported that gas removal efficiency of around 50% could be achieved in their counter pressure casting process and that reliable castings could be produced with hydrogen content reduced to 0.16 ml/100 g Al. If the hydrogen source is removed from the liquid metal, it implies that the oxide films added as inclusions will be harmless and the density index value will decrease linearly, which should be considered a valuable improvement for metal refining [18].

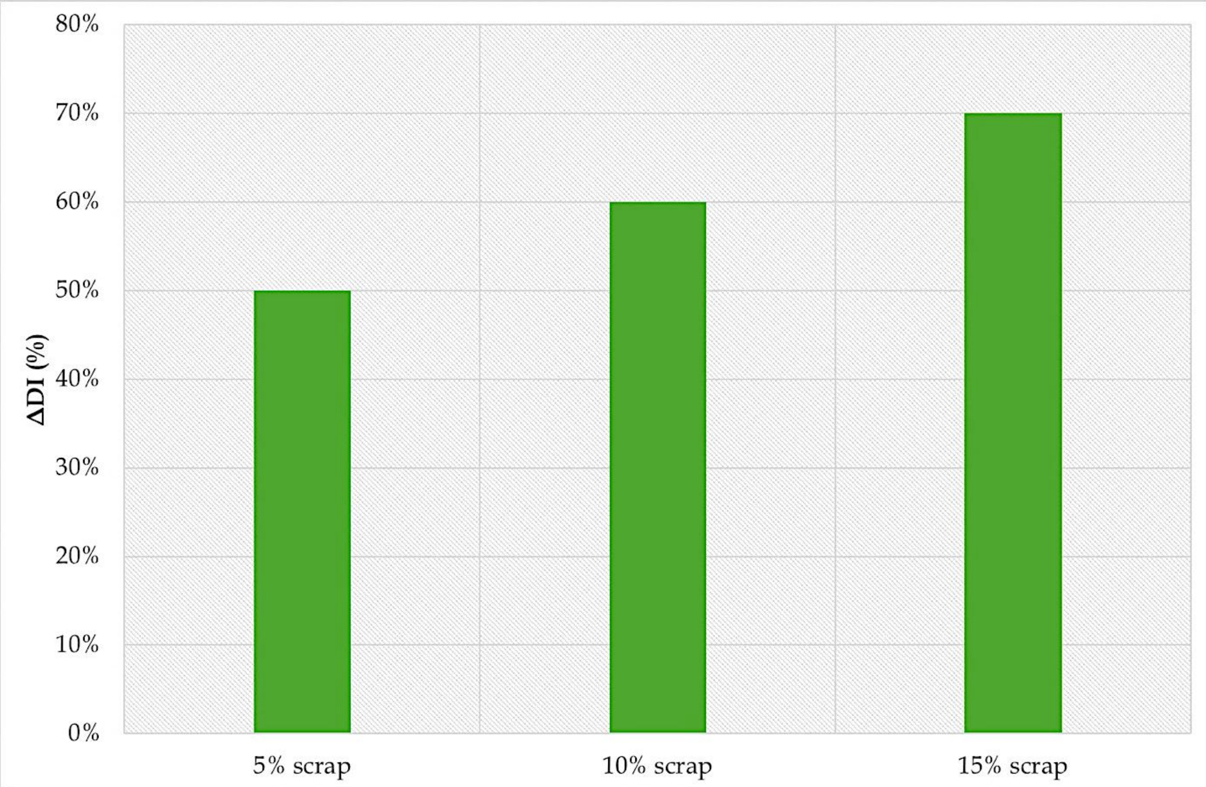

Figure 3. ΔDI values versus different scrap ratios.

Density Index value of 0.74% with 5% and 10% scrap ratios clearly indicates that the maximum efficiency achievable as a result of removing inclusions to the maximum extent possible using these gas removal process parameters is also the lowest Density Index value. This is precisely why many foundries in the industry adjust these parameters —either reducing or increasing— based on their own Density Index values. This is because, fundamentally, both the internal dynamics of this process and the unique contamination characteristics of each batch necessitate the continuous optimization of these parameters. This also implies that, in addition to each foundry having its own unique parameters, these parameters may need to be reviewed several times for each batch. Tan et al. [19] similarly suggested that machine learning could be used to make the optimization processes of these process parameters more useful, efficient, and economical.

