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Investigation on Tribological Behavior of Ductile Cast Irons with Nanosized Particles

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***Abstract*—The work in this study is focused on investigation of the tribological behavior of ductile cast iron with nanosized particles: titanium nitride TiN; titanium nitride 30% + titanium carbonitride 70% (30%TiN+70%TiCN). The ductile cast iron composition is: Fe-3,55C-2,67Si-0,31Mn-0,009S-0,027P-0,040Cu-0,025Cr-0,08Ni-0,06Mg wt%. Before the addition to the melt nanosized particles were coated with nickel by the electroless nickel deposition method EFFTOMNICKEL .The nickel coating on the nanosized particles ensures their wetting in the melt as well as their uniform distribution into the cast. The optical and quantity metallographic observations and wear test are performed to study the influence of the nanoparticle additives on the cast iron tribological properties. It is observed that the quantity proportion changes between pearlite, ferrite and graphite phase in the cast iron structure. The graphite shape is retained the same, but the nanosized additives decrease the average diameter of the graphite spheres Dmid and increase the quantity of the graphite phase in the structure of ductile cast irons. The cast iron wear resistance in the presence of nanosized additives of (TiN+TiCN) and TiN increases to 55–69% in comparison to wear resistance of the cast iron without nanoparticles.**

Keywords—nanosized particles, microstructure, hardness, wear resistance, ductile cast iron.

I. Introduction

The grey cast iron antifriction properties and wear resistance are well known and depend on the graphite presence in the cast iron structure. At the same quality of the graphite phase (shape, size, quantity and distribution) the wear resistance of the cast iron depends on the structure of the metal base. The graphite characteristics and the metal base structure define the mechanical properties, which could be changed by thermal processing and alloying, as well as the tribological properties of the grey cast iron [1]–[6]. In a small quantity the nanosized additives to the melt change the graphite morphology from flake-like to vermicular-like [7] and the matrix structure, which increases the wear resistance [7]–[12].

The aim of this study was to investigate the influence of different nanosized additives on the graphite characteristics, metal base microstructure and tribological properties of ductile cast iron samples.

II. Materials and methods

The samples from ductile cast iron with additives of nanosized particles: titanium nitride TiN; titanium nitride 30%TiN + titanium carbonitride 70%TiCN are investigated. The composition of ductile cast iron is: Fe-3,55C-2,67Si-0,31Mn-0,009S-0,027P-0,040Cu-0,025Cr-0,020Ni-0,039Mg wt%. The quantity of the nanosized additives into the cast iron is 0,01 wt %. The electroless nickel coating is deposited on the nanopowders prior to the casting by EFTTOM-NICKEL Method [13]. Nickel coating deposited on the nanosized particles improves their wetting and uniform distribution in the moulding volume.

The microstructure of cast iron samples is observed by means of the optical metallographic microscope GX41 OLIMPUS. The samples were treated with 2 % HNO_3 - C_2H_5OH solution before the examination. The microhardness of the coating was determined by Brinell Method. The quantity metallographic analysis is performed by „Olympus MicroImage" Software and the data for an average diameter Dmid of the graphite grains, their roundness as well the volume parts of graphite, pearlite and ferrite are received.

The experimental testing of the wear is performed in conditions of a fixed abrasive by a cinematic scheme „pin - disc" using method and a device for an accelerated testing. The device functional diagram is shown in Fig. 1.

The tested cylindrical sample 3 (body) is fixed in a loading head 6 as its frontal surface contacts with the abrasive surface 2 of a horizontal disc 1 (antibody). The antibody 2 rotates with a constant angular speed around its vertical axis. The cycle's number is accounted with a cyclometer 5. The device allows alteration of the sliding speed changing the disc angular speed from a control unit and trough changing of the distance between the rotation axis of the antibody 1 and the axis of the sample 3 toward the rotation axis of the disc.

