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ENERGY ASPECTS OF TRIBOLOGICAL BEHAVIOUR OF NODULAR CAST IRON

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Abstract. In the paper the energy aspects of the tribological behaviour of materials are determined by measuring the coefficient of friction in the contact between elements of the tribo-mechanical system. During experimental study the different heat threated nodular cast irons are investigated. The friction force and coefficient of friction were measured using realised tribometer with the line contact of a pin-on-disk. Study was performed on two types of nodular cast iron (EN-GJS-500-7 and EN-GJS-700-2 austempered by different isothermal procedure) as pins in contact with carbon steel (C40E) and grey iron disk (EN-GJS-250). The results show that the values of the friction coefficient are significantly influenced by the type of the pin and disk materials, sliding velocity, external load, as well as the other factors that determine the contact conditions. Tribological behaviour of these materials depends as well to a large extent on conditions under which was performed the heat treatment.

Keywords: nodular cast iron, heat treatment, tribology, coefficient of friction.

AIMS AND BACKGROUND

Energy aspects of tribology, in all phases of the life cycle of materials in the contact between elements various types, are often totally neglected[1–3]. The role of tribology in energy saving here are very high in many cases. It is well known that by reducing the coefficient of friction materials substantial amounts of energy can be saved due to reducing the production of wasted heat energy. These savings are relatively large in many cases, and present the primary tribological energy gains. Therefore,

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by improving characteristic of materials, tribological surfaces and lubricants, we can reach high energy gains. However, the role of tribology in energy saving is not easy to measure or estimate[4].

After established duration of contact, tribological behaviour of materials dependent both on the methods that determine them as well as on the conditions under which the contact between elements is realised. Tribological behaviour is determined by measuring friction force in the contact zone or by measuring the value of wear of one or both elements of the tribo-mechanical system[5,6].

Tribological behaviour of the tribo-mechanical systems primarily depends on the type of the contact materials. Thereby, not only on the physical and chemical properties of materials in the contact, but also to a significant extent of metallurgical transaction, namely conditions of their heat treatment[7–10].

Modern manufacturing processes are characterised by continuous changes in production machine pieces from the different type of materials. In past several years, are increasingly applied nodular cast irons, as material for numerous products, from automobile industry to machine tools industry. Growing application of nodular cast irons is a consequence of their good properties that are obtained after the heat treatment. Unfortunately, tribological behaviour of these materials are not sufficiently known[11,12].

The research of nodular cast irons with scientific notation has a strong presence. In the research work Jesic[1] initiative was taken to improve the technological properties of the nodular cast iron samples tested to the operation of actual structural components used in manufacturing industry. Samec et al.[13] present evaluate of the fatigue life of nodular cast iron which is used for production of brake disks. Gumienny[14] shows the results of the adhesive wear resistance of nodular cast iron with carbides.

Tribological behaviour of nodular cast iron, as and other materials, shall be determined through assessment of energy aspects in tribological systems and by measuring a selected wear parameter in time intervals of their functioning[15–17]. Thereby, it is especially important measurement methodology and choice of tribo-element materials. The laboratory measurement of the energy aspects is performed on a certain type of tribometers in which the process is usually achieved by sliding of the pin on disk, the disk on disk and so on[2,7,18]. The geometric parameters of wear (line, surface and volume) are measured using a microscope or other methods (contact, noncontact), and the amount of wear products identified by weighting methods or methods based on ferro spelling and radioactivity.

Previous studies of energy aspects on the tribological behaviour of nodular cast irons, has been demonstrated through a number of scientific and experimental works, shows that tribological characteristics depend on the physical, chemical, and mechanical properties of materials and conditions of the material surface layer[1,11–14]. In addition, the tribological parameters affect whether the material is composite and the amount of fibre contained in the material microstructure, as well as the effect of disk coating thickness on which studies were performed[19–21].

