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The Effects of Reinforcement with TaC on the Microstructure and Wear Properties of Lamellar Graphite Cast Irons

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ABSTRACT

In this study, changes in the wear volumes, wear rates, wear track profiles, and friction coefficients of lamellar graphite cast irons in which Tantalum Carbide (TaC) was added at different reinforcement ratios (A (0.025 wt.%), B (0.155 wt.%), C (0.285 wt.%), and K (unreinforced, 0 wt.%)) were investigated. Additionally, by examining the wear surfaces of the samples using a scanning electron microscope (SEM), their wear mechanisms were determined. As a result of the analyses, it was determined that different reinforcement ratios did not have a noticeable effect on wear track profiles under a load of 1 N. On the other hand, different reinforcement ratios showed an effect on wear track profiles under loads of 3 N and 5 N. The most perceptible wear track profile was formed in Sample C under 5 N. It was observed that increased load values resulted in increased wear volumes, but the increases in the wear rates of the samples were not significant, and the numerical values were close to each other. The highest wear volumes were determined in the reinforced C sample and the unreinforced K sample under 5 N load. As the magnitude of the load that was applied increased, the friction coefficients of Samples B and C decreased, but the friction coefficients of Samples K and A increased.

1. INTRODUCTION

The first development in the production of cast iron materials has been the production of lamellar graphite cast irons (gray cast irons) by applying the inoculation method [1, 2]. Lamellar graphite cast irons are the most frequently used material in machine manufacturing [3-7]. They are inexpensive and easily accessible materials in the manufacturing of piston rings and cylinder jackets in the automotive industry. The unique properties of cast iron consist of a combination of good mechanical and physical properties and economical manufacturing processes [8-14]. As a disadvantage, they have weak weldability [15].

One of the significant problems that are frequently encountered in today's industry is wear. In the technical sense, wear is the phenomenon where an unwanted change occurs in the material as a result of the separation of microparticles from the surface of the material caused by a mechanical factor or mechanical energy [16]. In a wear system, the main material (wearing material), the counter material (abrasive), the spacing material, load and motion constitute the primary elements of wear. The system created by all these elements is called a "Tribological System". In a wear system, environmental conditions are also important factors. The exposure of system elements to humidity or corrosive effects also speeds up wear [2, 17]. The properties of the main material (e.g., microstructure, surface hardness, heat treatment), the properties of the counter material, and atmospheric conditions such as temperature and humidity are factors that affect wear in a tribological system. In addition to these, some properties of materials depending on their service conditions (e.g., form of loading) have a substantial effect on their wear mechanism [18].

TaC is a highly popular material due to its resistance to high temperatures and good mechanical properties at high temperatures. In this study, materials were produced by adding TaC as reinforcement at varying ratios (A, B, C, and unreinforced K) to materials that are used in the production of lamellar graphite cast irons. Experimental samples were prepared from the materials produced at different reinforcement ratios, and mechanical and wear tests were carried out. In these tests, the effects of the TaC reinforcement ratios on lamellar graphite cast irons were investigated.

2. MATERIAL AND METHOD

2.1. Material manufacturing

The chemical compositions of the A, B, C and K (unreinforced) alloys are shown in Table 1. These alloys were melted in a casting furnace and poured separately into sand molds at a final pouring temperature of 1375°C. TaC had a purity of 99.9%, and its particle size was 3 μm. During the casting process, inoculation material was added at a ratio of 0.3% by weight. The chemical composition of the inoculation material is given in Table 2.

TABLE I.
CHEMICAL COMPOSITIONS OF SAMPLES (WT.%)

No	C	Si	Mn	P	S	Cr	Cu	Al	Ti	TaC
A	3.36	2.68	0.68	0.006	0.067	0.28	0.08	0.001	0.033	0.025
B	3.38	2.70	0.64	0.017	0.083	0.28	0.12	0.001	0.033	0.155
C	3.23	2.71	0.63	0.016	0.086	0.28	0.12	0.001	0.025	0.285
K	3.30	2.70	0.63	0.016	0,080	0.28	0.12	0.001	0.025	-

TABLE II.
CHEMICAL COMPOSITION OF INOCULATION MATERIAL

	% Si	% Al	% Ca	% Sr
Min-Max	73.0-78.0	0.50 max	0.100 max	0.80-1.40
Sample Castings	75.0	0.32	0.020	1.06

2.2. Sample preparation for wear tests

After the casting process, the samples were taken out of their sand molds when they reached room temperature. Samples for the wear tests were prepared at dimensions of 50 mm × 30 mm × 5 mm, and the wear test surfaces were polished. The wear tests were carried out in 3 repetitions for each reinforcement ratio.