The abrasive surface 2 of the antibody 1 is formed by impregnate corundum 60% harder then the tested materials. The used impregnate material in this study is Smirdex 330, Duraflex P80, 117SV.

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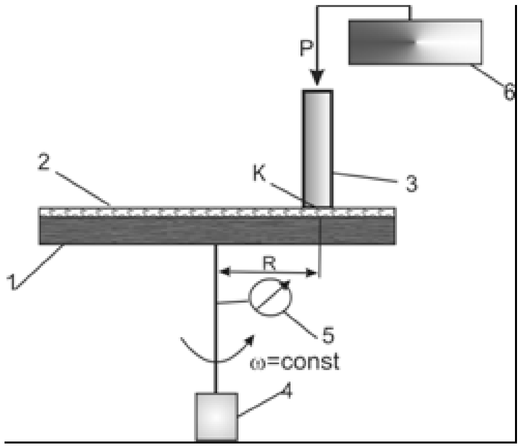

Fig. 1. Functional scheme of a device for wear testing of ductile cast iron samples with nanosized additives in a fixed abrasive

The methodology includes the following operations:

- Preparation of same cylindrical samples 3 with an equal surface roughness avoiding structural and physical and chemical changes of the samples surface. The sample dimensions are: base radius r=4mm and height 20mm;
- Measuring of the weight of the sample before and after a determinate friction road S by an analytical balance WPS 180/C/2 précised to 0,1[mg]. The samples are treated with a special solution to neutralize the static electricity before the testing;
- The sample 3 is mounted in a loading head, the desired normal load P and friction road S is assigned by a cycle counter 5;
- The absolute massive wear m [mg] is measured as a difference between a sample mass before and after a definite cycle number N (friction road S).

Test basic parameters:

1. Absolute massive wear m, [mg] - difference between the samples weight before and after appointed number of friction road S ;
2. Massive wear rate dm/dt [mg/min] - the lost weight of the sample surface for a minute;
3. Absolute intensity of the linear wear i - this is the lost thickness of the surface layer for a one friction cycle. It is a dimensionless number, which could be calculated by the formula having in mind the lost weight:

$$i = \frac{m}{\rho.A_a.S} \tag{1}$$

where: ρ is the density of the sample material ρ=7,8.103 [kg/m3], *Aa* is the nominal interaction contact surface, *S* is a friction road calculated by the number of cycles of the contact interaction N by the formula:

$$S=2.\pi.R.N \tag{2}$$

where R=42 [mm];

4. Absolute wear resistance I - it is determined as a reciprocal value of the wear intensity and respectively it is a dimensionless number etc.

$$I = \frac{1}{i} = \frac{\rho.A_a.S}{m} \tag{3}$$

The specific wear resistance I_S is a number presenting the friction road in meters, covered by 1 square millimeter contact ground in which 1mg ground material is lost. The dimension respectively is [m.mm2/mg];

5. Nominal contact pressure Pa [N/cm2] is the normal load P, distributed per a unit of a nominal (geometrical) contact surface etc.

$$p_a = \frac{P}{A_a} \tag{4}$$

In Table 1 the value of some basic test parameters are shown.

Table 1. Test parameters

Parameters	Value
Nominal contact pressure, Pa	$0{,}21.10^6$ [Pa]
Average speed of sliding, V	26,38 [cm/s]
Nominal contact surface, A_a	50,24 [mm^2]
Density ρ	$7{,}8.10^3$ kg/m^3]

Results and discussion

The structure of the tested cast irons consists from ferrite, pearlite and graphite (Figs 2,3 and 4). The quantitative metallographic analysis is performed to evaluate the nanosized additives influence on the graphite quantity, size and morphology, as well as on the volume ratio of ferrite and pearlite (Table 2). Analyses are made for three random fields of metallographic section, and average value is given. The nanosized additives in spheroidal graphite cast iron do not alter the graphite shape. They decrease the average diameter of the graphite spheres Dmid only from 11,00 to 10,52μm. The nanosized additives cause an increase in the quantity of the graphite phase in the range 35÷94% compared to cast irons without nanoparticles (Table 2).

