Barış İshak Sipcikoğlu
Graduated Student
Istanbul Technical University
Faculty of Chemistry-Metallurgy, Istanbul
Turkey

Burcu Yiğit
Graduated Student
Istanbul Technical University
Faculty of Mechanical Engineering, Istanbul
Turkey

Hüseyin Oflaz
Graduated Student
Istanbul Technical University
Faculty of Chemistry-Metallurgy, Istanbul
Turkey

Zeynep Parlar
Assistant Professor
Istanbul Technical University
Faculty of Mechanical Engineering, Istanbul
Turkey

Vedat Temiz
Assistant Professor
Istanbul Technical University
Faculty of Mechanical Engineering, Istanbul
Turkey

The Investigation of Friction and Wear Characteristic of Cast Iron against Manganese Phosphate Coated and Austempered Compressor Crankshaft

Refrigerator is one of the important technological household appliances, and as a result of increased energy cost, efficiency has become a subject of great importance in the refrigerator industry. Compressor is the most important device in the refrigerator which effects cooling performance. Reduction of frictional losses in the compressor where the relatively moving elements exist is of great importance in this respect. In the present study, austempered and MnP coated ductile cast iron's friction coefficient and wear loses when works conjugate with gray cast iron crankshaft bearing has been investigated experimentally for both dry and boundary lubrication condition with different speed and load conditions.

Keywords: *austempered cast iron, crankshaft, compressor, MnP coated cast iron.*

1. INTRODUCTION

Technological advances have led to a change in the home life largely as it affects every aspect of human life. When the technological household appliances have changed in many ways with the liveable life into our lives, life has become easier. Refrigerator is the one of the wide spread technological household appliances which has important role for healthy and longer storage of food. Nowadays, as a result of increased energy cost, efficiency has become the subject of great importance in the refrigerator industry. Compressor is the most important device in refrigerator which effects cooling performance. Reduction of frictional losses in the compressor between relatively moving surfaces is of great importance in this respect.

Cast irons have been used in many industrial applications for many years because of the thermal conductivity, good machinability, vibration damping ability, good strength properties and wear resistance. Moreover, cast irons are used in automotive industry as the piston, cylinder liner, clutch and brake system because of these properties, and their tribological behaviour are analyzed for these applications [1,2].

Gray cast iron and ductile cast iron are widely preferred for compressor crankshafts because of easy manufacturing, cost and high wear resistance properties. Also, in order to improve some properties of iron, some elements adopted to material as Ni, Cu, Cr and Mo and some other process can be applied as austempering, quenching and coating. Aluminium, bronze, copper-lead alloys and bronze-phosphate alloys are used as crankshaft bearing material.

In the literature research, studies of friction and wear behaviour of different cast iron's in comparison [3-6], and investigations of heat treatment affects on tribological behaviours of cast iron's [7,8] have been found. These studies were carried out in dry friction conditions. In the work carried out by Yavuz et al. the boundary friction case was also taken into consideration [9].

In our study, materials were coated and heat treated to reduce friction coefficient and wear losses on compressor crankshaft and these values were studied on a block-on-ring test apparatus.

In the present study, austempered and MnP coated ductile cast iron's friction coefficient and wear rates, when works conjugate with gray cast iron crankshaft bearing, have been investigated experimentally for both dry and boundary lubrication condition.

2. TEST APPARATUS AND MATERIALS

2.1 Test apparatus

A commercially available block-on-ring apparatus was used to determine the friction and wear properties of test specimens. The representation of the experimental setup is given schematically in Figure 1. As shown in Figure 1 normal load acting on the stationary test specimen (pin) is applied through the load holder by using dead-weights. Pin was mounted on the specimen holder, so that the cylindrical outside surface of specimen was in line contact with the counterface, as seen from Figure 2. The frictional force formed between the test specimen and the counterface during sliding motion was measured by a force transducer placed on the specimen holder. The force transducer has a load range ± 200 N with a sensitivity of ± 2 mV, which is equivalent to a

Received: March 2015, Accepted: June 2015
Correspondence to: Assis. Prof. Zeynep Parlar
Faculty of Mechanical Engineering,
İnönü Caddesi 65, 34437 Istanbul, Turkey
E-mail: parlarze@itu.edu.tr
doi:10.5937/fmet1503186S

maximum ± 0.1 N error in the measurements. The counterface was driven by a D.C. motor in 30 – 800 rpm (0.1 – 2.5 m/s) variable speed range. The wear experiments were carried out on the basis of loss of mass measured with a scale 0.0001 g in accuracy.

