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Investigation of Wear Properties of Grain Refined and Modified A319 Aluminum Alloy Produced with Sand and Permanent Mold

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Abstract-Due to its lightness and good strength properties, aluminum is one of the most widely used engineering materials in the automotive industry, aviation, aerospace industry and many other areas. Along with its widespread use in many sectors, quality expectations for aluminum alloys are also increasing with the developing technology. For this purpose, grain refinement with TiB and modification with Sr are common applications to increase the final product quality in aluminum castings. With the addition of these alloying elements, it is known that decreased grain size, increased fluidity and enhanced mechanical properties can be achieved. In this study, the change in wear properties of Ti grain refined and Sr modified A319 alloy was investigated. The samples were cast into sand and permanent mould in order to obtain different microstructures. The chemical composition was determined with optical emission spectrometry. Microstructure analysis and wear tests were also carried out. The abrasion tests were carried out using a pin-disc system under a dry atmosphere on 1040 steel disc. It was found that in the die cast grain-refined alloy, friction coefficient was low and thereby the wear rates were found to be the lowest. It has also been understood that the effect of the modifier changes positively depending on the content of eutectic Si in the structure.

Keywords- *A319, Sand Casting, Permanent Mold, Grain Refinement, Modifier, Wear*

I. INTRODUCTION

Aluminum-silicon alloys are frequently used in automotive and aerospace applications due to their lightness, good mechanical properties, high strength, high thermal conductivity and low thermal expansion properties, and most importantly their high fluidity in liquid phase due to the silicon content. The critical applications require the quality and mechanical properties of castings with these alloys to be continuously improved. Processes such as grain refinement and modification are commonly applied among castings to enhance the properties of aluminum alloys. Addition of titanium to liquid metal leads decreased shrinkage in grain structure and increases the castability of the alloy. Titanium (Ti) and boron (B) elements, which are considered to be grain refiners, show a rapid and significant grain refinement effect with a small amount of aluminum addition [1-6]. It is known that the grain refined aluminum castings exhibit higher flow and feedability, less porous and homogeneous structure, higher strength, fatigue resistance and wear resistance values compare to the no-grain refined structure [2-9].

By the addition of alkali metals to Al-Si alloys, the change of the size and distribution of eutectic silicon particles in the structure can be altered which is called modification. Such modification process can also be achieved by rapid solidification, vibration applied during solidification, solidification under high pressure and heat treatment. The modification of the casting structure is based on the conversion of the eutectic Si structure from lamellar to fibrous morphology [14]. The most practical and common application for modification is the modification by the addition of Na, Sr and Sb [11, 13]. However, in industrial applications only Na and Sr have strong effects [13, 15]. In a study; it has been found that the addition of Sr only affects the structure of Al dendrites positively except for the eutectic transformation effects of Si crystals and more effective at increasing cooling rates [16].

In this study, the change in the wear properties of Al5Ti1B-grain added and Al10Sr-modified A319 that is cast into sand and permanent moulds was investigated. Optical microscope examination, wear tests, chemical analysis tests were performed for the characterization of the materials.

II. EXPERIMENTAL DETAILS

In the study, A319 alloy casting tests were carried out in the form of grain refiners and modifying additives in sand and die molds. Master alloys Al5Ti1B was used as grain refinement and Al10Sr was used as modifier. Melting processes were carried out in the SiC crucible in the electric resistance furnace at 700 °C. After the melting is complete, it was degassed. Then the castings are made into the molds where the images are given in Figure 1. The die was preheated to 150 °C. In addition, in order to see the effect of modifications, samples were cast without any additions. The sample dimension is 20 mm diameter and 192 mm length.

Figure 1. Permanent mold, model plate image for sand mold casting

Figure 2. Wear test machine

On the test specimens, chemical composition, microstructure studies and wear tests were carried out. Wear tests were carried out on a pin-on-disc equipment at room temperature under dry conditions. The cylindrical pin flat ended specimens of the size of 6 mm in diameter and 50 mm length were tested against steel disc. Fig. 2 represents a schematic diagram of the pin-on-disc wear test configuration that was designed and used for this work.

Sliding wear data was recorded and the averages of at least three runs were measured. The average mass loss was used to calculate the specific wear rate (K_o) as

$$K_o = \frac{\Delta_m}{L * F * \rho} \tag{1}$$

Where Δm is average mass loss (g), L is sliding distance (m), F is the applied load (N) and ρ is density of the materials (g cm^{-3}).

III. RESULTS AND DISCUSSION

After castings were complete, the analysis was carried out on the spectrometer to determine the chemical composition of the samples taken from the test samples. Chemical analysis results of samples are given in Table 1. The analysis values given in Table 1 also indicate that master alloy is added at the desired values. For the microstructure studies, the samples were grinded with 180-1200 grits respectively and 3-1μm diamond polishing was carried out. After polishing, the microstructural investigations and images were taken using Nikon Eclipse L150A optical microscope. The images taken at 100X magnification from the cast specimens are given in Fig. 3.

