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Abrasive wear

ABRASIVE WEAR AND WEAR RESISTANCE OF HIGH STRENGTH CAST IRON CONTAINING Sn MICROALLOY

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ABSTRACT

A procedure for the study of wear of high strength (spheroid) cast iron under conditions of dry friction on surfaces with fixed abrasive following the kinematics scheme 'pin-on-cylinder' with spiral movement has been developed. Five type specimens of high strength cast iron without and with micro-alloy of various Sn contents – 0.08, 0.02, 0.06 and 0.12 mass.% were studied. The experimental results lead to graphs and diagrams of the relationships for the parameters mass and linear wear, wear rate and intensity, and wear resistance depending on process time, sliding way and normal load.

This study is connected with the completion of a PhD thesis and of the tasks under the Project ДУНК-01/3 'University R&D Complex for innovation and transfer of knowledge in micro/nano-technologies and materials, energy efficiency and virtual engineering' funded by the Bulgarian Ministry of Education and Science.

Keywords: tribology, high strength cast iron, micro-alloying, abrasive wear, wear resistance.

AIMS AND BACKGROUND

Being a natural composite material with steel metal matrix with embedded graphite phase, the high strength (spheroid) cast iron provides a complex of properties which makes it different from the conventional Fe–C alloys.

The mechanical and tribological properties are strongly dependent on the composition, structure, and on the size and distribution of the graphite inclusion,

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as well as on the presence of micro-alloying elements both in bulk and surface layer.

Tin (Sn) is most often used as alloying element. The usual quantities of less than 0.15 % do not influence the leaning to graphite adoption in the crystallisation process.

Alloying of spheroid cast iron by Sn causes perlitisation of the metal base, along with strength and hardness increase by decrease in the relative increment of collision resilience. This influences the parameters of friction and wear in the contact joints of machines[1–3].

The paper aims study of the parameters of wear of high strength cast iron micro-alloyed by various mass percent contents of tin (Sn) under conditions of dry friction on a surface with fixed abrasive particles.

EXPERIMENTAL

Materials. Sample specimens of high strength cast iron with the following mass percent contents of tin (Sn) 0.018, 0.020, 0.032 and 0.051% were investigated. The chemical composition and the designation of the sample specimens are given in Table 1. In Table 2 are shown the values of specimens hardness.

Table 1. Chemical composition of sample specimens

No	Chemical element (%)	Specimen number				
		0	1	2	3	4
1	C	3.87	3.87	3.87	3.87	3.87
2	Sn	–	**0.018**	**0.020**	**0.032**	**0.051**
3	Si	1.55	1.55	1.55	1.55	1.55
4	Mn	0.34	0.34	0.34	0.34	0.34
5	P	0.029	0.068	0.063	0.075	0.077
6	S	0.012	0.051	0.059	0.047	0.060
7	Cr	0.030	0.030	0.030	0.030	0.030
8	Mo	0.018	0.019	0.020	0.017	0.018
9	Ni	0.024	0.024	0.024	0.024	0.024
10	Co	0.013	0.017	0.014	0.013	0.013
11	Cu	0.051	0.058	0.077	0.059	0.070
12	Ti	0.0013	0.0013	0.0018	0.0015	0.0013
13	W	0.126	0.126	0.135	0.123	0.126
14	Pb	0.039	0.039	0.043	0.040	0.039
15	As	0.036	0.036	0.037	0.038	0.040
16	Zr	0.003	0.003	0.003	0.003	0.003
17	B	0.0083	0.0083	0.0074	0.0091	0.0088

Table 2. Specimens' hardness

Specimen No	**0**	**1**	**2**	**3**	**4**
Sn (%)	–	0.018	0.020	0.032	0.051
Hardness (HB)	179	197	203	262	277

Wedge-shaped sample specimens were obtained through gravitational casting in the factory 'Osam' in the city of Lovech.

Hardness was measured by means of a Brinell hardness meter of the type 2109TB, using a steel ball of diameter 10 mm and normal load 30 kN, by 15 s hold time[4].

Procedure and device for abrasive wear study. The experimental study was realised by a procedure and device for quick tests according to the kinematical scheme 'pin-on-disk'. Figure 1 shows the functional scheme of the device. The procedure was elaborated in the Laboratory of Tribology at the Faculty of Industrial Technology of the Technical University – Sofia. The actually valid standards were taken into consideration[5–8].