Investigations of the tribological behaviour of nodular cast irons conducted at several large industrial systems and universities have shown that they also primarily depend on conditions of their heat treatment[1,9,22]. Nodular cast iron with different nodule counts was used on the tribological aspects assessment by conventional and successive austempering processes[23]. Samples with the optimum mechanical properties were used to study the effect of austempering process on the tribological behaviour of austempered ductile iron[24]. The effect of graphite morphologies on the tribological behaviour of austempered cast iron is shown in Ref. 25.

This work aims towards giving a better background in the area of learning about the energy aspects of tribology. Using a realised tribological information system, examined was the tribological behaviour of nodular cast irons in terms of friction coefficient. Study was performed on device with stationary pin and rotating disk. The results of energy aspects on the tribological behaviour of the two type nodular cast iron indicate the importance of heat treatment on the resistance to the friction coefficient.

EXPERIMENTAL

Tribological behaviour of nodular cast iron EN-GJS-500-7 and EN-GJS-700-2, with three different heat treatments, was investigated in the present study. Figure 1 shows the initial microstructure of the nodular cast irons used in the test. Metallographic microstructure of nodular cast iron EN-GJS-500-7 was ferrite-pearlite, and of EN-GJS-700-2 was mostly pearlite. During the structural test of the nodular cast iron the etching was performed with 2% HNO_3 and magnified 500 times.

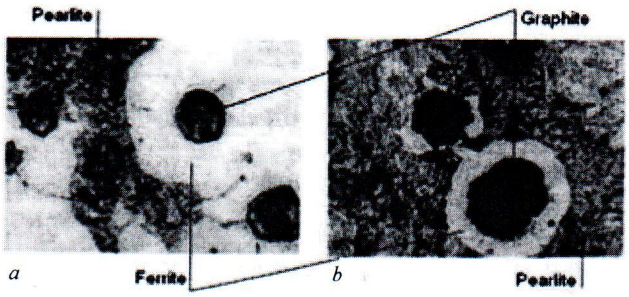

Fig. 1. Initial microstructure of nodular cast iron EN-GJS-500-7 was ferrite-pearlite base (*a*), and of EN-GJS-700-2 was mostly pearlite base (*b*)

The tests program of tribological behaviour was provided by measuring the coefficient of friction that occurs in a contact between the pins made of nodular cast iron and the disks made of cast iron EN-GJL-250 (Hardness of 52 HRC) and carbon steel C40E (Hardness of 46 HRC).

Table 1 shows the chemical composition of the material from which pins and disks are made.

Table 1. Chemical composition of pin and disk materials

Tribo ele-	Materials	Chemical composition (%)							
ments		C	Si	Mn	Mg	P	S	Cu	Ni
Pin	EN-GJS-500-7	3.85	2.90	0.076	0.035	0.02	0.030		1.5
	EN-GJS-700-2	3.76	2.35	0.510		0.02	0.004	1.48	1.5
Disk	EN-GJL-250	3.30	0.80	0.800		0.20			
	C40E	0.44		0.550					

Isothermal heat treatment is the procedure which carried by tempering the nodular cast iron used in the test. Figure 2*a* shows a diagram of the isothermal procedure used in austempering of nodular cast iron. The process of austempering was achieved by heating up to a temperature of 900°C, where it is held for about 90 min and then fast cooled to a temperature (520–250°C) where kept to 60 min, namely 90 min. This procedure gives a mostly bainite microstructure (Fig. 2*b*) that enables improved toughness, and in this case the wear resistance.