2.3. Wear tests

The wear tests were conducted using a reciprocating Tribotech tribotester device (Figure 1) under normal atmospheric conditions (22±1°C and 30±2% humidity) in a dry setting. Alumina balls with a diameter of 6 mm were used as the abrasive material. The tests were performed under load values of 1 N, 3 N and 5 N, with a sliding speed of 10 mm/s, a sliding length of 5 mm, and a total sliding distance of 50 m. Coefficients of friction were recorded during the tests. After the wear tests, the wear tracks were examined using a surface profilometer (Veeco Dektak 6M) and SEM [19, 20].

Figure 1. Wear test device

3. RESULTS AND DISCUSSION

3. 1. Wear tests

Coefficients of friction, wear track profiles, wear volumes and wear rates were determined in the wear tests for the samples that were prepared at different TaC reinforcement ratios (0.025, 0.155, and 0.285 wt.%), and the values were compared to those of the unreinforced sample (0 wt.%). Table 3 presents the wear volume, wear rate and mean coefficient of friction values of the samples.

TABLE III.
WEAR VOLUME, WEAR RATE AND MEAN COEFFICIENT OF FRICTION VALUES OF THE SAMPLES

Sample	Load (N)	Wear Volume ($\times10^{-3}$ mm^3)	Wear Rate ($x10^{-5}$ mm^3/Nm)	Mean Coefficient of Friction
K (0 wt.% TaC)	5	4.2	1.7	0.508
A (0.025 wt.% TaC)	5	3.8	1.5	0.475
B (0.155 wt.% TaC)	5	4.0	1.6	0.548
C (0.285 wt.% TaC)	5	4.3	1.7	0.555
K (0 wt.% TaC)	3	2.1	1.4	0.530
A (0.025 wt.% TaC)	3	2.4	1.6	0.516
B (0.155 wt.% TaC)	3	2.2	1.5	0.561
C (0.285 wt.% TaC)	3	2.9	1.9	0.608
K (0 wt.% TaC)	1	0.9	1.7	0.507
A (0.025 wt.% TaC)	1	1.2	2.3	0.453
B (0.155 wt.% TaC)	1	0.8	1.5	0.572
C (0.285 wt.% TaC)	1	0.9	1.9	0.575

As seen in Table 3, in the comparison of the results of each load value, with the increasing reinforcement ratios, there were no increases in the wear volume and wear rate values of the samples, and the values stayed more or less constant. With increased load values, there were increases in the wear volume results, while the wear rate results were similar to each other at different loads. The highest wear volume values were found under the 5 N load in Sample C as 4.3×10^{-3} mm^3 and the unreinforced K sample as 4.2×10^{-3} mm^3. The highest wear rate was found under the 1 N load in Sample A as 2.3×10^{-5} mm^3/Nm. Şimşek et al. added SiCp reinforcement into the A356 matrix at ratios of 5%, 10%, 15%, and 20% and subjected the samples to wear tests at 0.2 m/s, under a load of 15 N, and at a total distance of 1500 m. As a result of the tests, they determined that as the reinforcement ratio increased at constant load values, the number of particles breaking off the sample decreased, and thus, at increased reinforcement ratios, weight loss decreased [21]. In this study, when each load among the 1 N, 3 N and 5 N load values was analyzed independently of the other loads, it was seen that wear rates had an increasing trend along with increased reinforcement ratios, but there was no substantial change in the wear volumes.