SEM analysis of the fracture of the impact destructed cast iron samples with nanosized additives, show the nanoparticles presence in the graphite [11]. These results and that achieved from the quantity metallographic analysis prove the modified influence of the nanoparticles on the graphite phase in the cast iron samples.

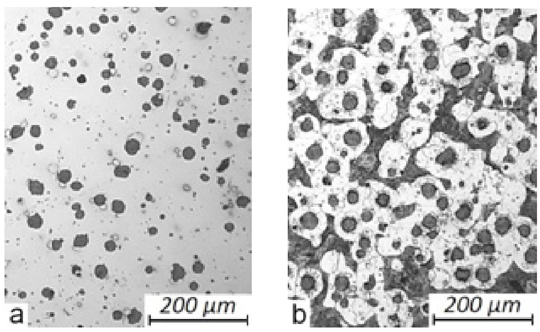

Fig. 2. Microstructure of not developed (a) and developed in 2% solution of HNO3 + ethyl alcohol (b) ductile cast iron samples without nanoparticles.

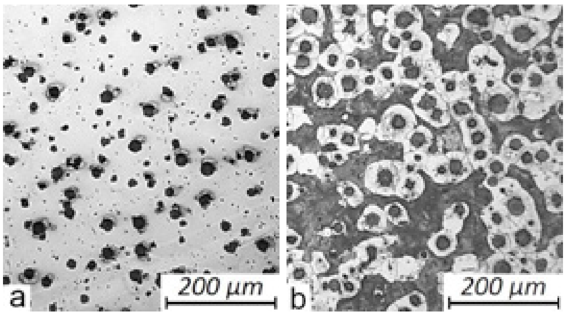

Fig. 3. Microstructure of not developed (a) and developed in 2% solution of HNO3 + ethyl alcohol (b) ductile cast iron samples with nanoparticles of TiN.

In this study the wear of three pieces of ductile cast iron samples is investigated (Table 3). The ductile cast iron samples hardness with and without nanoparticles varies from 165 to 185 HB (Table 2).

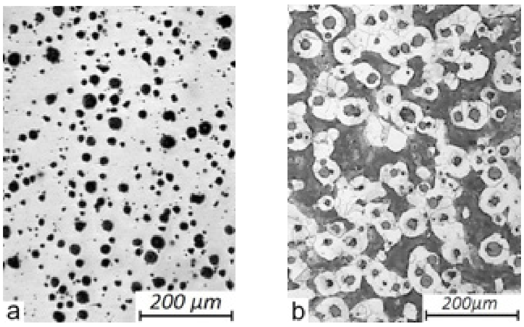

Fig. 4. Microstructure of not developed (a) and developed in 2% solution of HNO3 + ethyl alcohol (b) ductile cast iron samples with nanoparticles of (TiN+TiCN)

The experimental results for the massive wear m, wear rate dm/dt , absolute intensity of wear i and absolute wear resistance I of the samples and their alteration in a contact interaction time are received (Table 3).

For an assessment of the base structure wear resistance should have in mind its ability of changing as a result of the complicated processes during the operation. It is observed the micro geometry change, significant residual stresses, reinforcing of the surface layers trough the formation of sliding bands in the materials with a stable structure (after casting, improving and normalization) during the exploitation. During the exploitation of materials with a metastable structure (martensite, bainite, and residual austenite) it is observed structural and phase transformations in the surface layer and the wear resistance is defined by the intensity of formation and properties of the secondary structures. Graphite in the grey iron structure is an important factor for their wear bearing. There is no adhesion wear in some sections of the contact surface during a dry friction. The reason is the presence of graphite in the structure, which possess a lubricating ability and it appears to be a lubricating material. It is specified the wear resistance of the cast irons on a pearlite base is inversely proportional to the average distance between the graphite grains at given conditions (contact pressure and sliding speed).