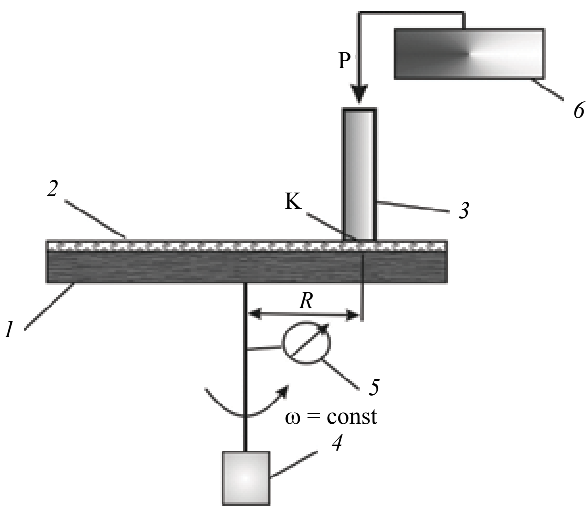


Fig. 1. Functional scheme of the device 'pin-on-disk'

The studied cylindrical specimen *3* (the body) was mounted fixed in an appropriate holder of the loading head *6*. Its position allows that the frontal surface K enters in contact with the abrasive surface *2* of the horizontal disk 1 (the counter-body). The horizontal disk *1* is rotating with constant rotational speed $\omega = const$ around its vertical axis. The number of revolutions of the disk 1 is read by the revolution-counter *5*.

The device allows variation of the relative sliding speed between specimen *3* and the disk *1* using two manners: by changing the rotational speed of the disk through a control unit or by variation of distance R between the revolution axis of counter-body 1 and the axis of specimen *3*. The abrasive surface *2* of counter-body *1* is being modelled through surfaces of impregnated carbo-corundum with hardness minimum 60% higher than the hardness of the tested coatings according to the requirements of the standard.

The procedure of the investigation comprises the following sequence:

1. The surfaces of all specimens, which are of equal cylindrical shape and size, are subjected to mechanical treatment in 3 stages – rough, grinding and polishing, up to obtaining equal roughness $R_a = 0.4 \times 0.6$ µm.

2. The mass of the specimen is measured before and after a given sliding path (number of cycles of interaction) by means of electronic balance of the type WPS 180/C/2 with accuracy up to 0.1 mg. Specimens are cleaned with a solution neutralising the static electricity before each measurement.

3. Specimen 3 is fixed in loading head *6* in a given position, and by means of system of leverages normal central load P is being set.

Parameters of wear. The parameters of the studied mass and linear wear are given in Table 3.

The designations in the table are as follows: A_a – apparent contact area of sliding; S – sliding path.

A factor 'comparative wear resistance' ε introduced, which is non-dimensional and gives the ratio between the absolute wear resistance of the tested specimen and the wear resistance of a chosen reference sample. A sample of high strength cast iron without Sn micro-alloy was accepted as reference sample by the authors.

All specimens were studied under equal conditions as given in Table 4.

Table 3. Parameters of wear

Parameters of mass wear	
Mass wear (mg)	$m_o - m$
Mass of the specimen before wear (mg)	m_o
Mass of the specimen after wear (mg)	m
Wear rate (mg/min)	$m_o - m/t$
Wear intensity (mg/m)	$m_o - m/S$
Specific intensity (mg/mm²m)	$m_o - m/A_a S$
Absolute wear resistance (m/mg)	$S/m_o - m$
Specific wear resistance (mm²m/mg)	$SA_a/m_o - m$
Linear wear	
Linear wear (µm)	$h_o - h$
Thickness of the specimen before wear (µm)	h_o
Thickness of the specimen after wear (µm)	h
Wear rate (µm/min)	$h_o - h/t$
Wear intensity (µm/m)	$h_o - h/S$
Specific intensity (µm/mm²m)	$h_o - h/A_a S$
Absolute wear resistance (m/µm)	$S/h_o - h$
Specific wear resistance (mm²m/µm)	$SA_a/h_o - h$

Table 4. Test parameters

Normal l oad	$P = 10.3$ (N)
Apparent contact area	$A_a = 78.5.10–6$ (m^2)
Apparent contact pressure	$P_a = 13.12$ (N/cm^2)
Average sliding speed	$V = 13.1$ (cm/s)
Type of the specimen	cylindrical
Material density of the specimen	7.8×10^3 (kg/m^3)
Initial roughness of the specimen	$R_a = 0.4\div0.6$ (µm)
Abrasive surface	corundum P 320

RESULTS AND DISCUSSION

A part of the experimental results for the parameters of wear are given in this paper in the form of Figs 2–7 and Table 5.