To determine the wear profiles of the samples, the depths and widths of the wear tracks that formed on the surface during the experiments were measured using a Veeco Dektak 6M model surface profilometer. Figure 2 shows the schematic representation of the depth and width of a wear track. Using these depth and width values and assuming that the wear track was semielliptical, wear volume was first calculated using equation (1), and then, wear rate was calculated using equation (2). The wear track profiles of the samples that were subjected to wear experiments are given comparatively in Figure 3.

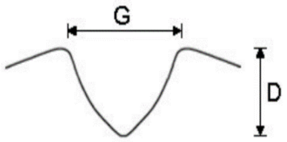

Figure 2. Schematic display of the depth and width of the wear track [20, 22, 23].

$$V = \frac{\pi}{4} \cdot G \cdot D \cdot \mathrm{L} \quad (1)$$

$$W = \frac{V}{F \cdot S} \quad (2)$$

V: Wear volume (mm^3), G: Wear track width (mm), D: Wear track depth (mm), L: Reciprocal motion amplitude (5 mm), W: Wear rate (mm^3 / Nm), F: Experimental load (N), S: Total sliding distance (50 m)

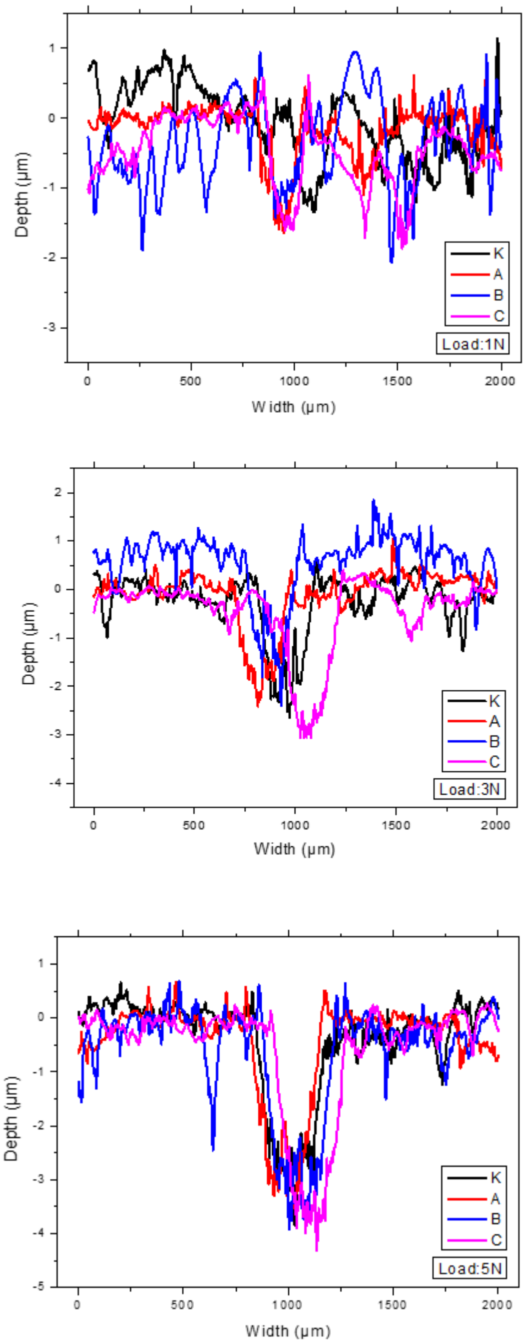

Figure 3. Comparison of the wear track profiles under 1 N, 3 N, and 5N

In the examinations of the wear track profiles of the samples, it was observed that changes in reinforcement ratios under 1 N of load did not have a noticeable effect on these profiles. On the other hand, under the 3 N load, changes in reinforcement ratios affected the wear track profiles of the samples. The most prominent wear track profile under the 3 N load was formed in Sample C. Under the 5 N load, the varying reinforcement ratios had the highest effects on the wear track profiles of the samples, where the most prominent wear track profile was found in Sample C.

The changes that occurred in the friction coefficients of the samples that were subjected to wear experiments depending on sliding distance can be seen in Figure 4. In the wear experiments, the coefficients of friction reached steady-state values following a sliding distance of 10 m, no significant change was observed in these values until the end of the experiments.

