

## **Wear Behavior of Austempered Ductile Iron with Nanosized Additives**

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**Keywords:**

*Nanosized particles  
Austempered ductile iron  
Hardness  
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**ABSTRACT**

*The microstructure and properties of austempered ductile iron (ADI) strengthened with nanosized additives of titanium nitride + titanium carbonitride (TiN + TiCN), titanium nitride TiN and cubic boron nitride cBN are investigated. The TiN, TiCN and cBN, nanosized particles are coated by electroless nickel coating EFTTOM-NICKEL prior to the addition to the melt. The spheroidal graphite iron samples are undergoing an austempering, including heating at 900 °C for an hour, after that isothermal retention at 280 °C, 2 h and 380 °C, 2h. The metallographic analysis by optical metallographic microscope GX41 OLIMPUS and hardness measurements by Vickers Method are performed. The structure of the austempered ductile iron consists of lower bainite and upper bainite. Experimental investigation of the wear by fixed abrasive are also carried out. The influence of the nanosized additives on the microstructure, mechanical and tribological properties of the austempered ductile irons (ADI) is studied.*

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### **1. INTRODUCTION**

The austempering of the iron-carbon alloys is an isothermal heat treatment, which reduces the internal stresses and deformations and increases the details' impact strength. The bainitic structure is formed at this type of heat treatment, which is widely applicable in constructional steels and ductile iron processing due to its high strength and increased toughness [1,2]. Incomplete austempering is also applied in case of heat treatment of some hypereutectoid and ledeburite steels [3]. The possibility of wider practical application of this heat treatment type requires an additional data for the bainitic transformation in iron-carbon alloys

with different composition including alloys with nanomodifiers. Nanosized particles added to the iron melt in a small quantity transform the graphite morphology from laminar to vermicular one [5], increase the graphite quantity [6] and change the matrix structure, which increases the cast iron wear resistance [4-6].

The aim of the performed investigation is to study the tribological properties, the microstructure and hardness of austempered ductile iron, containing additives of nanosized particles – titanium nitride+titanium carbonitride (TiN + TiCN), titanium nitride TiN and cubic boron nitride cBN.

## 2. MATERIAL AND INVESTIGATION METHODS

The composition of the austempered cast iron samples is: Fe-3,55C-2,67Si-0,31Mn-0,009S-0,027P-0,040Cu-0,025Cr-0,08Ni-0,06Mg wt%. The *TiN*, *TiCN* and *cBN*, nanosized particles are coated by electroless nickel coating EFTTOM-NICKEL [7] prior to the edition to the melt. The nickel coating improves the particles wetting into the melt and their uniformity distribution into the casting volume.

The ductile cast iron samples are undergoing austempering, including heat treatment at 900 °C for an hour, after that isothermal retention at 280 °C, 2 h and 380 °C, 2h.

The austempered ductile iron samples' microstructure is observed by means of an optical metallographic microscope GX41 OLIMPUS. The samples surface is treated with 2 % HNO<sub>3</sub> - C<sub>2</sub>H<sub>5</sub>OH solution. The hardness testing is performed by Vickers method (Table 1).

