Wear Resistance of Austempered Ductile Iron with Nanosized Additives

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Abstract: The wear resistance, microstructure and mechanical properties of austempered ductile iron (ADI) with nanosized additives of cubic boron nitride cBN are investigated. Samples of ductile iron are put under austempering at the following conditions: heating at 900°C, 1 h and isothermal retention at 280°C, 2 h and 380°C, 2 h with the aim to achieve a lower bainitic structure and an upper bainitic structure. The experimental wear testing of austempered ductile irons is performed in friction conditions of a fixed abrasive by a cinematic scheme „pin - disc” using an accelerated testing method and device. The microstructure of the ADI is investigated by metallographic and X-Ray analyses. The Vickers hardness testing and impact strength examination are carried out. The influence of the nanosized additives of cBN on the wear resistance, microstructure, impact strength and hardness of the ADI is investigated.

Keywords: nanoadditives, austempered ductile iron, hardness, wear resistance, microstructure.

1. Introduction

Ductile cast iron is a structural material, characterized with high strength, toughness and wear resistance. The graphite presence into the ductile iron provides resistance to mechanical wear and improves its machining. It is possible to influence graphite morphology, also the material base structure using alloying, heat treatment or through a combination of these two processes to achieve the optimum in the cast irons properties. The austempering of the cast irons is a heat treatment leading to a formation of a bainitic structure in the metal base. This transition is a reason for the internal stresses and deformations reduction and details impact strength enhancement. During this heat treatment the lower or upper bainitic structure is formed, which leads to material high strength, increased toughness and a wide practical use in the treatment of structural steels and ductile cast irons [1,2]. Incomplete austempering is also applicable to the heat treatment of some hipper eutectoid and ledeburite steel [3,4].

The possibility for wider practical application of this type of heat treatment requires an additional data in the bainitic transformation of iron – carbon alloys of different composition, considering alloys within nanoadditives [5-9].

The aim of this study is to investigate the wear resistance, microstructure and mechanical properties of austempered ductile iron, containing the nanosized additives of cubic boron nitride cBN.
2. Materials and Investigation Methods

The composition of the spherical graphite iron samples is: Fe-3.55, C-2.67, Si-0.31, Mn-0.009, S-0.027, P-0.040, Cu-0.025, Cr-0.08, Ni-0.06, Mg wt%. The cBN nanosized particles are coated by electroless nickel method EFT TOM - NICKEL [10] 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 spherical graphite iron samples undergo to austempering, including heating at 280°C for 1 hour, after that isothermal retention at 380°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 vol. % HNO₃ - C₂H₅OH solution.

The hardness testing is performed by Vickers method. The impact strength testing with Charpy impact test is carried out.

The austempered ductile iron samples are examined by X-Ray diffraction analysis to find out the retained austenite quantity in the structure before and after tribological testing. X-ray powder diffraction patterns for phase identification were recorded in the angle interval 35-115° (2θ), on a Philips PW 1050 diffractometer, equipped with Cu Kα tube and scintillation detector. Data for cell refinements and quantitative analysis were collected in θ-2θ, step-scan mode in the angle interval from 35 to 115° (2θ), at steps of 0.03° (2θ), and counting time of 3 s/step. Quantitative analysis was carried out by BRASS - Bremen Rietveld Analysis and Structure Suite [11].

The experimental wear testing of austempered ductile iron is performed in friction conditions of a fixed abrasive by a cinematic scheme „pin - disc“ using an accelerated testing method and device [7]. The impregnate material Corundum 220 is used as an abrasive surface during the test. The basic experimental parameters are: Nominal contact load, Pa=0.4. 10⁶ [Pa]; Average sliding speed = 24.5 [cm/s]; Nominal contact surface, Aa = 50.24 [mm²]; Density, ρ = 7.80.10³ [kg/m³].