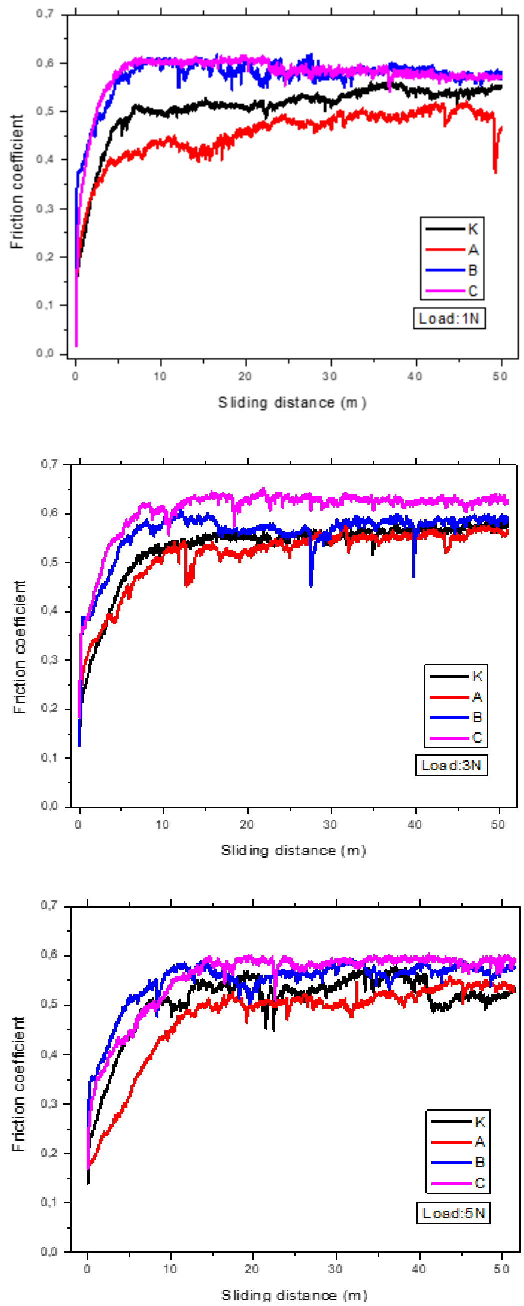

Figure 4. Comparison of the coefficients of friction under 1 N, 3 N, and 5 N

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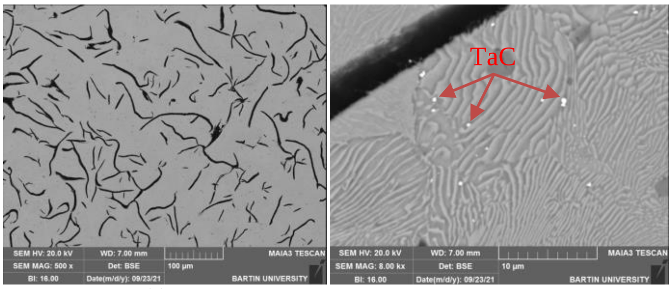

(a) (b)