Figure 4. Cross sections of RPT specimens.

As clearly and distinctly visible from the cross-sections of the RPT samples shown in Figure 4, the porosity increased with the amount of scrap metal prior to the degassing process with respect to porosity existence. This situation is directly attributed to the fact that the chips are very finely cut and have a large surface area, leading to the formation of significant oxide layers during melting, which are then introduced into the charge, primarily resulting in combustion losses. Similar findings have been reported in the literature for aluminum alloys produced using different alloys and casting techniques [18]. The removal of increased impurities and inclusions in the liquid metal through the degassing process has been successfully achieved, as clearly observed in RPT samples taken after the degassing process from charges with three different scrap quantities added. Yüksel et al. [20] investigated the effects of different flux compositions on the quality of liquid metal in a similar alloy. They found that the more inclusions present in the melt, which can be measured using the Bifilm Index, the number of inclusions corresponding to the created bubbles in the metal bath during the gas removal process is also correspondingly high. This not only improves the efficiency of the gas removal process but also enables metal refining to be carried out at the maximum level.

3.2. K-mold test

The K-mold test is a simple and portable control method developed in Japan to quickly assess the cleanliness of liquid aluminum by visual inspection. Unfortunately, its industrial use in Turkey is quite limited, despite the advantages of the test include rapid results, ease of application, low cost, portability, and sensitivity to oxide films and inclusions [6]. Figure 5 shows the mold used for this test and one of the samples cast.

a.

b.

Figure 5. a. K-mold, b. K-mold test specimen with five sections.

Figure 6. K-mold test specimens with different scrap ratios.

The dimensions of the samples shall be 240 mm x 36 mm x 36 mm, and the black areas indicating the presence of oxide inclusions on the broken surface of each square section (36 mm x 36 mm) shall be counted. The total number of these black marks/areas is then divided by the number of square sections to determine the K-mold value or K-factor. This simple formula of the K-factor is shared below in Equation (2);

$$K = S / N \tag{2}$$

Where, K: K-mold value or K-factor, S: Total number of inclusions detected in the sections, N: Number of sections examined.

After determining the K-mold or K-factor, the following criteria are considered to evaluate this value in terms of liquid metal quality [4].

- $K < 0.5$ — Liquid metal is clean.
- $0.5 < K < 1$ — Acceptable, but cleaning is recommended.
- $K > 1$ — Must be cleaned.

Figure 6 shows the fracture surfaces of K-mold tests with different scrap ratios. Five fracture surfaces were examined for each measurement, and the measurements were calculated according to different scrap ratios. These calculations resulted in the bar graph shown in Figure 7.