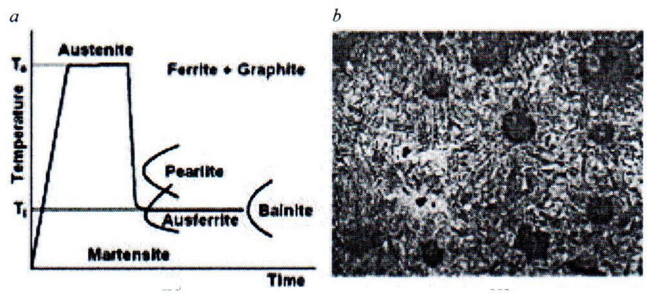

Fig. 2. Diagram of the isothermal procedure (*a*) and with bainite microstructure of nodular cast iron (*b*)

The conditions under which heat treatment were pins conducted are shown in Table 2, along with basic information about the actual microstructure and high hardness values measured in the frontal areas. The austempering temperature and tempering time were identical for thermal treatment of all samples (T_a/t = 900°C/90 min). Temperatures of isothermal tempering and time of tempering duration (T_i/t) were different, in order to obtain different microstructure of nodular cast iron. More information about microstructure of heat treated nodular cast iron is presented in Ref. 1.

Table 2. Heat treatment of nodular cast iron pins

Types of pin material	Conditions of heat treatment		Results of heat treatment	
	T_a/t (°C/min)	T_i/t (°C/min)	hardness (HB)	microstructure
EN-GJS-500-7 (Pin 1) EN-GJS-700-2 (Pin A)	900/90	520/60	302	graphite nodules the bainite of basis
EN-GJS-500-7 (Pin 2) EN-GJS-700-2 (Pin B)	900/90	250/60	363	deformed graphite nodules the martensite basis
EN-GJS-500-7 (Pin 3) EN-GJS-700-2 (Pin C)	900/90	350/90	285	graphite nodules the needle-based bainite

The measuring system for the tribological behaviour of materials used was a tribometer with on-line contact. The basic characteristics of the tribometer are normal load F_n = 1–500 N and sliding velocity v = 0.1–5 m/s. During experiment the friction force F_t was measured by using a Kistler dynamometer, where previously the pin was positioned. By measuring the friction forces at different levels of normal load and sliding velocity, the coefficients of friction $\mu = F_t/F_n$ for a given combination of contact pairs are determined.

The complete results of measurements of tribological behaviour of these two types of nodular cast are stored in database which belongs to a realised Tribological Information System. The schematic view of research procedure with the basic structure of the measuring chain and with image of the Tribometer 'Pin-on-Disk' TPD-93 is shown in Fig. 3.

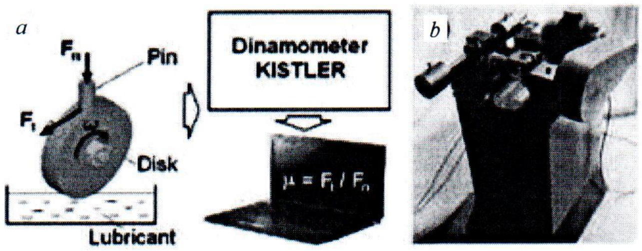

Fig. 3. Schematic view of research procedure (*a*) and image of the Tribometer 'Pin-on-Disk' TPD-93 (*b*)

In this case the parameters of pin and disk topography are important prior to and following the formation of contact trace. Basic parameters are shape, dimension and surface roughness. Shape of pin and disc can be seen in Fig. 3. Dimensions of the pin and disk are ∅10 × 12 and ∅68 × 8 mm, respectively. Width and depth of the pin trace were b_p = 0.84 and δ_p = 0.0013 mm, respectively. Surface roughness of the pin through which the contact was made with the disk was around R_a =

0.25–0.34 μm. Figure 4 shows the typical appearance of frontal surface roughness of the pin, obtained by measuring with 'Talysurf No 6'.