3. Experimental results and analysis

The iron structure after austempering at 280°C, 2 h consists of lower bainite (Figure 1) and at 380°C, 2 h – of upper bainite (Figure 2). Bainite is an oriented structure, consist of α – phase needles (bainitic ferrite), of carbides and untransformed austenite. The α – phase is formed from austenitic areas (containing lower carbon) by martensitic mechanism and is carbon over-saturated α – solid solution. Part of the untransformed austenite undergoes martensitic transformation and part of it remains in the structure as retained austenite A upon cooling from the isotherm to ambient temperature [1, 2]. The nanosized additives change the bainitic transformation kinetic and accelerate γ → α transformation. The quantity of the retained austenite A in the samples with nanoadditives of cBN is 21% for the lower bainitic structure and 30.2% for the upper bainitic structure. For the samples without nanoadditives the quantity is respectively 30, 6% and 40, 4% (Table 1). The retained austenite quantity is more for the samples with upper bainitic structure than this one for the samples with lower bainitic structure.

| № of sample | Nanosized additive | Hardness HV10 | Impact strength KC MJ/m² | Wear resistance I | Retained austenite A, % before wear test | Retained austenite A, % after wear test |
|------------|--------------------|---------------|---------------------------|------------------|-----------------------------------------|----------------------------------------|
| 1 | lower bainite | - | 388 | 0.771 | 7.13.10⁶ | 30,6 | 25,0 |
| 2 | cBN | 422 | 0.884 | 9.56.10⁶ | 21,0 | 11,8 |
| 3 | upper bainite | - | 314 | 1,137 | 7.67.10⁶ | 40,4 | 31,3 |
| 4 | cBN | 312 | 1,387 | 8.03.10⁶ | 30,2 | 25,3 |
This is associated to the mechanism peculiarities of the bainitic transformation in the upper and lower interval of the bainitic region. The lower bainitic hardness (388-422 HV10) is higher than this one of the upper bainite (314-312 HV10) (Figure 3). α – phase carbon over-saturation in the lower bainite is more than this one in the upper bainite, which is the answer for its higher hardness. The retained austenite quantity is more for the samples with upper bainitic structure than this one for the samples with lower bainitic structure, which defines their higher toughness (Figure 4). The wear resistance of the samples with nanosized cBN additives and lower bainitic structure is about 34% higher than this one of the samples without nanoadditives. The addition of nanosized cBN increases the wear resistance for the samples with upper bainitic structure with 5% (Figure 5). The quantity of the retained austenite in the tested samples before and after tribological testing is defined by X-Ray analysis (Table 1). It is concluded that the retained austenite quantity decreases in all samples after teribological testing (Figure 6).
The standard measured properties (hardness, etc.) not always are reliable criteria for the steel and cast iron wear resistance. The tribological properties of the metallic materials significantly depend on the structural condition, forming on the contact surface during the friction. When the material is exposed to an intensive plastic deformation the structural transformation goes off in the frictional contact area in the metastable structures (retained austenite, martensite, bainite). They greatly influence on the effective surface strength and respectively on the material tribological properties. The metastable retained austenite may be subjected to $\gamma \rightarrow \alpha$ martensitic deformation. During friction the retained austenite transforms partly into deformation martensite with the same amount of carbon as in high carbon austenite. This deformation martensite is untempered martensite characterized with high hardness and ability for intensive strengthening by wear [8,9]. The quantity of retained austenite for the lower bainitic structure decreases from 30.6% to 25% during friction for the samples without nanoadditives (Table 1) and from 21% to 11.8% for the samples with nanoadditives (Table 1, Figure 7). The formation of deformation martensite from the metastable retained austenite in the frictional area probably is one of the reasons for the wear resistance increase of these materials.
Figure 7. X–ray diffraction pattern of austempered ductile iron sample 2 before (a) and after (b) wear test.

4. Conclusions

The wear resistance, hardness, impact toughness and microstructure of austempered ductile irons without and with nanosized additives of cBN are investigated. Nanosized additives change the bainitic transformation kinetic and accelerate austenite transformation in bainite. Austempered ductile irons with nanosized cBN additives possess higher wear resistance (5-34%) and higher impact strength (15-22 %) in comparison to the samples without nanoadditives. The ADI with nanoadditives and lower bainitic structure have highest wear resistance ($I = 9.56, 10^6$). It is found that the partial transformation of the metastable retained austenite to deformation martensite in the greatest extent proceeds in these materials during friction load, which influences on their wear resistance.

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