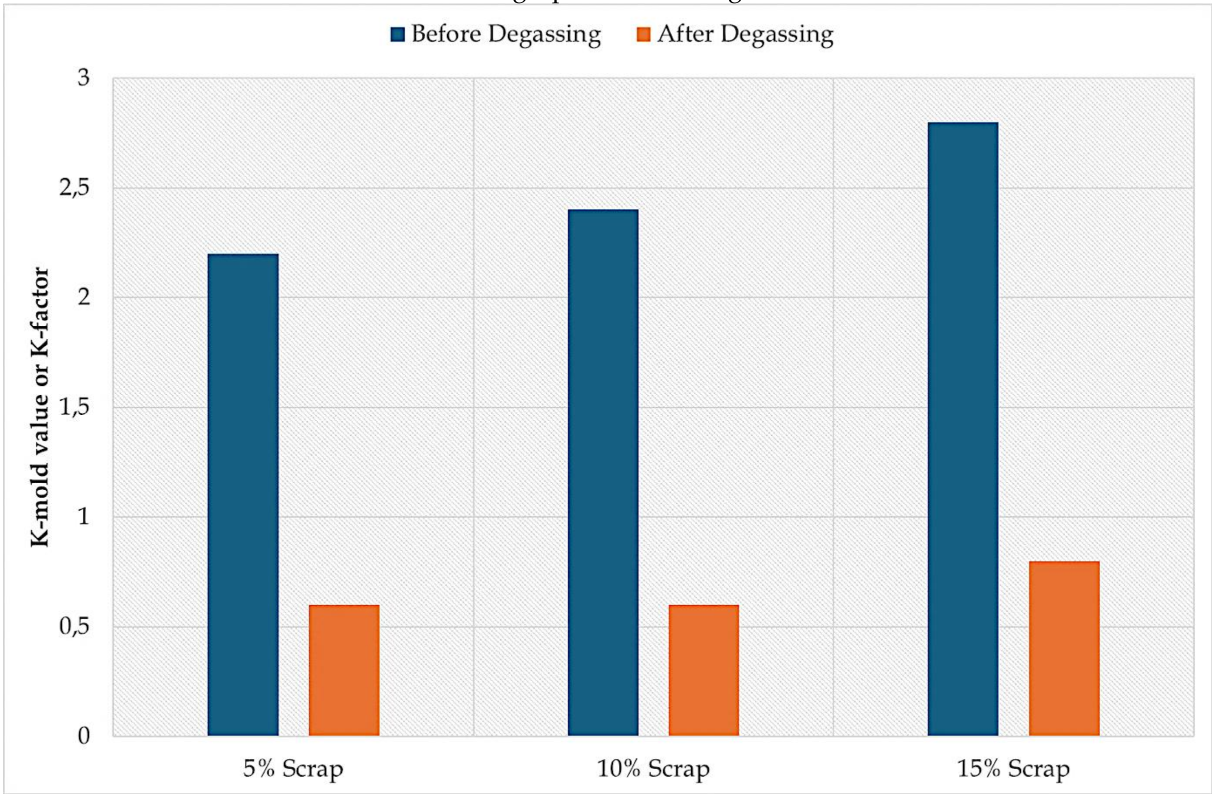

Figure 7. K-mold values or K-factors of the specimens with different scrap ratios.

When examining K-mold values or K-factors, a similar trend to the Density Index is observed. It is understood that an increase in scrap quantity leads to an increase in the number of impurities or inclusions within the liquid metal. Since it is well known that the impurities classified as inclusions in aluminum and its alloys are actually their own oxides [20], it is understood that these impurities, like in the Density Index, result from the penetration of oxides into the liquid metal bath due to combustion losses, stirring, and introducing the solid charge materials [21].

As measures to be taken for these inclusion sources, instead of adding chips freely, they should be briquetted to form more compact raw materials. This reduces surface areas, resulting in denser charge materials, thereby preventing each addition from contaminating the liquid metal. As a result, starting the degassing process with cleaner liquid metal may allow for more flexible application of process parameters, leading to more efficient, economical, faster, and effective metal preparation processes. Similar results have been supported by other researchers [10, 23]. Mate et al. [23] have demonstrated that in their liquid metal cleaning studies using flux additives, the K-factor or K-mold values were reduced to 1-2 levels after the degassing process. Based on the K-mold values used in their publications, they claim that when the process is carried out correctly, the combination of gas removal and fluxing results in proper refining of the metal.

4. CONCLUSIONS

In this study, the following results were obtained;

- The highest efficiency was achieved with these process parameters and the lowest value of 0.74 is also the lowest Density Index value that can be achieved with these parameters.
- Metal contamination increased with increasing scrap amount and the inclusion removal efficiency increases in proportion to the increase in contamination level after degassing.
- The highest efficiency in ΔDI values was achieved in the charge using 15% scrap with an improvement of 70%.
- It is thought that even lower levels of density index and K-mold values can be achieved by optimizing the degassing process parameters.
- The K-mold value or K-factor increased as the scrap amount increased, reaching a value of 2.8, which is considered to be a highly contaminated metal in this study, and decreased significantly to around 0.8 after degassing. The K-mold technique, like other liquid metal recovery methods, is a practical method and has shown that a 73% improvement can be achieved.
- Although this study applied the Density Index to assess metal quality, the Density Index never gives information about the character of the pores, such as size, number, location, etc., and industry and academia ignore this very important criterion and produce robust parts or conduct experiments by chance every day. These deficiencies should be addressed by referring to the Bifilm Index for metal quality measurements.

Declaration of Ethical Standards

Authors declare that all ethical standards have been complied with.

Credit Authorship Contribution Statement

Mehmet Tokatlı: Investigation, Analyses, Writing.
Murat Çolak: Supervision, Review, Editing.
Çağlar Yüksel: Investigation, Supervision, Review, Editing.

Declaration of Competing Interest

The authors declare that there are no declarations of interest.

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Data Availability

The data obtained from this study are available from the corresponding author upon reasonable request.

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