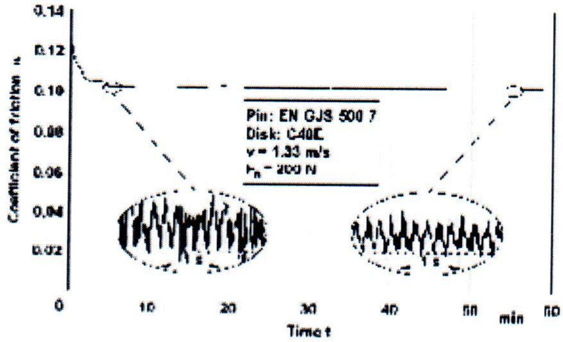

Fig. 4. Example of frontal pin surface roughness

In the experimental study three sliding velocity were used, as follows: $v = 1.05$; 1.33 and 1.65 m/s. Normal force in the contact zone (external load) was realised through the carriers weight and dynamometer ranged from F_n = 160–450 N. The study included experimental tests in the duration of 60 min of effective contact.

In the course of contact with oil lubrication was done by POLAR 32 (Viscosity ISO 32, Quality level DIN 51503 KC) and swimming in an oil bath disk mounted below it, with temperature ambient. The realised oil film thickness indicates the occurrence of boundary lubrication.

RESULTS AND DISCUSSION

Tribological behaviour of nodular cast iron from the energy aspects is determined by measurements of the friction force F_t, namely the coefficient of friction $\mu = F_t/F_n$ in corresponding conditions of contact realisation between the elements of tribo-mechanical system.

The coefficient of friction is changing during the constant contact conditions of exploitation. At the beginning of contact, the coefficient of friction has the highest value. In the first phase of contact duration the coefficient of friction fall down to certain value. Approximately constant value of the friction coefficient is held almost until the end of the second phase of contact duration. In the third phase of contact duration between the elements of the tribo-mechanical system, when the catastrophic wear appears, the coefficient of friction suddenly changes the value. In Fig. 5 is shown dependence of contact duration on the coefficient of friction, obtained experimentally.

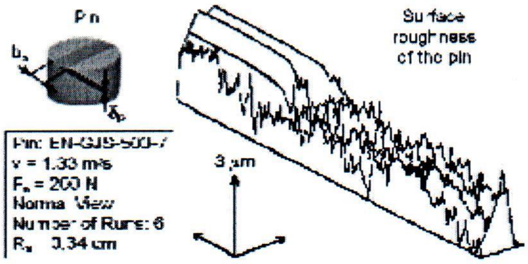

Fig. 5. Variation of the friction coefficient on the contact duration of the elements tribo-mechanical system

Through comparison of the friction coefficient values, obtained by experiment at the end of contact, was determined the influence of normal load, sliding velocity, type of the pin materials and heat treatment, for the material of disks, for certain contact conditions with the elements of tribo-mechanical system.

The influence of the normal force value on the coefficient of friction was not observed during this experimental program. Figure 6 shows an example of experimental results that show the size of the coefficient of friction in the contact zones of the pin made of nodular cast iron EN-GJS-500-7 (treated with three types of heat treatment) and the disk made of grey iron EN-GJL-250.

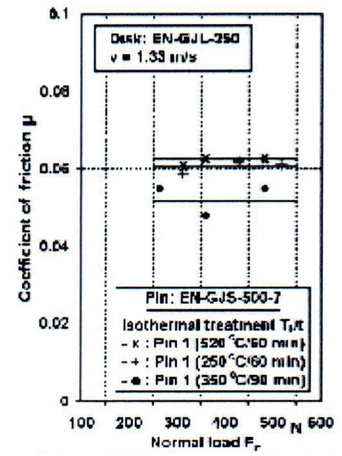

Fig. 6. Dependence of normal load on friction coefficient

The influence of sliding velocity on the value of the coefficient of friction is significant in a relatively narrow limits of its changes (from 1.05 to 1.65 m/s) for all three types of the contact between the disk made of grey iron EN-GJL-250 and pins made of nodular cast iron EN-GJS-500-7. Figure 7 shows how to modify the coefficient of friction with the change of sliding velocity on the contact pairs, when pins of nodular cast iron EN-GJS-500-7 treated with three types of heat treatment.