Figure 5. SEM Microstructure image of sample no. B, a,b

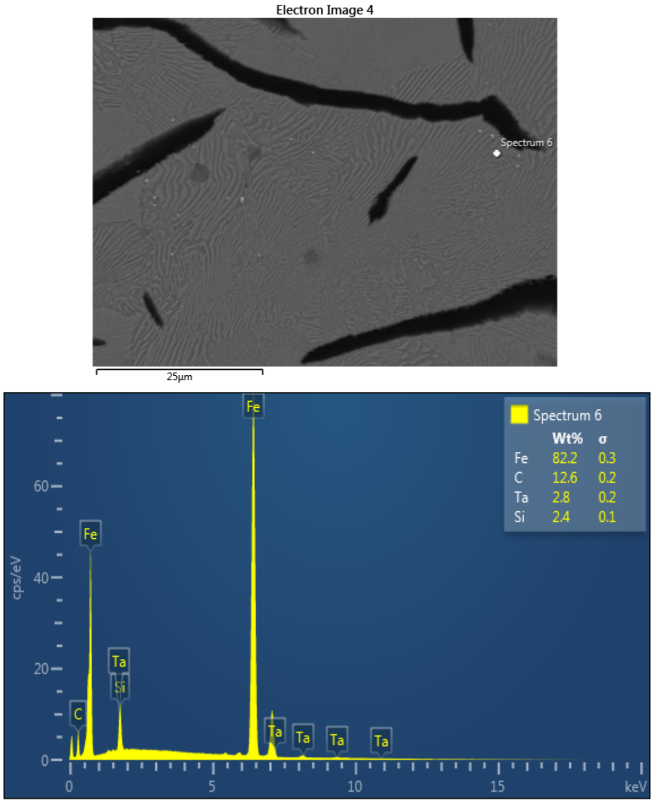

Figure 6. EDS Analysis of sample no. B

As demonstrated in Figure 4, as the load values applied to the samples increased, the friction coefficients of Samples B and C decreased, but the friction coefficients of Samples K and A increased. The reason for this was that the contact surface between the sample and Alumina ball created high frictional heat and force values during its constant reciprocal motion under high loads. When each of the 1 N, 3 N and 5 N load values was analyzed separately from the others, it was found that under a constant load, as the reinforcement ratio increased, there was also an increase in the coefficient of friction. The highest coefficient of friction was found in Sample C under all three load values. In the study conducted by Arslan, the AZ91 magnesium alloy that was produced with the cold chamber high-pressure die casting method was subjected to dry sliding wear tests under three different loads as 2 N, 5 N and 10 N, with an amplitude of 10 mm, a sliding speed of 5 mm/s, and a total sliding distance of 12 m. The author observed that increased hardness values resulted in lower coefficients of friction on the wear surfaces of the samples. They identified a relationship between coefficients of friction and hardness. The amount of wear that was inversely proportional to hardness was, on the other hand, directly proportional to the coefficient of friction. That is, as the amount of wear decreased, the coefficient of friction was observed to increase [24].

3. 2. Microstructure analyses

SEM (Scanning Electron Microscope) images (Figure 5) and EDS (Energy Dispersive X-Ray Spectrometer) images (Figure 6) of the samples before the wear test are shown.