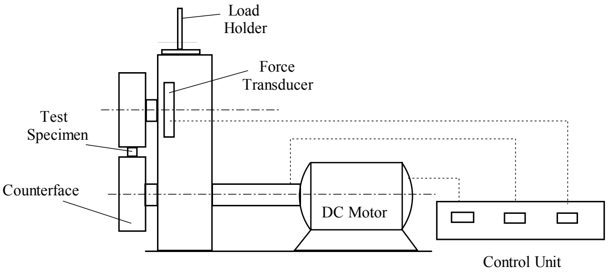

Figure 1. Principle diagram of the test system

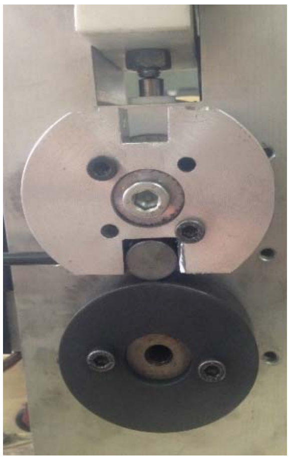

Figure 2. General view of test specimen and counterface

2.2 Materials

The counterface (disk) was manufactured a cylindrical shape with a width of 15 mm and a diameter of 60 mm. Two different disks were prepared with two different methods for experiments; the first one is GGG40 ductile cast iron which was austempered, and the second one is the GGG40 ductile cast iron which was MnP coated. SEM images of these disks showing their internal structure is given in the Figure 3. Surface roughness values of these disks are given in Table 1. The pin was made of GG25 gray cast iron having 12 mm diameter and 10 mm in length.

Table 1. Surface roughness of materials

Material	Surface roughness, *Ra* [μm]
MnP coated disk	1.05
Austempered disk	0.36

Additionally, hardness values of materials used for pin and disk materials were also determined since the hardness of metallic materials may have a critical influence on the tribological characteristics of these relatively moving surfaces. Results of hardness tests are given in Figure 4 in HV scale.

2.3 Experimental procedure

The experiments were carried out in the 18 – 20 °C environmental temperature and 50 – 60 % relative humidity. Before the experiments, both counterface and pin surfaces were cleaned with carbon tetrachloride. The force transducer was adjusted to initial value at the beginning of each experiment. To investigate the effect of sliding speed and normal load on friction coefficient, 10 different sliding speed (0.2 – 2 m/s), and three different normal load (10, 20 and 40 N) values were studied. The variations of friction coefficient with respect to sliding speed were recorded at dry and boundary lubricated conditions. The properties of compressor oil, which was used on boundary layer condition, are shown in Table 2.

