ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 15
Special Issue 1/2015

51 – 54

11/1

Comparison of Austempered Ductile Iron and Manganese Steel Wearability

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Received 28.04.2015; accepted in revised form 05.05.2015

Abstract

The results of comparison of the wear resistance of manganese steel X120Mn12, S235IR steel and austempered ductile iron ADI are presented. The aim of this study is to determine the possibility of replacing an item made of X120Mn12 steel with another material. For this purpose, all of the samples were measured for Brinell hardness. The samples were then tested for wear resistance in a specially designed test stand. The test resided in shot penning the surface of the test samples within the shot stream with the defined parameters. The test stand used in the test ensured the shot penning parameter stability. The test samples underwent multiple tests in which shot penning occurred in reccurrent cycles. Three test limits were established for the present study: 60, 120 and 180 cycles. The wear resistance measure in this study was the decrease in the tested sample's weight expressed in grams and calculated for a unit of the shot-penned surface. The obtained results confirmed the possibility of using ADI as a possible replacement of manganese steels in specific cases. Of the eight types of the samples tested, the two ADI samples exhibited abrasion resistance which was comparable to that of the reference sample, while one exhibited better resistance. What constitutes the optimal chemical composition and the corresponding optimal heat treatment for particular cases remains an issue for further research.

Keywords: Austempered Ductile Iron, Manganese steel, Wear resistance, Hardness

1. Introduction

More than 40 years have passed since the first commercial use of ADI [1]. The main advantage of this material is a combination of high strength properties with good ductility and at the same time low manufacturing cost [2]. The technology is very simple. It includes the austenitizing process, usually at temperatures of 815-950^{o}C and isothermal quenching in temperatures 230-400^{o}C [3]. Selection of the temperature and the time of austempering makes it possible to control the strength and elongation of austempered ductile iron. Research on improving these properties is conducted in many research centers all over the world. Research concentrates on the optimization of both the austenitizing and the isothermal quenching processes and the ideal selection of chemical composition [3-6]. An attractive combination of properties, low cost and unsophisticated chemical composition mean that ADI is competitive not only in relation to the traditional cast iron, but also to the cast, and in some cases even to aluminum alloys [7-10].

In this article, the authors present the results of preliminary studies on the possibility of replacing, in particular applications, the X120Mn12 steel parts, such as steel linings elements and rotor blades of casting cleaning plants.

2. Experimental procedure

The chemical composition of test samples and the properties of ductile cast iron (as cast) are shown in table 1 and table 2, respectively. The specimens for studies were cut from the plate-type castings to dimension of about 55x46x15mm. Each of the elements was carefully measured in order to determine the actual surface to be tested for abrasion wear resistance. A sample of specimens is shown on Figure 1. Steel S235 and steel X120Mn12 plates were used as reference samples. The surfaces of the manganese steel samples and the low-carbon steel samples which underwent abrasion treatment were comparable to those of the ausferritic cast iron samples. However, in the former case, the height of the samples was smaller.

Table 1.
Chemical composition of ductile cast iron (in %)

C	Si	Mn	P	S	Cr	Cu	Ni	Mg
3,53	2,73	0,59	0,03	0,01	0,05	0,45	0,54	0,05

Fig. 1. The sample of specimens

Table 2.
Properties of ductile cast iron (as cast)

Properties	Units	Values
Ultimate Tensile Strength	R_m [MPa]	732
Yield Strength	$R_{0,2}$ [MPa]	456
Elongation	A5 [%]	7
Hardness	HB	255

The samples were austenitized at two temperatures: 900˚C and 950˚C. The time of austenitization varied within the range of 90-140 minutes. The austenitization was followed by rapid quenching. The isothermal quenching was carried out in the liquid tin bath in the temperature range from 220°C to 250°C. The process time varied: it was 60, 90 or 120 min. The precise parameters of the various heat treatments are shown in Table 3.
For all the samples, Brinell hardness was measured with the help of the hardness testing machine KP15002P. Abrasive wear was also measured on a specially created test stand. The scheme of the measurement of wear resistance is shown in Figure 2.