**Table 1.** Nanoadditives, hardness and wear resistance.

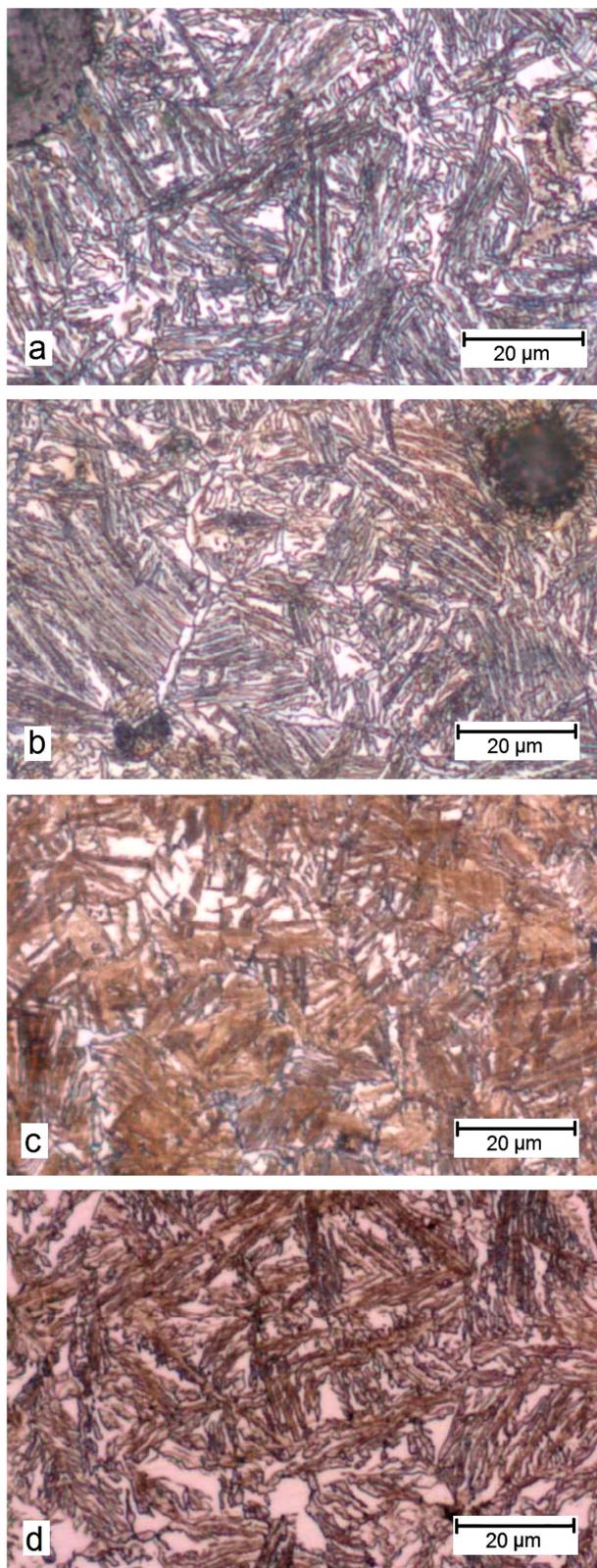
Nº of sample	Micro structure	Nanosized additive	Hardness HV10	Wear resistance <i>I</i>
1	upper bainite	-	314	5,9.10 <sup>6</sup>
2		<i>TiN</i> + <i>TiCN</i>	319	7,75.10 <sup>6</sup>
3		<i>TiN</i>	317	6,13.10 <sup>6</sup>
4		<i>cBN</i>	312	7.10 <sup>6</sup>
5	lower bainite	-	388	7,8.10 <sup>6</sup>
6		<i>TiN</i> + <i>TiCN</i>	413	5,46.10 <sup>6</sup>
7		<i>TiN</i>	405	7,34.10 <sup>6</sup>
8		<i>cBN</i>	422	6,79.10 <sup>6</sup>

The experimental wear examination of the cast and austempered ductile iron (ADI) is performed in friction conditions of a fixed abrasive by a cinematic scheme „pin - disc” using an accelerated testing method and device [6].

## 3. EXPERIMENTAL RESULTS

The cast iron structure consists of upper bainite after austempering at 380 °C for 2 hours and of lower bainite after austempering at 280 °C for 2 hours (Fig. 1). The bainite is an oriented needlelike grain structure of  $\alpha$ -phase (bainitic ferrite), carbides and untransformed austenite. The  $\alpha$ -phase is formed in the low carbon austenite area by a martensitic mechanism [1,2].

Upon cooling from the temperature of the isotherm to ambient one, a part of the untransformed austenite undergoes martensitic transformation and other its part remains as a retained austenite A in the structure.



**Fig. 1.** Lower bainitic (c) and upper bainitic (a,b,d) microstructure. (a- sample1; b- sample 2; c, d- sample 8).

The nanosized additives change the bainitic ferrite morphology and the austenitic conversion degree during the austempering (Fig. 1). The hardness of the austempered, with upper bainitic structure samples changes from 312 to 319 HV10 (Fig. 2a) and this one of the samples with lower bainitic structure changes from 388 to 422 HV10 (Fig. 3a). The austempered samples hardness with lower bainitic structure is higher than this one of the samples with upper bainitic structure, which is explained with the different carbon satiety of the  $\alpha$ -phase (bainitic ferrite) and with the varying degree of austenitic transformation in the lower and upper part of the bainitic area [1,2].

The experimental data for massive wear  $m$ , the speed of wear  $dm/dt$ , absolute intensity of wear  $i$  and absolute wear resistance  $I$  of the samples and their alteration with the time of the contact interaction (Table 2 and 3) are received. The massive wear  $m$  dependence on cycle's number  $N$  (friction road) and massive wear speed  $dm/dt$  dependence on the friction time  $t$  are presented in Figs. 4 and 5. Figures 2b and 3b show the wear resistance  $I$  of austempered ductile cast iron samples with upper and lower bainitic structure for the same friction road  $L = 700$  [m].