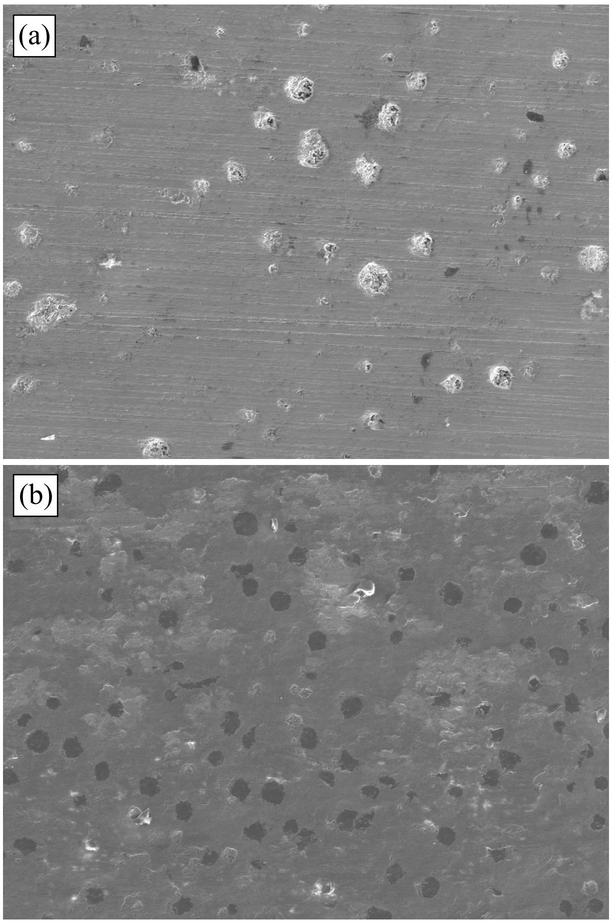

Figure 3. SEM images of disks surface, 250 ×: (a) austempered and (b) MnP coated

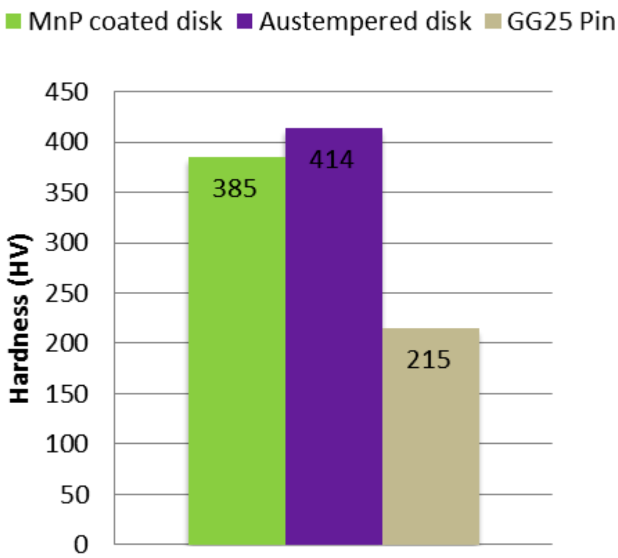

Figure 4. The variation of materials hardness

Table 2. Properties of compressor oil

Oil properties	Density at 15 °C [kg/m^3]	Kinematic viscosity at 40 °C [mm^2/s]	Kinematic viscosity at 100 °C [mm^2/s]	Pour point [°C]
	827	5.0	1.7	– 45

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Friction tests

As a result of systematical experiments, at first step the variations of coefficient of friction with sliding speed were determined in both dry and boundary lubrication conditions. These variations are presented in Figure 5 and 6 for MnP coated and austempered disk, respectively. Experiments were repeated under 10, 20 and 40 N normal loads.

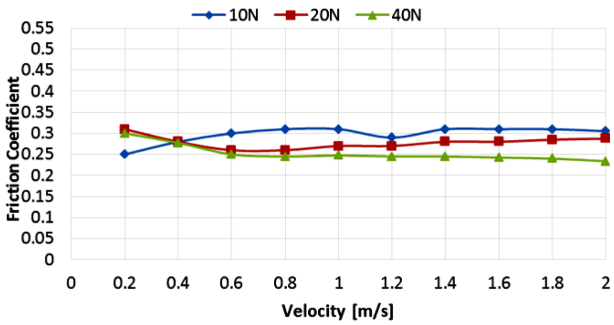

Figure 5. Friction coefficient of MnP coated disk in dry conditions

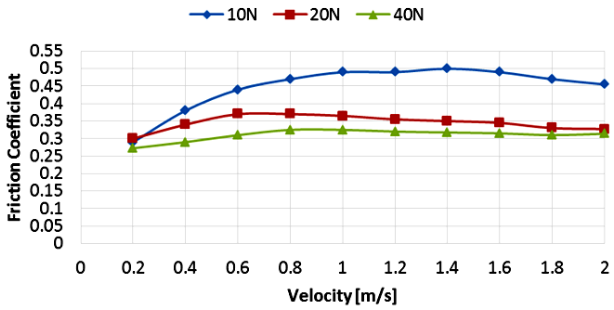

Figure 6. Friction coefficient of austempered disk in dry conditions

As seen from the Figure 5, MnP has a constant friction coefficient after 0.6 m/s sliding speed, and after this speed value its friction coefficient remains constant. In general, as the normal load increases the resulting coefficient of friction somewhat decreases. The magnitude of sliding speed does not affect the value of friction coefficient remarkably.