The above investigations confirm the authors outcome of earlier studies, namely that micro-alloying of high strength cast iron with Sn influences its mechanical and tribological properties[2,9]. Increasing the Sn % contents leads to increase in the hardness of the high strength cast iron. The highest values of wear are for the specimens without Sn micro-alloy.

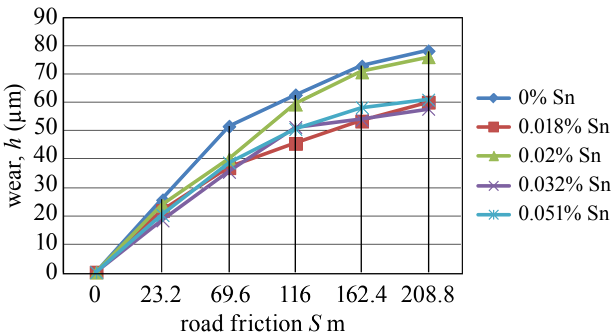


Fig. 2. Variation of linear wear with the friction path

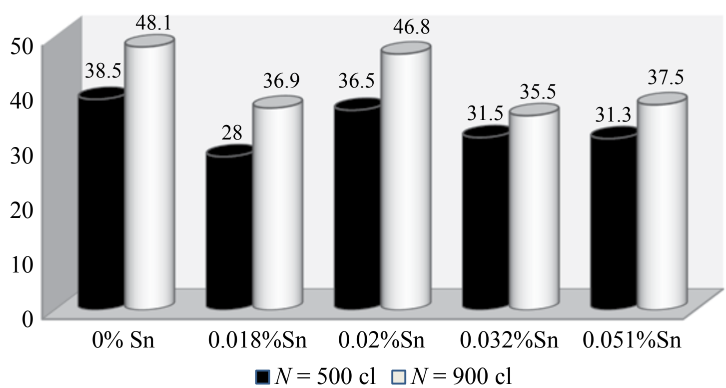


Fig. 3. Diagram of mass wear of all specimens for 2 friction cycles

Fig. 4. Variation of wear rate (μm/min) with the number of friction cycles

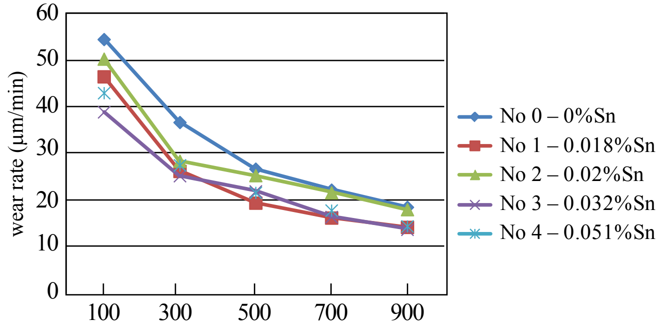
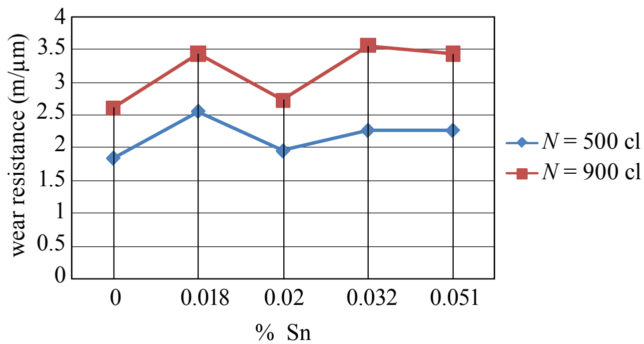


Fig. 5. Variation of wear resistance with the Sn % contents for 2 friction cycles



