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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 percents 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 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.

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

1. INTRODUCTION

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 make 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, 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 crystallization process.

Alloying of spheroid cast iron by Sn causes perlitization of the metal base, along with strength and hardness increase by decrease of the relative increment of collision resilience. This influences the parameters of friction and wear in the contact joints of machines [1,2,3].

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.

2. MATERIALS, PROCEDURE AND PARAMETERS OF WEAR

2.1. 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%. The chemical composition and the designation of the sample specimens are given in Table 1.

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

Hardness was measured by means of 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]

Table 2 shows specimens' hardness.

Table 1: Chemical composition of sample specimens

№	Chemical element, %	Specimen's 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's No.	**0**	**1**	**2**	**3**	**4**
Sn, %	-	0,018	0,020	0,032	0,051
Hardness, HB	179	197	203	262	277

2.2 Procedure and device for abrasive wear study

The experimental study was realized 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 [5,6].

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 the 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 the distance *R* between the revolution axis of the counter-body 1 and the axis of the specimen 3.

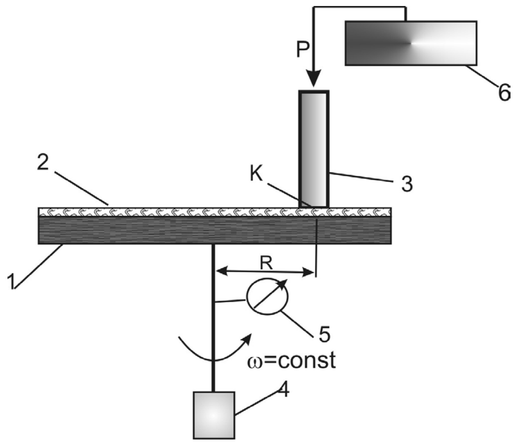

Figure 1: Functional scheme of the device "pin-on-disk"

The abrasive surface 2 of the counter-body 1 is being modeled 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 three stages – rough, grinding and polishing, up to obtaining the equal roughness $Ra = 0{,}4 \div 0{,}6\ \mu m$.

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 neutralizing the static electricity before each measurement.

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

2.3 Parameters of wear

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

Table 3. Parameters of wear

Mass wear	
mass, [mg]	m_o-m
wear rate, [mg/min]	m_o-m/t
wear intensity, [mg/m]	m_o-m/S
specific intensity, [mg/mm^{2}m]	m_o-m/A_aS,
absolute wear-resistance, [m/mg]	S/m_o-m
specific wear-resistance, [mm^{2}m/mg]	S.A_a/m_o-m
Linear wear	
wear, [µm]	h_o-h
wear rate, [µm/min]	h_o-h/t
wear intensity, [µm/m]	h_o-h/S
specific intensity [µm /mm^{2}m]	h_o-h/A_aS
absolute wear-resistance, [m/ µm]	S/h_o-h
specific wear-resistance [mm^{2}m/ µm]	S.A_a/h_o-h

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

The factor "comparative wear-resistance" ε is 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 are studied under equal conditions given in Table 3.

Table 3: Test parameters

normal load	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	Ra = 0,4÷0,6 [µm]
abrasive surface	Corundum P 320

3. EXPERIMENTAL RESULTS

A part of the experimental results for the parameters of wear are given in this paper in the form of graphs, tables and diagrams.

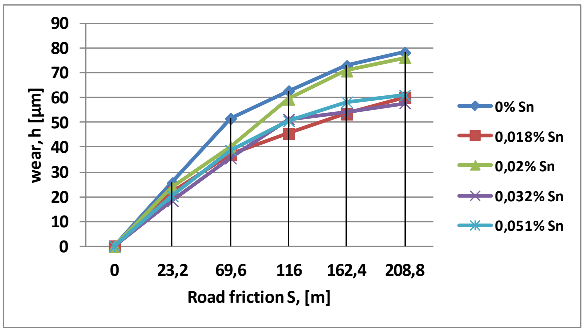

Figure 2. Variation of linear wear [µm] with the friction path [m]

