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The effects of boro-tempering heat treatment on microstructural properties of ductile iron

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ABSTRACT

In this study, the effects of boro-tempering heat treatment on microstructural properties of ductile iron were investigated. Test samples with dimensions of 10 × 10 × 55 mm were boronized at 900 °C for 1, 3 and 5 h and then tempered at four different temperatures (250, 300, 350 and 450 °C) for 1 h. Both optical microscopy and scanning electron microscopy were used to reveal the microstructural details of coating and matrix of boro-tempered ductile iron. X-ray diffraction was used to determine the constituents of the coating layer. The boride layer formed on the surface of boro-tempered ductile cast iron is tooth shape form and consisted of FeB and Fe2B phases. The thickness of boride layer increases as the boronizing time increases and tempering temperature decreases. Tempering temperature is more effective than boronizing time on the matrix structure. Boro-tempering heat treatment reduces the formation of lower and upper ausferritic matrix temperature according to classical austempering. This causes formation of upper ausferritic matrix in the sample when tempered at 300 °C. This is in contrast to general case which is the formation of lower ausferritic matrix via austempering at this temperature.

1. Introduction

Austempered ductile iron (ADI) has attracted as a substitute for forged steel components in several structural applications such as automotive, agricultural, railroad, construction, and defense. The combination of high levels of strength with good ductility, good fracture toughness, and high fatigue strength and wear resistance make ADI attractive for these applications [1–7,26,36,37]. Furthermore, it has the advantage of design and manufacturing flexibility, lower material cost, lower production cost, lower density, better machinability and higher damping capacity than steels [1,8–10,27].

Up to now, numerous studies have been performed on microstructural and mechanical properties of the material [7,11–17,21]. New studies have been focused to improve its present properties, especially surface properties. It has been well known that the mechanical properties of engineering materials largely depend on modified by means of case hardening or coating [18]. Unfortunately, case hardening techniques such as, carburizing, nitriding, carbonitriding, cyaniding, chromizing, boronizing and chemical vapor deposition (CVD) are not available to apply austempered ductile irons without damaging of original ausferritic matrix. Attention has, therefore, shifted modern surface engineering techniques like laser surface engineering [19], hybrid silica sol–gel coating [20] and low-temperature coatings for improving wear, fatigue and corrosion resistance of ADI [21–23].

In recent years, physical vapor deposition (PVD) using lower processing temperature has been widely adopted to coat various films, such as diamond-like carbon (DLC), CrN, TiN, TiCN on the surface engineering for surface modification. It has been reported that DLC film processes excellent mechanical properties and a low friction coefficient against many materials [21,22].

Hsu et al. [21,22] utilized electroless nickel (EN) and cathodic arc deposition (CAD) technologies with lower processing temperature to treat ADI and then evaluated the availability of applying the EN and CAD-DLC duplex coatings on ADI. Authors reported that the ADI's microstructure did not deteriorate after the surface treatment due to the coating temperature of EN and CAD-DLC processes below austempering temperature of ADI. They also determined that the DLC/EN duplex coated specimen had the highest hardness (1312 $HV_{0.05}$), followed by DLC–ADI specimen (1088 $HV_{0.05}$), EN–ADI specimen (409 $HV_{0.05}$) and then uncoated ADI (396 $HV_{0.05}$).

Base on the surface modification techniques given above, firstly, austempering heat treatment is carried out on ductile iron and then a certain surface modification technique or coating is applied on austempered ductile iron. All of these surface modification techniques requires a two-step process which includes austempering and surface modification or coating. When above mentioned surface modification techniques are applied, ausferritic microstructure is deteriorated causing the ADI to lose its excellent properties [21].

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