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New Possibilities of Shaping the Surface Properties in Austempered Ductile Iron Castings

D. Myszka
Institute of Manufacturing Technologies, Warsaw University of Technology,
Narbutta 85, 02-524 Warsaw, Poland
Corresponding author. E-mail address: myszkadawid@wp.pl

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Abstract

The paper presents recent developments concerning the formation of surface layer in austempered ductile iron castings. It was found that the traditional methods used to change the properties of the surface layer, i.e. the effect of protective atmosphere during austenitising or shot peening, are not fully satisfactory to meet the demands of commercial applications. Therefore, new ways to shape the surface layer and the surface properties of austempered ductile iron castings are searched for, to mention only detonation spraying, carbonitriding, CVD methods, etc.

Keywords: Austempered ductile iron, Surface treatments, Surface properties, Castings, Heat treatments

1. Introduction

In Austempered Ductile Iron (commonly called ADI) has over 30-year history of the development and commercial applications [1]. This is because of its unique properties, competing successfully with a number of steel grades. These properties are the result of heat treatment properly performed on high-quality ductile iron castings. Owing to this treatment, the microstructure contains a mixture of ferrite and austenite called ausferrite. Recent publications, in addition to focusing the attention on new ways of heat treatment and the new ADI grades, discuss also the problem of the surface layer in castings made from this material. This issue is not simple, because ADI loses its optimal properties at temperatures higher than 300°C [2], and therefore the traditional methods of influencing the surface properties, such as e.g.nitriding, are very difficult in practical application. This is the reason why other techniques of changing the surface layer in ADI castings to change also its properties are searched for.

2. The surface layer of ADI castings

Focusing attention on the properties of the surface layer in ADI castings is justified by the potentially broad applications of this material. Due to the specific microstructure of ADI, its surface treatment is very difficult. The problem is that above the temperature of 300°C, ADI can lose both its strength and ductility (Fig. 1) [2]. Therefore, treatments are sought that shall not require temperature changes above this level, or other original ways of increasing the performance properties of the surface layer in ADI products.

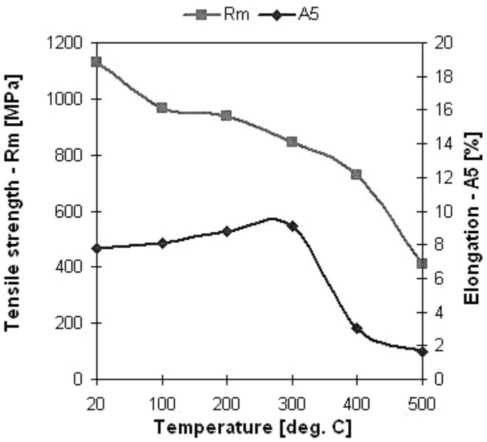

Fig. 1. The results of mechanical tests carried out on ADI at high temperature [2]

The easiest way to improve the surface properties of ADI is by shot peening. It is a widely recognized technique for increasing the fatigue strength and surface hardness [3]. The hardening is a result of introducing to the surface layer high compressive stresses and initiating the deformation-induced martensitic transformation, as has been demonstrated in studies carried out at the Institute of Precision Mechanics (Fig. 2) [4].

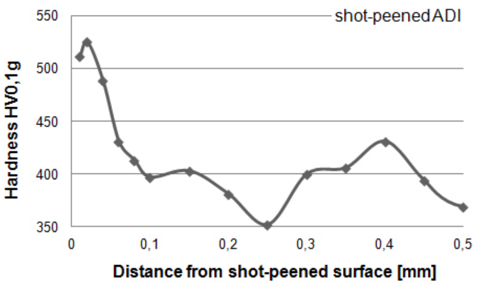

Fig. 2. Hardness distribution in the surface layer of ADI specimen after shot peening

The most interesting possibilities to change the surface properties of ADI were found by the author in the articles written by Cheng-Hsun Hsu [5-7]. In a series of articles, several methods were discussed, which have been used to create the layers of TiN and TiAlN, and the duplex layers of CrN/EN, Cr_2O_3/EN and others, serving mainly as a means to provide increased corrosion resistance compared with the base ADI.

The author conducted his own original research applying two types of the ADI surface treatment. The first was the deposition of Al_2O_3-TiO_2 and WC/Co coatings by detonation methods [8]. It was found that, compared to the ADI without surface treatment, the application of Al_2O_3-TiO2 coatings, resistant to elevated temperatures, increased both hardness and friction wear resistance. Still better results were noted for the WC/Co layer, for which the hardness reached $1400HV_{0,1g}$, thus resulting in a significant increase of the friction wear resistance with very good adhesion of the layer to the substrate (Figs. 3 and 4).

a)

b)

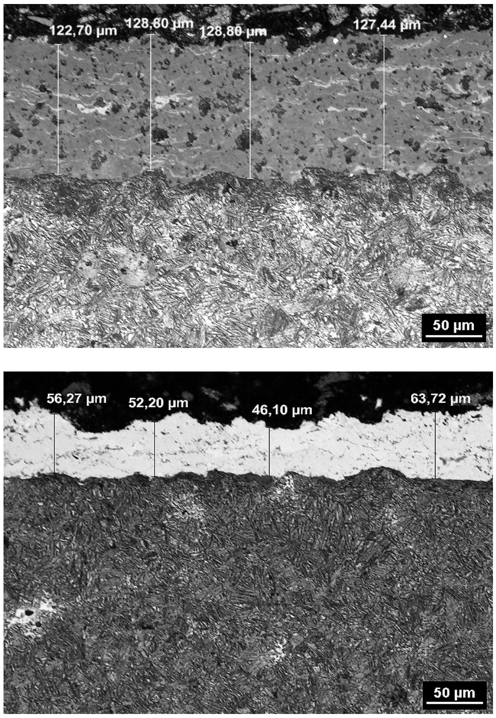

Fig. 3. Microstructure of Al2O3-TiO2 coatings (a) and WC/Co coatings (b) applied on ADI