The results show that the value of the friction coefficient is significantly influenced by sliding velocity, as well as, with the type of the pin materials heat treatment.

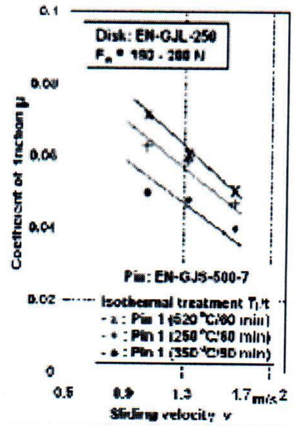

Fig. 7. Dependence of sliding velocity on friction coefficient

Figure 8 shows the results of the friction coefficient measurements, by performing an experimental program in which the main objective was to determine the impact of materials of the disk on the value of the coefficient of friction, during the use of pins made by heat treated nodular iron under different conditions. The size of the friction coefficient is significantly influenced by the type of the disk material (cast iron EN-GJL-250 and carbon steel C40E) in contact and with all six types of pins (three made of nodular cast iron EN-GJS-500-7 and three made of nodular cast iron EN-GJS-700-2).

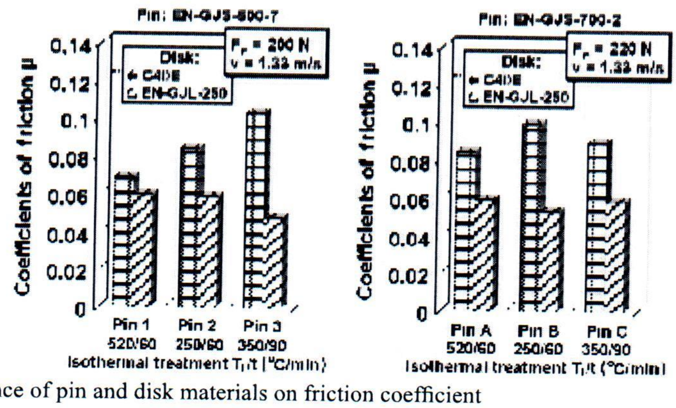

Fig. 8. Influence of pin and disk materials on friction coefficient

Based on experimental study it was established that on the value of the friction force, namely coefficient of friction is significantly influenced by factors that determine the conditions of contact realisation between the elements of tribo-mechanical system (material, geometric and kinematic parameters of contact). From analysing the results it was concluded that the energy aspects on the tribological behaviour of nodular cast iron depend on the structural characteristic of the materials pin and disk. It was noted, however, that the impact of materials on the size of the disk friction coefficient depends on the type of pins heat treatment.

The obtained results can be used for the proper selection of the type and regime of the nodular cast iron heat treatment, with the aim of improving the tribological behaviour of the contact pairs. Optimisation of tribological parameters, based in order to obtain low as possible friction coefficient, and the better tool wear characteristic helps in the selection of materials that are exposed to the sliding friction.

Complete information about the tribological behaviour of these and other types of materials or elements of the tribo-mechanical system is stored in the authors database of the tribological information system.

CONCLUSIONS

Energy aspects of the tribological behaviour of nodular cast iron measured by coefficient of friction are relative and depend on the conditions under which the contact is achieved.

Tribological behaviour two types of nodular cast iron, EN-GJS-500-7 and EN-GJS-700-2, depend to a large extent on the conditions under which is its heat treatment performed, namely by the microstructure that receives by heat treatment.

When comparing the tribological behaviour of nodular cast iron it is necessary to take into account the sliding velocity and type of other material the contact pair in tribo-mechanical system. Neglecting these two factors of contact conditions makes comparison of tribological characteristics unreliable and unrealistic.

The experimental studies of the improved tribological behaviour of nodular cast iron can be used during the selection of materials and heat treatment in order to reduce the friction and wear of the selected contact materials in the specific industrial conditions.

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