As seen from Figure 6, the friction coefficient of austempered ductile iron disk increases with increasing sliding speed for low values of speed. After a certain speed, around 1 m/s, variation coefficient of friction with sliding speed diminishes. The change of friction coefficient with normal load takes place similarly with the former disk. As the normal load increases, the resulting friction coefficient decreases. Friction coefficient reduces at a lower rate from 0.6 m/s at 20 and 40 N load conditions.

In Figure 7, the variations of friction coefficients of MnP coated disk against the same pin at boundary lubrication conditions are shown. MnP coated cast iron has a stable curve for all load conditions. Friction coefficient does not change remarkably with speed.

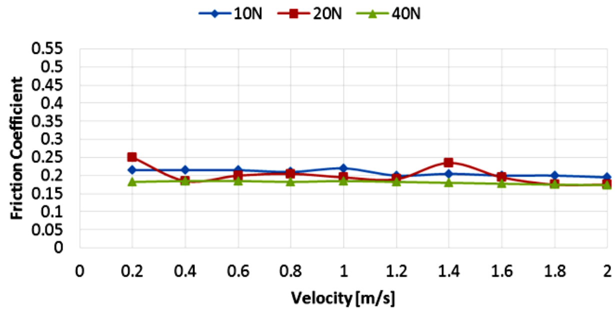

Figure 7. Friction coefficient of MnP coated disk in boundary lubrication conditions

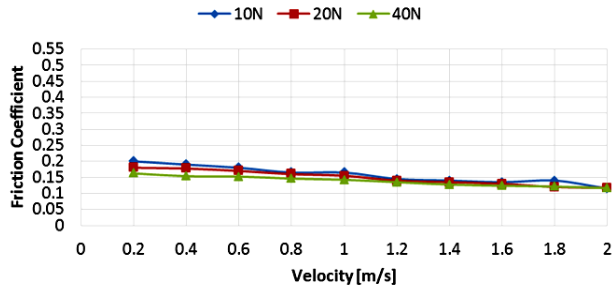

Figure 8. Friction coefficient of austempered disk in boundary lubrication conditions

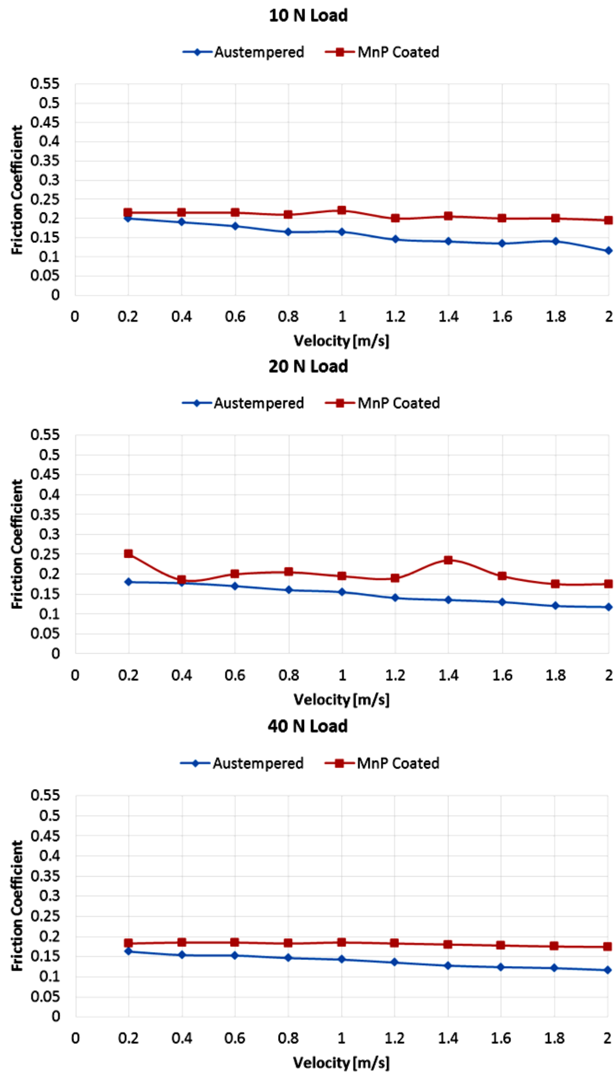

Figure 9. Comparison of disk materials in different normal load conditions

In Figure 8, friction coefficients of austempered ductile cast iron decreases as the speed increase for all normal load conditions. Variation curves seem almost identical for all cases. The reason for this condition is the lubricating effect of compressor oil.