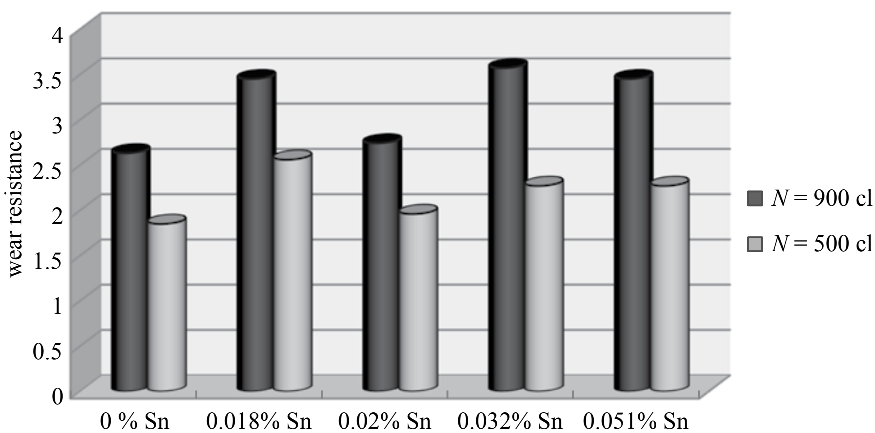


Fig. 6. Wear resistance of cast iron (m/μm) at various Sn % contents for friction cycles number *N*=900 cl and *N*=500 cl

All specimens containing Sn show higher wear resistance compared with cast iron without Sn contents. A direct dependence exists between the % contents of Sn and hardness and wear resistance of cast iron in the studied limits of Sn contents. Deviation of this dependence is observed for the specimen with 0,02% Sn contents. The same statement is to be seen in the earlier studies of the authors.

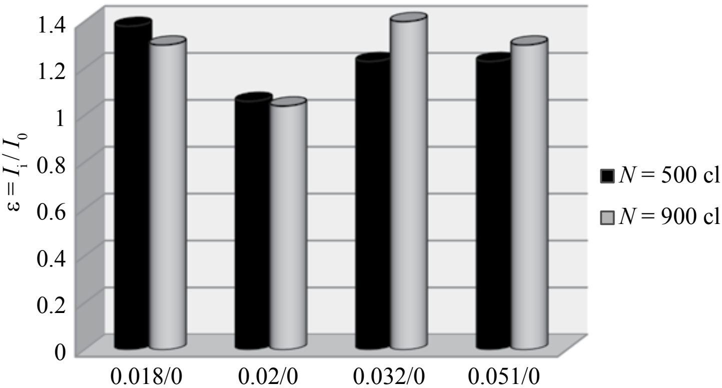


Fig. 7. Diagram of the comparative wear resistance by reference sample high strength cast iron without Sn micro-alloy for 2 friction cycles

Table 5. Comparative wear resistance by using as reference sample high strength cast iron without Sn micro-alloy

Number of cycles (N)	Comparative wear resistance, $\varepsilon_{i,0}$			
	$\varepsilon_{1,0}$	$\varepsilon_{2,0}$	$\varepsilon_{3,0}$	$\varepsilon_{4,0}$
$N = 500$ cl	1.38	1.06	1.23	1.23
$N = 900$ cl	1.3	1.04	1.4	1.3

Maximum wear resistance is obtained for 0.032% Sn contents. At higher contents – 0.051%, the wear resistance decreases.

The wear resistance is equal for sliding path of 500 cycles at 0.032 and 0.051% contents, however the comparative wear resistance for the cast iron with lower Sn contents (0.032%) is higher (Table 5).

CONCLUSIONS

Comparative study of abrasive wear and wear resistance has been carried out for specimens of high-strength cast iron with micro-alloy of tin of different percent contents.

Micro-alloying with Sn improves wear resistance of cast iron however, this influence is not unambiguous. After a value of increment of Sn quantity, the wear resistance begins deceasing.

The maximum value of the relative wear resistance strongly depends on the friction paths length, given in our case by the number of cycles.

Although the authors have no photos of the microstructure at this stage of the study, the last observation could be interpreted as result related to the non-homogeneous distribution of the graphite phase in the structure of the specimen.

Wear and wear resistance are the parameters, which are most sensitive to the structure of material and the time of wear process (the friction path). It is possible that in some stages of the wearing process a structure of higher contents of the graphite phases is available in the contact zone.

The relationship between wear and friction path under conditions of abrasive wear is not linear function (Figs 2 and 4). A period of running-in is observed, which is of various duration for specimens with different contents of tin. The period of running-in will be subject of individual study.

The obtained results are sign for the authors that future systematic complex investigations on tin are needed, including also comparative study with high strength cast iron alloyed with copper.

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This study is connected with the completion of a PhD dissertation and of the tasks under the Project ДУНК-01/3 'University R&D Complex for innovation and transfer of knowledge in micro/nano-technologies and materials, energy efficiency and virtual engineering' funded by the Bulgarian Ministry of Education and Science.

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