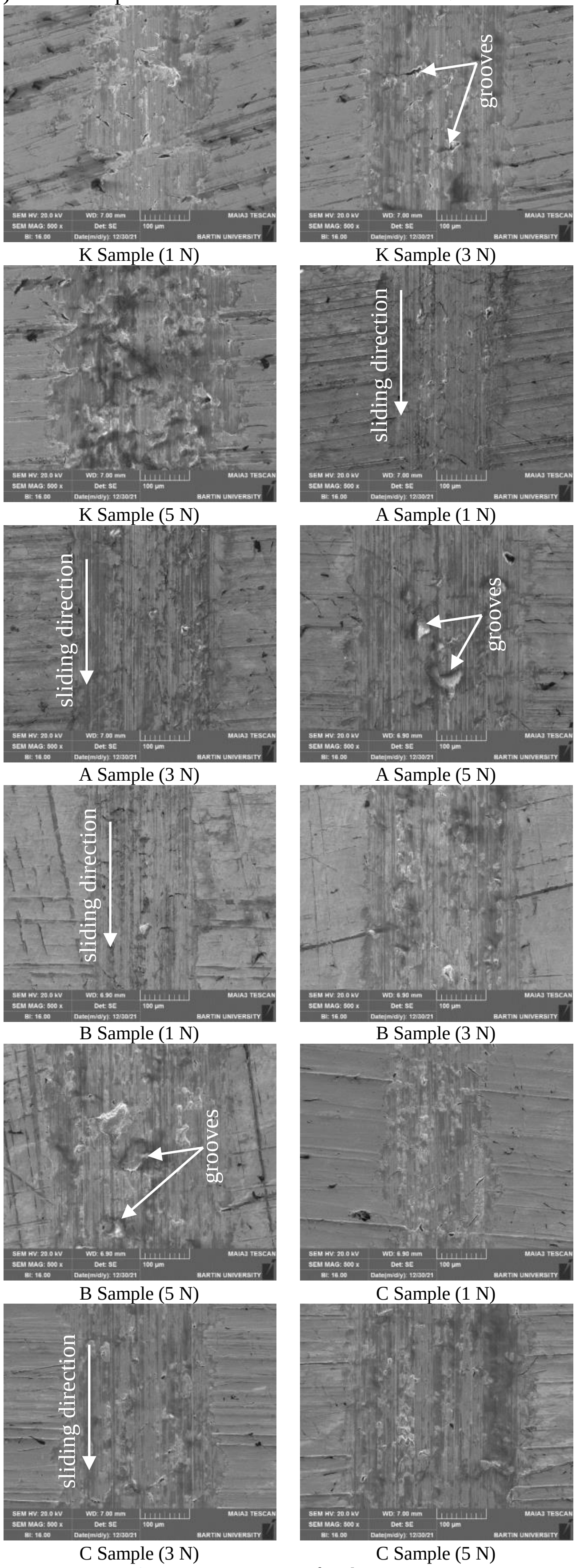

Figure 7. SEM images after the wear tests

The SEM images of the microstructures of the sample surfaces after the wear tests are shown in Figure 7.

As demonstrated in the SEM images in Figure 7, in Sample K that did not include TaC reinforcement, increased load values resulted in increased wear volumes. The highest wear occurred under the 5 N load in the form of abrasion. There were also abrasions on the wear surfaces for the load values of 1 N and 3 N, but these abrasions were not as severe as those that formed under the 5 N load. According to the SEM images of Sample A, abrasive wear occurred on the surface under the 5 N load. Under the load values of 1 N and 3 N, wear was observed without abrasion. The SEM images of Sample B revealed abrasive wear under the 5 N load. The wear surfaces of Sample B did not show abrasion under the 1 N and 3 N loads, and these results were similar to those of Sample A. Based on the SEM images of Sample C, because the highest reinforcement ratio was in this sample, no abrasion was observed under the 1 N, 3 N and 5 N loads. The appearance of the wear surface was similar for all load values.

4. CONCLUSION

a) Varying reinforcement ratios did not have a noteworthy effect on the resulting wear track profiles under the 1 N load. On the other hand, different reinforcement ratios resulted in changes in the wear track profiles under 3 N and 5 N. The most noticeable wear track profile was found in Sample C under the 5 N load.
b) Increased load values resulted in increased wear volumes, but they did not result in significant wear rate value changes, and the wear rate values were similar to each other. The highest wear volume was found under the 5 N load as 4.3×10^{-3} mm^3 in Sample C and 4.2×10^{-3} mm^3 in Sample K.
c) When each of the load values of 1N, 3N, and 5N was analyzed independently of the others, it was observed that as the reinforcement ratio increased, there was a tendency for the wear amounts to increase.
d) The friction coefficient values decreased while the load values which is applied to the B and C samples was increased. On the other hand, for K and A samples, the friction coefficient values increased while load values were increased.
e) At constant load values, as the reinforcement ratio increased, the coefficients of friction also increased. The highest coefficient of friction was found in Sample C for all three load values.