As seen from Figure 9, the austempered ductile cast iron has better friction coefficient from MnP coated ductile cast iron for all normal load conditions. In particular, the difference increases with the rate of speed increase in 10 and 40 N load conditions.

In boundary lubrication condition, friction coefficient of MnP coated ductile cast iron decreases when compared to dry running conditions as expected, but the decrease in austempered ductile cast iron is much more drastic. Austempered ductile cast iron gives a little bit small coefficient of friction values with respect to MnP coated one (Fig. 10).

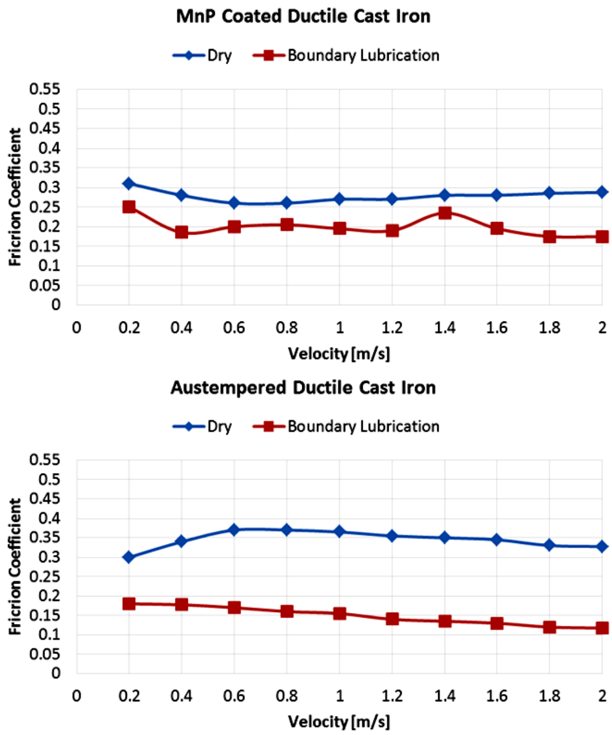

Figure 10. Comparison of test materials in dry and boundary lubrication conditions

3.2 Wear tests

Wear tests were performed with 20 N normal load, 0.5 m/s sliding speed and 3000 m sliding distance in dry running conditions. The variation of the friction coefficient along the sliding distance is shown in Figure 11. There are no significant changes in friction coefficient with sliding distance as can be seen from the Figure 11. The result of wear tests is given in the Figure 12 as a mass loss of pins itself. It has been observed that the pin material showed more material loss when sliding against the austempered disk compared to sliding against MnP coated disk.

An example of wear traces of the pin can be seen in the SEM image of the pin (250 ×), in Figure 13. In Figures 14 and 15, optical micrographs of worn pin sliding against MnP coated and austempered cast iron disks are shown respectively. In these micrographs, wear marks are clearly visible.