**Table 2.** Test results for massive wear, wear speed, intensity of wear and wear resistance (samples 1÷4).

Friction road, S [m]		140	280	420	560	700
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	22,3	32,7	38,6	42,4	46,5
	sample 2	19	24,4	28	32,8	35,3
	sample 3	20	25	32,6	38,2	44,8
	sample 4	16,3	24	27,1	33,8	39,1
Wear speed, dm/dt [mg / min]	sample 1	9,49	6,96	5,48	4,52	3,96
	sample 2	8,08	5,19	3,97	3,49	3,0
	sample 3	8,51	5,32	4,62	4,06	3,81
	sample 4	6,94	5,11	3,84	3,6	3,33
Intensity of wear, i	sample 1	0,406.10 <sup>-6</sup>	0,298.10 <sup>-6</sup>	0,234.10 <sup>-6</sup>	0,194.10 <sup>-6</sup>	0,169.10 <sup>-6</sup>
	sample 2	0,346.10 <sup>-6</sup>	0,222.10 <sup>-6</sup>	0,17.10 <sup>-6</sup>	0,149.10 <sup>-6</sup>	0,129.10 <sup>-6</sup>
	sample 3	0,364.10 <sup>-6</sup>	0,228.10 <sup>-6</sup>	0,198.10 <sup>-6</sup>	0,174.10 <sup>-6</sup>	0,163.10 <sup>-6</sup>
	sample 4	0,297.10 <sup>-6</sup>	0,218.10 <sup>-6</sup>	0,164.10 <sup>-6</sup>	0,154.10 <sup>-6</sup>	0,142.10 <sup>-6</sup>
Wear resistance, I	sample 1	2,46.10 <sup>6</sup>	3,36.10 <sup>6</sup>	4,27.10 <sup>6</sup>	5,15.10 <sup>6</sup>	5,9.10 <sup>6</sup>
	sample 2	2,89.10 <sup>6</sup>	4,5.10 <sup>6</sup>	5,88.10 <sup>6</sup>	6,69.10 <sup>6</sup>	7,75.10 <sup>6</sup>
	sample 3	2,75.10 <sup>6</sup>	4,39.10 <sup>6</sup>	5,05.10 <sup>6</sup>	5,75.10 <sup>6</sup>	6,13.10 <sup>6</sup>
	sample 4	3,37.10 <sup>6</sup>	4,59.10 <sup>6</sup>	6,1.10 <sup>6</sup>	6,49.10 <sup>6</sup>	7.10 <sup>6</sup>

**Table 3.** Test results for massive wear, wear speed, intensity of wear and wear resistance (samples 5÷8).

Friction road, S [m]		140	280	420	560	700
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 5	14,2	20,4	24,4	29,3	35,2
	sample 6	26,4	33,6	37,7	44,9	50,2
	sample 7	14,6	21,7	27,2	34,8	37,4
	sample 8	15,9	23,7	29,4	35	40,4
Wear speed, dm/dt [mg / min]	sample 5	6,04	4,34	3,46	3,12	2,99
	sample 6	11,2	7,15	5,35	4,78	4,27
	sample 7	6,21	4,62	3,86	3,7	3,18
	sample 8	6,76	5,04	4,17	3,72	3,44
Intensity of wear, i	sample 5	0,259.10 <sup>-6</sup>	0,186.10 <sup>-6</sup>	0,148.10 <sup>-6</sup>	0,133.10 <sup>-6</sup>	0,128.10 <sup>-6</sup>
	sample 6	0,48.10 <sup>-6</sup>	0,306.10 <sup>-6</sup>	0,229.10 <sup>-6</sup>	0,204.10 <sup>-6</sup>	0,183.10 <sup>-6</sup>
	sample 7	0,266.10 <sup>-6</sup>	0,198.10 <sup>-6</sup>	0,165.10 <sup>-6</sup>	0,158.10 <sup>-6</sup>	0,136.10 <sup>-6</sup>
	sample 8	0,29.10 <sup>-6</sup>	0,22.10 <sup>-6</sup>	0,178.10 <sup>-6</sup>	0,159.10 <sup>-6</sup>	0,147.10 <sup>-6</sup>
Wear resistance, I	sample 5	3,86.10 <sup>6</sup>	5,38.10 <sup>6</sup>	6,75.10 <sup>6</sup>	7,5.10 <sup>6</sup>	7,8.10 <sup>6</sup>
	sample 6	2,08.10 <sup>6</sup>	3,27.10 <sup>6</sup>	4,37.10 <sup>6</sup>	4,9.10 <sup>6</sup>	5,46.10 <sup>6</sup>
	sample 7	3,76.10 <sup>6</sup>	5,05.10 <sup>6</sup>	6,06.10 <sup>6</sup>	6,31.10 <sup>6</sup>	7,34.10 <sup>6</sup>
	sample 8	3,45.10 <sup>6</sup>	4,54.10 <sup>6</sup>	5,62.10 <sup>6</sup>	6,27.10 <sup>6</sup>	6,79.10 <sup>6</sup>