REFERENCES

[1] E. Tan, "The effect of adding ratio of copper to the wear behavior of rolls manufactured by cast iron", M.S. thesis, Institute of Sciences, Pamukkale University, Denizli, Turkey, 2005.
[2] D. Sağlam, "Wear properties of cast iron", M.S. thesis, Institute of Sciences, Marmara University, İstanbul, Turkey, 2009.
[3] D. Mu and B. Shen, "The kinetics and dry-sliding wear properties of boronized gray cast iron", Advances in Materials Science and Engineering, vol. 2013, pp. 1-7, 2013.
[4] H. Berns, "Comparison of wear resistant MMC and white cast iron", Wear, vol. 254, no. 1-2, pp. 47-54, 2003.
[5] C. Kowandy, C. Richard, Y. M. Chen, and J. J. Tessier, "Correlation between the tribological behaviour and wear particle morphology-case of grey cast iron 250 versus Graphite and PTFE", Wear, vol. 262, no. 7-8, pp. 996–1006, 2007.
[6] E. Albertin and A. Sinatora, "Effect of carbide fraction and matrix microstructure on the wear of cast iron balls tested in a laboratory ball mill", Wear, vol. 250-251, no. 1, pp. 492-501, 2001.
[7] J. Asensio, J. A. Pero-Sanz, and J. I. Verdeja, "Microstructure selection criteria for cast irons with more than 10 wt.% chromium for wear applications", Materials Characterization, vol. 49, no. 2, pp. 83-93, 2002.
[8] A. R. Riahi and A. T. Alpas, "Wear map for grey cast ıron", Wear, vol. 255, no. 1-6, pp. 401–409, 2003.
[9] M. K. Bilici, "Wear Properties Of An Alloy Cast Iron", M.S. thesis, Institute of Sciences, Marmara University, İstanbul, Turkey, 2004.
[10] R. Ghasemi and L. Elmquist, "A study on graphite extrusion phenomenon under the sliding wear response of cast iron using microindentation and microscratch techniques", Wear, vol. 320, pp.120-126, 2014.
[11] Z. Chen, T. Zhou, R. Zhao, H. Zhang, S. Lu, W. Yang and H. Zhou, "Improved fatigue wear resistance of gray cast iron by localized laser carburizing", Materials Science & Engineering A, vol. 644, pp. 1-9, 2015.
[12] T. Willidal, W. Bauer and P. Schumacher, "Stress/strain behaviour and fatigue limit of grey cast iron", Materials Science and Engineering A, vol. 413-414, pp. 578-582, 2005.
[13] G. Bertolino and J. E. Perez-Ipina, "Geometrical effects on lamellar grey cast iron fracture toughness", Journal of Materials Processing Technology, vol. 179, pp. 202-206, 2006.
[14] M. Ramadan, M. Takita and H. Nomura, "Effect of semi-solid processing on solidification microstructure and mechanical properties of gray cast iron", Materials Science and Engineering A, vol. 417, pp. 166-173, 2006.
[15] A. Sadeghi, A. Moloodi, M. Golestanipour and M. M. Shahri, "An investigation of abrasive wear and corrosion behavior of surface repair of gray cast iron by SMAW", Journal of Materials Research and Technology, vol. 6, no. 1, pp. 90-95, 2017.
[16] F. Münker, "Wear properties of hardened cast irons", M.S. thesis, Institute of Sciences, Marmara University, İstanbul, Turkey, 2010.
[17] F. Okay, "An investigation of adhesive wear behavior of TiN coated austempered ductile iron with PVD", M.S. thesis, Institute of Sciences, Gazi University, Ankara, Turkey, 2006.
[18] H. İ. Filiz, "The effect of microstructure on impact sliding wear behavior of aisi D2 cold work tool steels, M.S. thesis, Graduate Education Institute, Istanbul Technical University, Istanbul, Turkey, 2021.
[19] O. Tazegul, F. Muhaffel, O. Meydanoglu, M. Baydogan, E. S. Kayali and H. Cimenoglu, "Wear and corrosion characteristics of novel alumina coatings produced by micro arc oxidation on AZ91D magnesium alloy", Surface & Coatings Technology, vol. 258, pp. 168-173, 2014.
[20] B. Bilim, "Investigation of wear behaviour of hot dip aluminized tool steels produced by powder metallurgy", M.S. thesis, Graduate Education Institute, Istanbul Technical University, Istanbul, Turkey, 2021.
[21] I. Şimşek, D. Şimşek and D. Özyürek, "Investigation of Wear Behaviors of Al-SiC Composite Materials Produced by Semi-Solid Process Method", SETSCI Conference Proceedings, vol. 4, no. 1, pp. 545-548, 2019.
[22] S. İ. Akray, "The effect of coatings on wear characteristics of spherodial graphite cast iron", M.S. thesis, Institute of Sciences, Istanbul Technical University, Istanbul, Turkey, 2007.
[23] A. Ayday, "Surface Properties Improvement of Nodular Cast Iron Modified by Electrolytic Plasma Technology", PhD Thesis, Institute of Sciences, Sakarya University, Sakarya, Turkey, 2013.
[24] R. Arslan, "Döküm presi ile elde edilen magnezyum alaşımlarının mekanik özelliklerinin belirlenmesi", M.S. thesis, Institute of Sciences, Kırşehir Ahi Evran University, Kırşehir, Turkey, 2019.

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