When the distance between graphite grains decreases the protective properties of the surface carbon layer are improved and cast iron wear resistance increases.

In the presented study the tested cast iron with and without nanomodifiers possess an equilibrium ferrite – pearlitic base structure. Nanosized particles change the pearlte-ferrite proportion. The microstructure tests by optical and quantity metallographic analysis show that nanosized additives increase the graphite quantity and decrease the distance between graphite grains without changing the graphite shape. The intensity of wear of the cast irons with nanoparticles decrease, the wear resistance increases – with 69% for the cast iron with TiN additive and with 55% for the cast iron with (TiN + TiCN) additives (Table 3).

Table 2.
Nanoadditives, graphite characteristics, graphite, pearlite and ferrite quantity

№ of the sample	**Nanosized particles**	**D_{mid} µm**	**Roundness**	**Volume part of: [%]**			**Hardness** HB
				graphite	**pearlite**	**ferrite**	
1	-	11,00	1,59	8,44	32,12	59,44	185
2	*TiN*	10,64	1,49	11,36	34,28	54,36	165
3	*TiN+TiCN*	10,52	1,28	16,36	25,36	58,28	180

Table 3.
Test results for massive wear *m*, wear rate *dm/dt,* intensity of wear *i* and wear resistance *I*.

Friction road, *S* [m]		**140**	**280**	**420**	**560**	**659**
Cycles number, *N*		**500**	**1000**	**1500**	**2000**	**2500**
Time, *t* [min]		**2,35**	**4,7**	**7,05**	**9,4**	**11,75**
Massive wear, *m* [mg]	sample 1	18,3	24,5	28,2	30,8	32
	sample 2	8,2	10,8	15,5	18	19
	sample 3	10	12,9	15,5	19,2	20,8
Wear rate, *dm/dt* [mg/min]	sample 1	7,79	5,21	4	3,28	2,72
	sample 2	3,49	2,3	2,2	1,91	1,62
	sample 3	4,25	2,74	2,2	2,04	1,77

Intensity of wear, ***i***	sample 1	$0,071.10^{-6}$	$0,095.10^{-6}$	$0,109.10^{-6}$	$0,119.10^{-6}$	$0,124.10^{-6}$
	sample 2	$0,032.10^{-6}$	$0,042.10^{-6}$	$0,06.10^{-6}$	$0,07.10^{-6}$	$0,075.10^{-6}$
	sample 3	$0,039.10^{-6}$	$0,05.10^{-6}$	$0,06.10^{-6}$	$0,074.10^{-6}$	$0,08.10^{-6}$
Wear resistance, ***I***	sample 1	$14,08.10^{6}$	$10,53.10^{6}$	$9,17.10^{6}$	$8,4.10^{6}$	$8,06.10^{6}$
	sample 2	$31,25.10^{6}$	$23,80.10^{6}$	$16,67.10^{6}$	$14,29.10^{6}$	$13,6.10^{6}$
	sample 3	$25,64.10^{6}$	20.10^{6}	$16,67.10^{6}$	$13,5.10^{6}$	$12,5.10^{6}$

Conclusions

The tribological properties, microstructure and hardness of unalloyed ductile cast iron without and with nanosized additives are investigated. The nanosized particles change the quantity proportion between pearlite, ferrite and graphite in the cast iron structure. Nanoadditives of (TiN+TiCN) and TiN in the ductile cast irons have a modifying effect on the graphite phase. They reduce the average diameter of the graphite grains. The graphite shape doesn't change but its quantity increases, the distance between the graphite grains decreases, which have an effect on the cast iron wear behavior. The wear resistance of the ductile cast irons with nanosized additives of (TiN+TiCN) and TiN increases by 55-69% compared with this one of the same cast iron composition without nanoparticles.

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