Table 3.
Heat treatment parameters of ADI

Sample number	Austenitization		Quenching	
	Temperature [°C]	Time [min]	Temperature [°C]	Time [min]
ADI1	900	135	250	120
ADI2	900	120	240	120
ADI3	900	140	240	90
ADI4	900	125	225	60
ADI5	900	130	225	60
ADI6	900	103	225	115
ADI7	950	90	225	60
ADI8	950	90	220	90

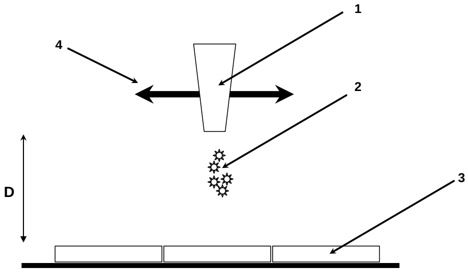

Fig. 2. The schema of the test device for the abrasive resistance: 1) nozzle of the lance; 2) steel grit (type GH40 steel grit is softer than the aluminum oxide one and does not fracture as easily, which makes it ideal for aircraft and aero-space applications.); 3) specimen; 4) nozzle path; D distance between nozzle and specimen

The ductile cast iron samples and the control samples were placed in a holder as in Figure 3 and shot penned.

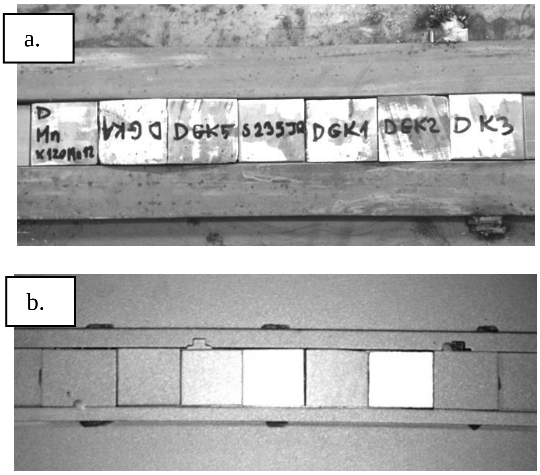

Fig. 3. The samples mounted in the holder: a - before, b - after the grit blasting

The test resided in shot penning the surface of the test samples within the shot stream with the defined parameters. The test stand used in the test ensured the shot penning parameter stability. The tests were performed using the following blasting parameters:

distance between lance nozzle and specimens 500 mm, air pressure in the blasting lance 0,75 MPa, diameter of lance nozzle 17 mm, speed of travel of the blasting lances 0,5 m/s, the angle between the blasting jet and the specimen surface 90°. Steel grit consists of grains with a predominantly angular shape. These grains are obtained by crushing steel shot and therefore, they have sharp edges and broken sections. Harder than steel shot, steel grit is also available in different sizes and hardnesses. GH STEEL GRIT has the maximum hardness and remains angular in its operating mix. This steel grit does not shatter readily, yet has a fast, effective cutting action, making it ideal for deep descaling and etched surface requirements. Metabrasive Steel Grit is made in accordance with ISO 11124-3: 1993, (BS7079: Part E3: 1994). Steel grit blasting is ideal for aggressive cleaning applications, it will quickly strip off many types of surface contaminants from steel and other foundry metals. The angular nature of steel grit produces an etched surface on metal for superior adhesion of paint, epoxy, enamel, rubber and other coatings. The test samples underwent multiple tests in which shot penning occurred in reccurrent cycles. Three test limits were established for the present study: 60, 120 and 180 cycles. The wear resistance measure in this study was the decrease in the tested sample's mass expressed in grams and calculated for a unit of the shot-penned surface.

3. Results

3.1. Hardness

Brinell hardness measurements were conducted with the hardness testing machine KP15002P. The parameters are presented in table 4.

Table 4.
KP15002P hardness testing machine parameters

Intender	Load	Time
ball 2,5 mm	187,5 kg	35 s

The mean values of hardness measurements are shown in table 5.

Table 5.
The mean values of hardness for various specimens

Sample number	Hardness [HB]	SD*
ADI1	386,4	4,2
ADI2	410,2	3,0
ADI3	394,6	2,5
ADI4	412,8	5,5
ADI5	452,2	5,9
ADI6	451,0	9,2
ADI7	379,2	13,9
ADI8	451,0	13,0
S235IR	227,0	10,4
X120Mn12	208,6	2,2

*SD – standard deviation

Figure 4 is a graphical representation of the results shown in Table 5.