The wear resistance is a multifactorial parameter and to make its prognosis using the standard measured properties (hardness etc.) could be wrong, since these features are not always reliable criteria for the steels'and irons" wear resistance evaluation. The metastable structures in the iron-carbon alloys as a martensite, bainite and retained austenite have higher resistance to abrasive wear in comparison to this one of the stable structures (ferrite, pearlite etc.). The intensive strengthening is going off during the wear process due to dynamic strain ageing of martensite and partial transformation of the metastable retained austenite in a strain-induced martensite [8].

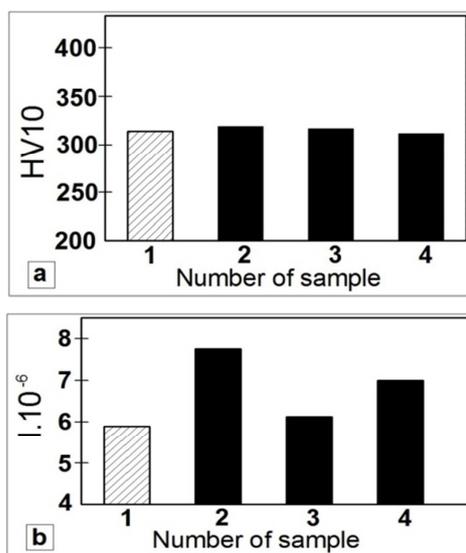


Fig. 2. Hardness HV10 (a) and wear resistance  $I$  (b) of austempered ductile iron samples without (1) and with (2,3,4) nanoadditives.

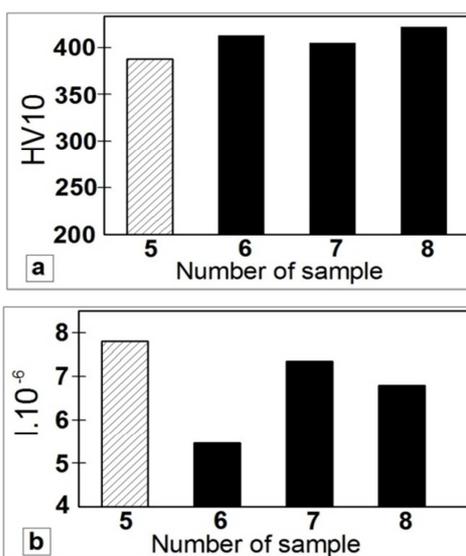


Fig. 3. Hardness HV10 (a) and wear resistance  $I$  (b) of austempered ductile iron samples without (5) and with (6,7,8) nanoadditives.