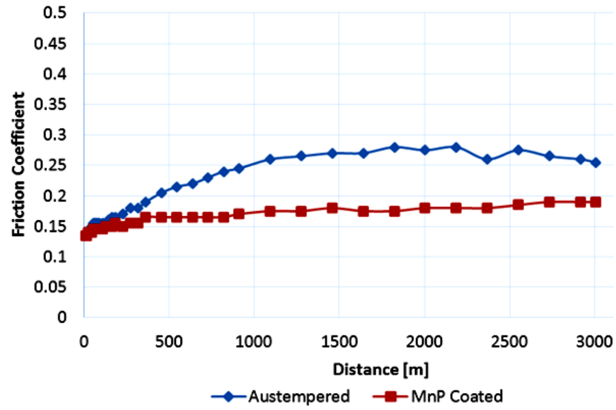

Figure 11. Variation of friction coefficient during a wear test

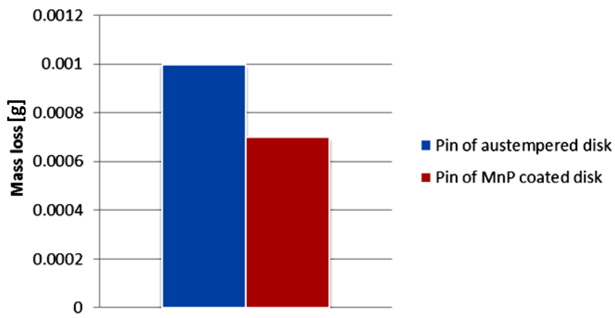

Figure 12. Mass loss of pins

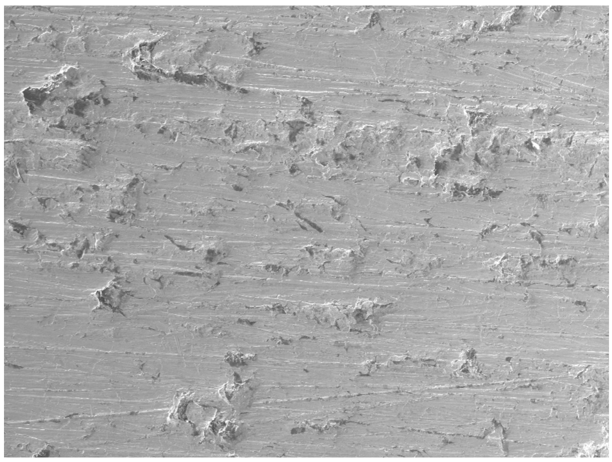

Figure 13. Wear traces on pin (250 ×)

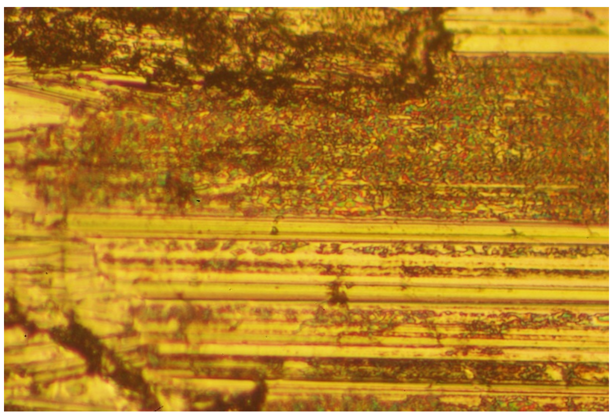

Figure 14. Pin surface in contact with MnP coated disk (250 ×)

4. CONCLUSION

In this study, a comparison was made between MnP coated ductile cast iron and austempered ductile cast iron in dry and boundary lubrication conditions as alternative crankshaft materials. MnP coated disk has better results in friction and wear tests in dry conditions, but in boundary lubrication conditions the austempered disk has significantly better results than MnP coated disk.

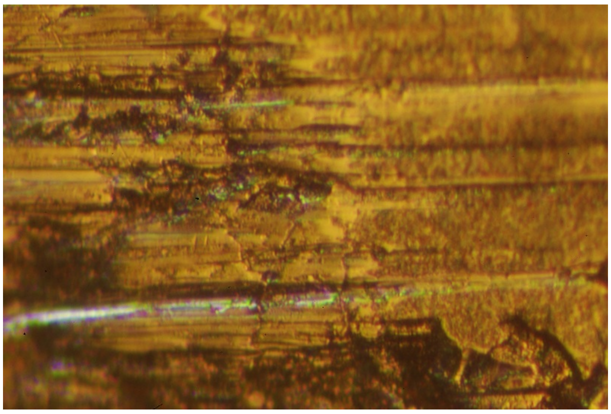

Figure 15. Pin surface in contact with austempered disk (250 ×)

Since the compressor crankshaft operates in an environment containing mineral oil, experimental results suggest that austempered ductile cast iron is a better choice for compressor crankshaft with respect to MnP coated ductile cast iron.

In order to get more detailed information about the usage of austempered ductile cast iron as a compressor crankshaft material, it should be tested under real operating conditions.