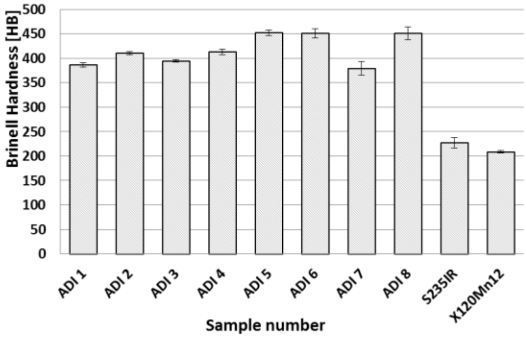

Fig. 4. The mean values of hardness of steels and ADI iron obtained for different variants of the heat treatment (standard deviations of measurements are shown)

As expected, the reference steel samples have considerably lower hardness than those made of ADI. The hardness of steel samples is minimally above 200HB. On the other hand, the ADI sample hardness ranges between nearly 400 to more than 450HB. For all of the tested samples, both the steel and the ADI ones, a considerable repeatability of the hardness measurements was obtained, which is expressed as the low value of the measurement standard deviation (represented in the form of whiskers in Fig.4). The hardness of the ADI samples depends on the heat treatment parameters. The highest hardness was obtained in the case of samples ADI5, ADI6 and ADI8.

3.2 Abrasive wear

The abrasive wear was determined as the weight loss of the sample in relation to the grit blasted surface.

Table 6 shows the results of the measurement of abrasion obtained respectively for 60, 120 and 180 cycles. The results are given as the weight loss, weight loss in percent, and weight loss per unit surface of the sample subjected to abrasion.

Figure 5 illustrates the loss of weight per unit surface of the tested materials.

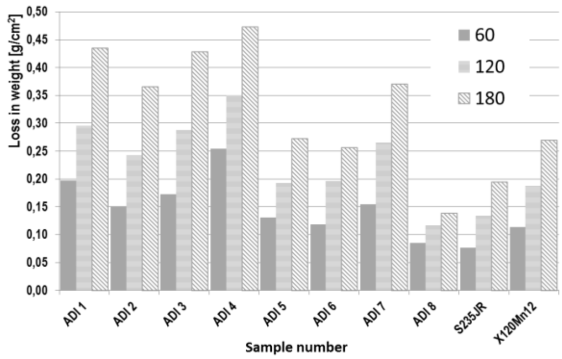

Fig. 5. The mean values of abrasive wear of steels and ADI iron obtained for different variants of the heat treatment

As can be seen from the diagram in Figure 5, samples ADI6 and ADI5 exhibited abrasion resistance comparable to that obtained for the steel samples X120Mn12, but worse than steel S235JR. ADI8 sample has the highest wear resistance of all the tested materials.

Table 6.
The results of the measurement of abrasion

Sample number	Sample initial mass [g]	Loss in weight [g]			Loss in weight [%]			Loss in weight [g/cm^2]		
		60	120	180	60	120	180	60	120	180
ADI 1	225.0	4.8	7.2	10.6	2.13 %	3.20 %	4.71 %	0.167	0.296	0.435
ADI 2	234.6	3.8	6.2	9.3	1.62 %	2.64 %	3.96 %	0.149	0.244	0.366
ADI 3	236.5	4.3	7.2	10.7	1.82 %	3.04 %	4.52 %	0.172	0.289	0.429
ADI 4	239.3	6.5	9.0	12.1	2.72 %	3.76 %	5.06 %	0.254	0.352	0.473
ADI 5	223.3	3.3	4.9	6.9	1.48 %	2.19 %	3.09 %	0.131	0.194	0.273
ADI 6	228.1	3.0	5.0	6.5	1.32 %	2.19 %	3.09 %	0.118	0.197	0.256
ADI 7	227.2	4.0	6.9	9.6	1.76 %	3.04 %	4.23 %	0.155	0.267	0.371
ADI 8	220.9	2.1	2.9	3.4	0,95 %	1.31 %	1.54 %	0.085	0.118	0.138
S235JR	194.8	1.9	3.4	4.9	0.98 %	1.72 %	2.49 %	0.077	0.135	0.195
X120Mn12	195.6	2.9	4.7	6.8	1.46 %	2.40 %	3.45 %	0.114	0.188	0.270

4. Summary

The results of the study confirm a very complex character of the mechanism of wear. The study in [10] was concerned with testing for wear resistance (test pin on disc) the ausferritic cast iron with the composition close to that investigated in the present study . The study demonstrated that ADI is a possible replacement material for the Hadfield steel in the heavy load conditions. In turn, in the case of load which is not a heavy but which is a long-term one, where for manganese steel the expected TRIP effect was not observed, the employment of the ADI replacements is possible. What is important, however, is the precise selection of both the austenitization and the thermal quenching parameters. Obtaining a material with high hardness is not equivalent with obtaining a material with high wear resistance. The strengthening mechanisms which operate within the ADI outer layer under stress are still studied [11-12]. In the present study, the highest wear resistance was obtained for cast iron which was austenitized in the temperature of 950°C for 90 minutes and quenched isothermically in liquid tin for 90 minutes in the temperature of 220°C.

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