TABLE I. CHEMICAL ANALYSIS VALUES OF TEST SAMPLES (% WT.)

Alloy	Mold Type	Al	Si	Fe	Cu	Mn	Ti	B	Sr
A319	Sand	Balance	5,026	0,358	2,812	0,372	0,008	0,001	0,001
A319	Permanent	Balance	5,132	0,364	2,796	0,374	0,009	0,001	0,001
A319 + Al5Ti1B	Sand	Balance	4,992	0,332	2,722	0,354	0,168	0,006	0,001
A319 + Al5Ti1B +Al10Sr	Sand	Balance	4,820	0,324	2,640	0,344	0,172	0,0087	0,124

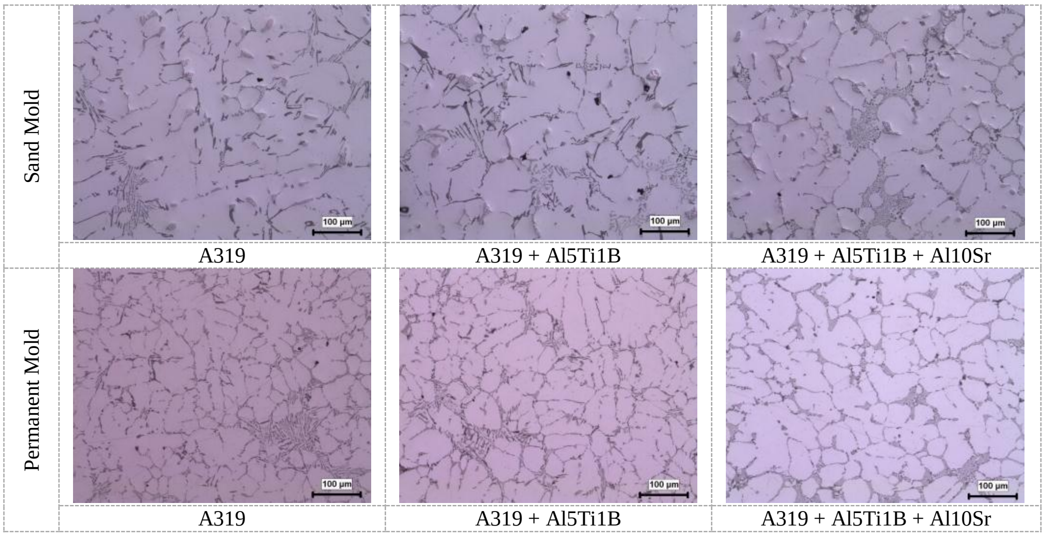

Figure 3. Cast sample microstructure pictures (100X).

Fig. 4 gives the friction coefficient results of sand mold and permanent mold samples of A319 aluminum alloy, Al5Ti1B and A110Sr added A319 alloys less than 1.0m/s sliding speed and 20N load. As can be seen, the Al5Ti1B grain refined and A110Sr modified A319 alloy revealed the lowest friction coefficient. This reduction was found to change from 12.4 to 18.2% for sand mold samples and 7.3 to 15.1% for permanent mold samples, respectively. When the casting techniques are compared, it is determined that the friction coefficient of permanent mold casting is decreased significantly compared to the sand mold casting. The coefficient of friction of the sand mold sample was 0.3871 and decreased by 26.5% to 0.3058 for permanent casting.