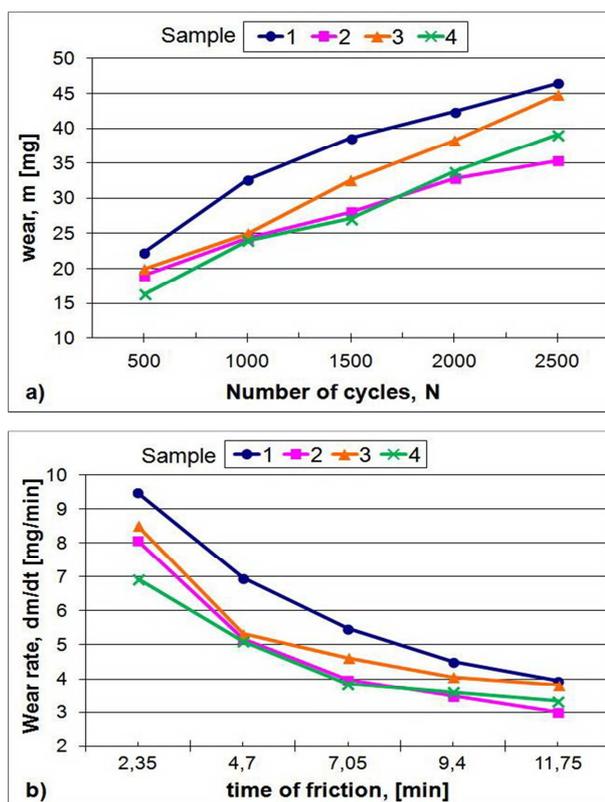


Fig. 4. Dependence of the massive wear  $m$  on the cycles number  $N$  (a) and of the wear speed  $dm/dt$  on the friction time  $t$  (b) (samples 1÷4).

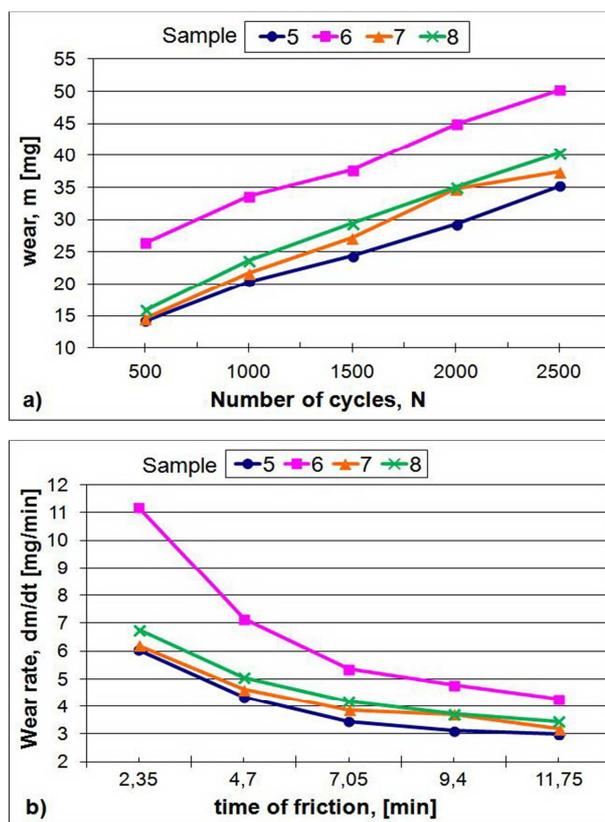


Fig. 5. Dependence of the massive wear  $m$  on the cycles number  $N$  (a) and of the wear speed  $dm/dt$  on the friction time  $t$  (b) (samples 5÷8).

The samples hardness with upper bainitic structure without and with nanoadditives are similar in values (312÷319 HV10). The wear resistance  $I$  of these cast irons consisting nanosized additives is in the range between  $6,13 \cdot 10^6 \div 7,75 \cdot 10^6$  and it is with 4 to 32 % higher than this one of the cast iron samples without nanoadditives ( $I = 5,9 \cdot 10^6$ ). Samples hardness with lower bainitic structure is 388÷422 HV10. The wear resistance of the cast iron samples with lower bainitic structure without nanoadditives ( $I = 7,8 \cdot 10^6$ ) is higher than this one of the cast iron samples with nanoadditives ( $I = 5,46 \cdot 10^6 \div 7,34 \cdot 10^6$ ). The obtained results for the wear resistance values of the tested cast irons samples are probably related to the characteristics of structures upper bainite, lower bainite, retained austenite and martensite during abrasive wear. The different quantitative proportion between the structural components in the samples with and without nanoadditives defines the degree of strengthening and the resistance during abrasive wear due to strain ageing of the carbon sated  $\alpha$ - solid solution (martensite and bainitic ferrite) and also to partially transformation of the retained austenite into deformation martensite.

#### 4. CONCLUSION

The microstructure, hardness HV10 and tribological properties of austempered ductile cast iron samples without and with nanosized additives of titanium nitride + titanium carbonitride (TiN + TiCN), titanium nitride TiN and cubic boron nitride cBN are investigated. The nanosized particles change the bainitic ferrite morphology in the austempered iron structure. In the cast iron with a upper bainitic structure the nanosized additives increase the wear resistance with 4÷32 % in comparison to this one of the irons without nanoadditives. The results for the wear resistance of the irons with lower bainitic structure show the highest value ( $I = 7,8 \cdot 10^6$ ) for the cast iron without nanoadditives.

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