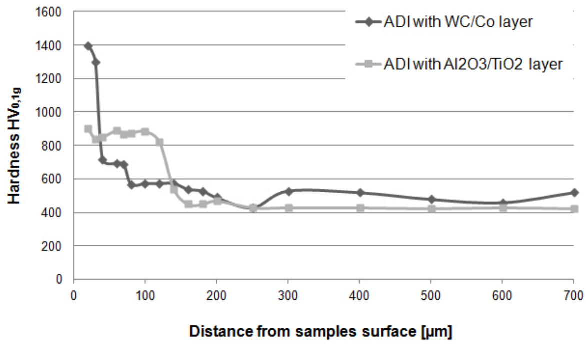

Fig. 4. Hardness distributions in Al2O3-TiO2 (a) and WC/Co coatings (b) applied on ADI

Another example of studies on the surface properties of ADI castings is the original way of nitriding or nitrocarburising the surface of precision castings during austenitising of ductile iron. As a result of this, specifically carried out treatment, all the examined surface properties of ADI are increasing, i.e. the friction wear resistance, corrosion resistance, and fatigue strength (Fig.5) [9,10]

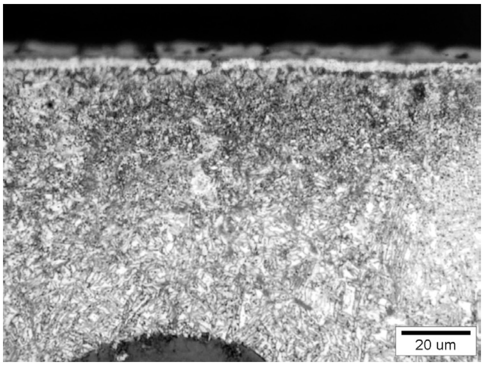

Fig. 5. Microstructure of the surface layer in ADI sample after carbonitriding

3. New methods of heat treatment

Special attention also deserve the innovative methods of heat treatment carried out to obtain the ADI. In this group, recently, much attention has been paid to the two-step austempering. This method allows producing greater amounts of retained austenite and increases both fracture toughness and hardness. The author's studies also to some extent contributed to this method of making ADI. The author has proposed and carried out the studies, owing to which the ADI is obtained in one technological cycle in a vacuum furnace with gas cooling [11]. In these furnaces it is also possible to produce ADI by multi-step austempering treatment [12].

The heat treatment of cast iron in a vacuum furnace with gas cooling system can offer numerous advantages. On the one hand, the whole process can be controlled in a very precise manner by a numerical control system while, on the other, it is possible to avoid the adverse effects that commonly occur during surface austenitising and austempering in a salt bath at all manufacturing plants known to the author. Due to the use of vacuum at high temperatures, the phenomena unfavourable to the casting surface properties, such as decarburising, do not occur. Another beneficial aspect of this process is eliminating the need for the transport of castings from the austenitising and austempering temperature. In vacuum furnaces, this process is carried out in one chamber by introducing into this chamber a particular gas under pressure. The result is controlled partial cooling of castings, which leads to the desirable transformations taking place in the cast iron microstructure (Table 1, Fig.6) [11]. An important aspect of vacuum processes, when applied to obtain ADI, is also total elimination of the toxic salt bath.

Table 1.
The mechanical properties of ADI after the process of heat treatment carried out in a vacuum furnace with gas cooling

Designation	R_m [MPa]	$R_{0,2}$ [MPa]	A_5 [%]	HB
ADI 1	956	619	10,3	348
ADI 2	936	643	8	354

Fig. 6. A universal vacuum furnace with gas cooling operating at the Institute of Precision Mechanics in Warsaw

An original aspect of the proposed type of process is the possibility to apply a sub-zero treatment to the castings processed [13]. This process is also meeting the demand of modern times for other than the traditional ones types of heat treatment, such as cyclic treatment, treatment combined with freezing, etc. Hence it follows that making ADI in a vacuum furnace with gas cooling system may favorably affect further extension of the application of this technology in the industry.

New processes of the ADI manufacture also enable shaping the surface properties of castings. Avoiding the adverse effect of surface phenomena has as an immediate consequence the formation of ausferritic microstructure in the surface layer, which has many positive features in contact environments. This can be shown on the example of studies made for the mining industry [14], where the results of abrasive wear resistance tests carried out on ADI as compared to 36HNM steel, and L35HM and L35GSM cast steels have been presented. The high potential usefulness of ADI in these applications has been demonstrated.

4. Summary

The article presents a number of opportunities to shape the surface layer in ADI castings and new methods of bulk shaping of the microstructure. It is worth noting that bulk shaping of the properties will also affect the surface layer, which means that the problem of the modification of surface properties and properties in the entire casting volume should always be considered as one integral whole.

The most important method for shaping the surface layer is considered by the author the method of detonation spraying. Applying this technology it is possible to form a layer of nearly any thickness, completely changing the surface characteristics in terms of both properties and surface geometry. Obviously, the detonation spraying method has some limitations, e.g. the layers can be applied only on some surfaces, but the benefits it provides are indisputable.

Of special interest is the method of vacuum heat treatment, which creates quite new areas for shaping the surface properties and producing both the traditional as well as entirely new grades of the heat treated cast iron. The main benefits resulting from the use of vacuum devices include the lack of adverse surface effects on the machined casting surfaces. Opportunities that are today created by a vacuum treatment extend to other areas, including e.g. the possibility of nitriding, carburising, etc.

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