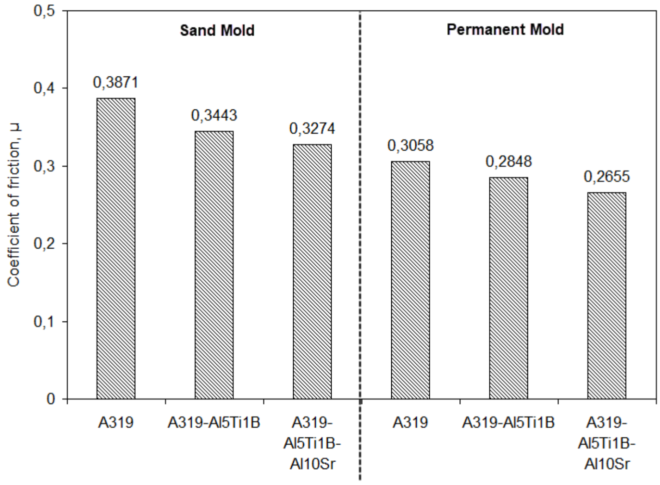

Figure 4. Friction coefficient results of A319 and its alloys

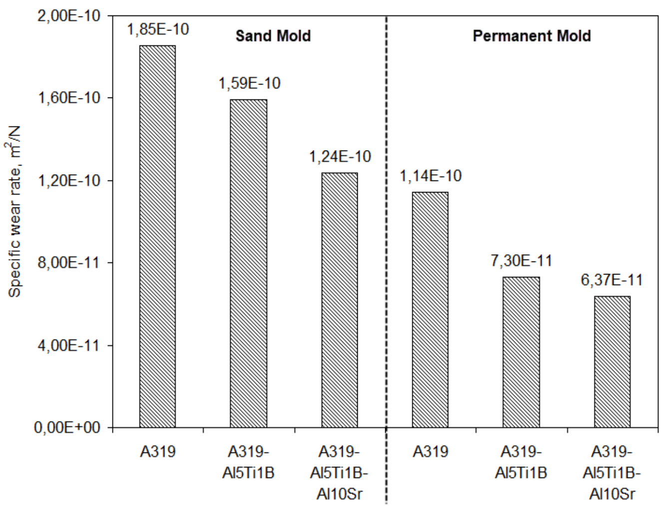

Figure 5. Wear rate results of A319 and its alloys

The specific wear rates of A319 alloy produced by both sand mold and permanent casting at a sliding speed of 1.0 m / s and a load of 20N are given in Fig. 5. In general, the specific wear rate for A319 alloys, Al5Ti1B and A110Sr added A319 alloys were 10^{-10} m^2/N. As can be seen, Al5Ti1B grain refined and A110Sr modified A319 alloy significantly reduced the wear rates. The wear rate of A319 alloy produced using sand mold decreased by 16.4% and 50% depending on the additive. These values were 56.4% and 79.4%, respectively for permanent cast samples. In the 1.0m / s sliding speed and 20N load, the lowest specific wear rate is for A319-Al5Ti1B-Al10Sr alloy with a value of $6{,}36E^{-11}$ m^2/N produced by permanent mold method while the highest specific wear rate was obtained in A319 alloy produced by sand casting. When the permanent mold wear rate was compared with the sand mold, the specific wear rate was decreased by an average of 62.2%.

Fig. 6 shows the friction coefficient-sliding distance relationship of A319 alloys produced by sand mold and permanent mold casting. As can be seen in both figures, the coefficient of friction has occurred in two stages, the run-in-period and the steady-state period. As it is seen in the figures, the steady state is achieved after about 200m sliding distance. Al5Ti1B grain refined and A110Sr modified A319 shows the lowest friction coefficient.

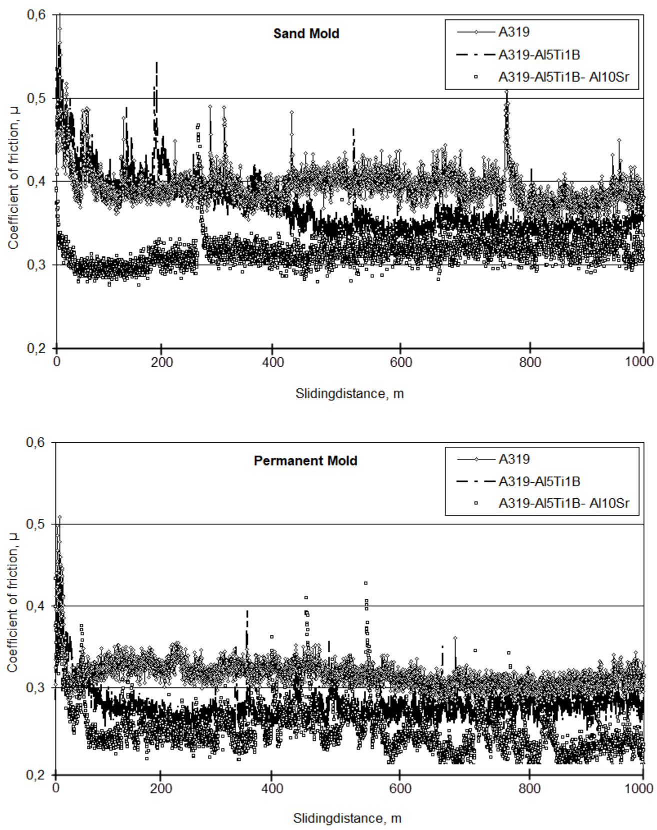

Figure 6. Coefficient of friction-sliding distance of Sand mold and permanent mold of A319 alloys (Sliding speed:1.0 m/s, Load:20 N)

IV. RESULTS

In this study, Al5Ti1B as grain refiner and Al10Sr as modifier were added to A319 alloy. When the results of the effect of the alloying additives on the wear properties are evaluated,

1. Grain refiner (TiB) and modifier (Sr) reduced the coefficient of friction and wear rate in alloy A319.
2. When the casting method differences were examined, it was found that the friction coefficient and the wear rate of the samples produced by the permanent mold method decreased by 26.5% and 62.2%, respectively, compared to the samples produced by the sand mold.

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