ACKNOWLEDGMENT

In our study, we appreciated ARÇELİK Inc. allowing for material and laboratory support, TrakyaDöküm Inc. for material support and Poziterm Heat Treatment for process support.

REFERENCES

[1] Zhanming, J., Yanfei, L., Yuansheng, J., Kaihe, J., Shijian, W. and Zhao, W.: Sliding wear of cast-iron coatings and cast-iron-cast-iron pairs in lubricated contact, Wear, Vol. 152, No. 2, pp. 253-261, 1992.

[2] Hirasata, K., Hayashi, K. and Matsunami, H.: Friction and wear of spheroidal graphite cast iron under severe sliding conditions, in: Dowson, D., Priest, M., Dalmaz, G. and Lubrecht, A.A. (Eds.): *Tribological Research and Design for Engineering Systems*, Elsevier, Amsterdam, 2003, pp. 643-652.

[3] Ghaderi, A.R., Nili Ahmadabadi, M. and Ghasemi, H.M.: Effect of graphite morphologies on the tribological behavior of austempered cast iron, Wear, Vol. 255, No. 1-6, pp. 410-416, 2003.

[4] Hirasata, K., Hayashi, K. and Inamoto, Y.: Friction and wear of several kinds of cast irons under severe sliding conditions, Wear, Vol. 263, No. 1-6, pp. 790-800, 2007.

[5] Straffelini, G., Giuliari, C., Pellizzari, M., Veneri, E. and Bronzato, M.: Dry rolling-sliding wear of austempered cast iron, Wear, Vol. 271, No. 9-10, pp. 1602-1608, 2011.

[6] Cardoso, P.H.S., Israel, C.L. and Strohaecker, T.R.: Abrasive wear in austempered ductile irons: A comparison with white cast irons, Wear, Vol. 313, No. 1-2, pp. 29-33, 2014.

[7] Nicoletto, G., Tucci, A. and Esposito, L.: Sliding wear behavior of nitrided and nitrocarburized cast irons, Wear, Vol. 197, No. 1-2, pp. 38-44, 1996.

[8] Fordyce, E.P. and Allen, C.: The dry sliding wear behaviour of an austempered spheroidal cast iron, Wear, Vol. 135, No. 2, pp. 265-278, 1990.

[9] Yavuz, P., Yeşilçubuk, A., Ürgen, M. and Kazmanlı, K.: *Tribological behaviour of manganese phosphate coating on gray cast iron in boundry lubrication regime*, in: *Proceedings of the 2nd International Surface Treatment Symposium (ISTS 2014)*, 25-27.06.2014, Istanbul (Turkey), pp. 120-125.

ИСПИТИВАЊЕ КАРАКТЕРИСТИКА ТРЕЊА И ХАБАЊА ЛИВЕНОГ ГВОЖЂА У КОНТАКТУ СА МАТЕРИЈАЛОМ КОЛЕНСТОГ ВРАТИЛА НА КОЈИ ЈЕ НАНЕТА МАНГАН-ФОСФАТНА ПРЕВЛАКА ОДНОСНО КОЈИ ЈЕ ТЕРМИЧКИ ОБРАЂЕН ИЗОТЕРМАЛНИМ КАЉЕЊЕМ

Бариш Исхак Спђиколу, Бурђу Јиит, Хусеин Офлаз, Зејнеп Парлар, Ведат Темиз

Фрижидер је један од битних апарата за домаћинство, а његова ефикасност је, услед повећања цене електричне енергије, данас јако битна. Компресор је најважнији део фрижидера који утиче на ефикасност хлађења. Смањење губитака услед трења између делова у релативном кретању, који се налазе у компресору, је због тога од великог значаја. У раду су експериментално одређени коефицијенти трења и величине хабања два контактна пара, тј. нодуларно ливено гвожђе термички обрађено изотермалним каљењем, односно са нанетом манган-фосфатном превлаком, у контакту са сивим ливеним гвожђем (материјалом од кога се праве лежаји коленастог вратила). Експериментална испитивања су извршена у условима без подмазивања и у условима граничног подмазивања, при различитим брзинама клизања и нормалним оптерећењима.