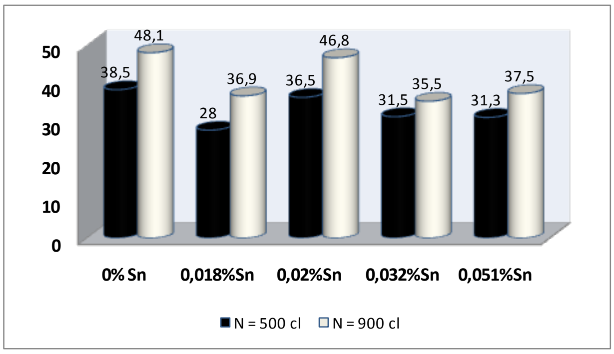

Figure 3. Diagram of mass wear [mg] of all specimens for two friction cycles

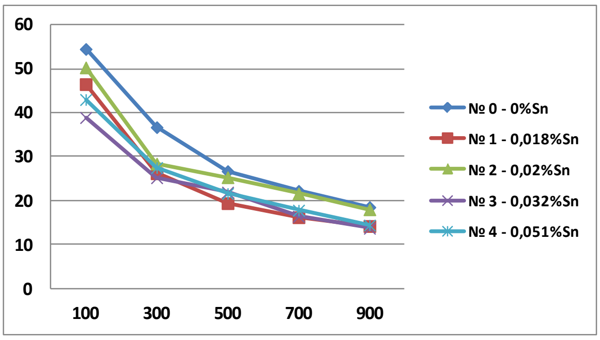

Figure 4. Variation of wear rate [µm/min] with the number of friction cycles

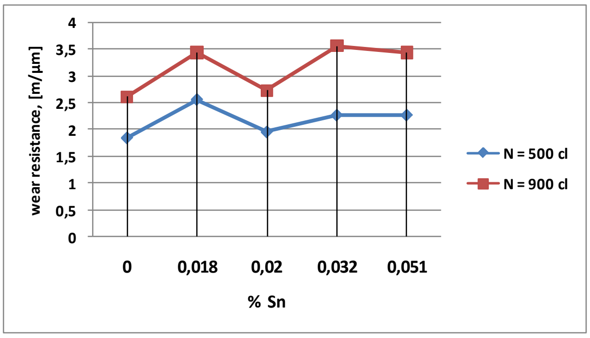

Figure 5. Variation of wear-resistance [m/µm] with the Sn % contents for two friction cycles

Table 4: 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

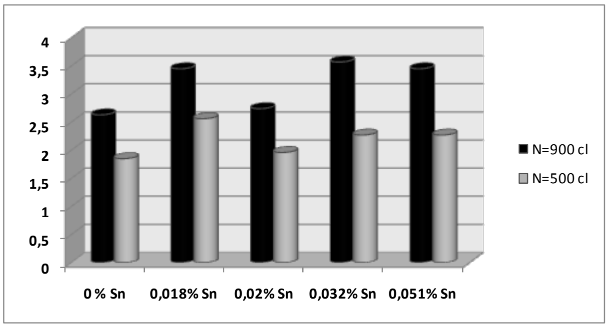

Figure 6 Wear-resistance of cast-iron [m/μm] at various Sn % contents for friction cycles number N=900 cl and N=500 cl

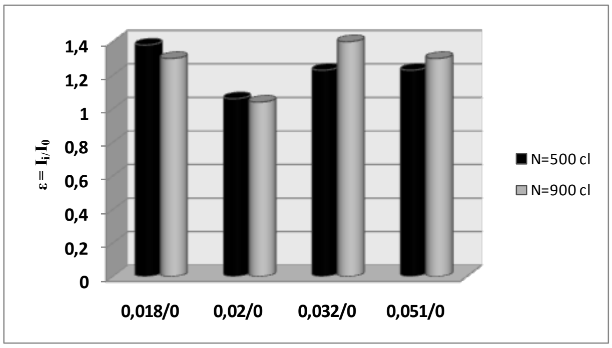

Figure 7. Diagram of the comparative wear-resistance $\varepsilon_{i,0} = I_i/I_0$ by reference sample high strength cast iron without Sn micro-alloy for two friction cycles

4. RESULTS ANALYSIS, OUTCOME AND CONCLUSIONS

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 [2,7].

Increasing the Sn % contents leads to increase of the hardness of the high strength cast iron.

The highest values of wear are for the specimens without Sn micro-alloy. 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.

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 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 4. 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.

Acknowledgement

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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