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Research Paper

Experimental analysis on characteristics of Carbidic Austempered Ductile Iron

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Abstract

ADI is a material known for Impact toughness, hardness and wear resistance. Carbidic Austempered Ductile Iron [CADI] is a ductile iron which contains high wear resistance alloy carbides in its matrix and is produced by selecting proper composition of material through melting route. Two different alloy compositions of carbon equivalent close to the eutectic composition with variation in the chromium content are used in this study. A detailed microstructure characterization of the material is studied. Effects of austempering parameters on the mechanical properties like impact toughness, hardness and wear resistance are evaluated. Improvements in themechanical properties are found and are correlated with the microstructure. SEM analysis of the wear surface is also studied.

Keywords: *Ductile iron, Austempering, Carbides, Wear resistance.*

1. Introduction

Industry is discovering various materials and processes combinations that exhibit surprisingly good in strength and wear resistance. Austempered ductile iron is one among in that and has long been recognized by industries for its high tensile strength, ductility, wear resistance and toughness [1]. The ausferrite matrix gives enough toughness and it is produced by the austempering process. The high carbon austenite phase present in the ductile iron has a tendency of strain hardening the surface [2]. This phase offers the high wear resistance to this metal. Copper, Molybdenum and Nickel promotes the formation of ausferrite matrix in ADI [3]. Alloying of these elements increase the amount of retained austenite and hence the mechanical properties [4-8].
Due to these behaviors, the ADI can be an alternate for the forged steels [9, 10] components. ADI strength to weight ratio is more than that of the aluminium. So ADI can replace aluminium material also, where the strength of the component is to be considered for minimum weight. The effect of austempering and alloying of manganese on ADI is also studied [11]. From the literature, it is evident that the alloying and austempering lead to improved mechanical properties. S.K.Putatunda [12] has used a new processing method called step-down austempering process for ADI production. But the role of chromium and austempering time on mechanical properties is still not fully disclosed.

CarbidicAustempered Ductile Iron

Recently a new ADI, containing carbides in the ausferrite matrix has been introduced in the market. This is called CarbidicAustempered Ductile Iron [CADI]. Carbides are the known strong wear resistance compounds compared to other materials. But these carbides alone are not directly used due to their higher brittleness. They are combined with tough ausferrite matrix; the combination gives a superior quality material.
The addition of carbides in the ausferrite matrix may decrease the toughness. So the challenges are related to the development of a material and processing parameters in order to get both the constituents in the final microstructure. The available literature related to CADI material shows only the application examples, microstructure and the abrasive wear resistance [13-16].
Carbide content of the material is increased by reducing the graphitizing elements, Increasing the cooling rate of solidification, Introducing carbide stablishing elements like chromium, manganese, molybdenum and titanium. The literature [16] shows the effect of high cooling rate using copper chills. In practical applications the use of chills in intricate shapes like hollow part with profiles is complicated. So a method of production of CADI without chill is to be investigated. This study explains the production of carbidic ductile iron by melting route, its austempering heat treatment parameters and their characteristics. Use of chills and reduction of graphitizing elements have not been applied.
Carbide stabilizing agents like manganese and molybdenum have a tendency to segregate in the grain boundaries. This will decrease the properties of ADI [18]. Alternatively the chromium content of the base metal is increased in this study to induce the carbides. Controllers analysis for non-linear system has been reported [22-31].

2. Material and Methods

2.1. Foundry Considerations for CADI Production

Iron scraps and steel turnings are melted in an induction furnace and the composition of carbon, silicon is adjusted. The melt is heated upto 1590°C. Aluminium level in the melt should be kept less than 0.05% in the alloy to reduce the tendency to slag and dross formation. The sulphurcontent in the melt should be less than 0.01%. More sulphur reduces the magnesium recovery and nodularity of the ductile iron. Sulphur reacts with the magnesium and forms Mg_2S and it has been removed from the melt.

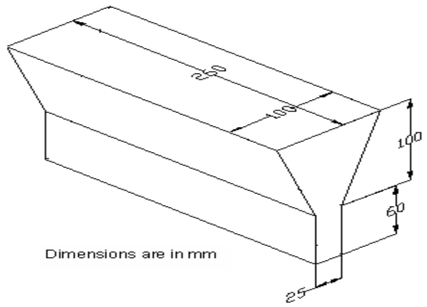

Fig. 1: Y-Block Casting

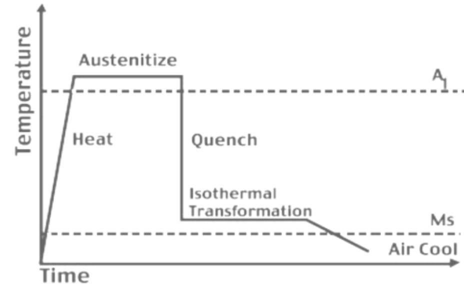

Fig. 2: A schematic of Austempering process

The liquid metal is magnesium treated in a magnesium treatment ladle. The magnesium master alloy contains 9 wt % magnesium and the master alloy added is 1.5 wt % of melt. The temperature loss during treatment is around 50°C, treatment temperatures of around 1540°C is employed. Now, required amount of hot ferrochrome is added into the melt to increase the chromium level. The melt is transferred to pouring ladle and (Alloy of barium and calcium) inoculant is inoculated. The treated melt is poured within five minutes to avoid the magnesium fading. Fading reduces the nodularity of the metal.

The magnesium treated melt is poured into the sand mold within the specifiedtime and temperature. Y-block castings are casted as per ASTM standards and the dimensions are given in Figure 1. The composition of the metal is analyzed using 40 element vacuum spectrometer and the results are shown in Table 1. The cast material with carbide is known as carbidic ductile iron [19].

Table 1: Chemical composition of the samples by wt %

Alloy Designation	*C*	*Si*	*Mn*	*P*	*S*	*Ni*	*Cr*	*Mo*	*Cu*	*Ti*	*Al*	*Mg*	*Fe*	***CE***
DI	3.586	2.495	0.468	0.024	0.008	0.007	0.026	0.000	0.315	0.040	0.012	0.049	92.96	4.426
CDI	3.372	2.745	0.458	0.034	0.008	0.010	0.980	0.018	0.644	0.039	0.010	0.039	91.72	4.298

2.2. The Austempering Process

The Austempering process consists of austenitizationat higher temperature, rapid cooling to austempering temperature and maintaining in that temperature for longer period as shown in Figure 2. The selection of austenitizing temperature depends on the chemical composition of the ductile iron. The austenization temperature should be chosen so that the composition is in austenite and graphite phase. The austenizing time is according to alloy content of the ductile iron, more alloyed material required longer time to austenitize. The austenitization is done in salt bath (Nitride & Nitrate mix) at 910°C for two hours.

For the Austempering the quenching media is kept at a temperature above martensite start temperature. In this work austempering temperature varied between 250°C and 400°C. Austempering time is varied between one and four hours in a time gap of one hour. After austempering, the specimens are cooled to room temperature in air quenching. This cooling rate does not control the metal properties, because the carbon content of the austenite is more enough to reduce the martensite start temperature.

2.3. Characterization

2.3.1. Microstructure Examination

Specimens are polished, etched using 5% nital [19] and microphotographsare taken using Nikon Epiphoto-Dx optical microscope equipped with high resolution digital camera.

2.3.2. Strength and Hardness

The Brinell hardness test is completed using B-3000 Model Hardness tester having load capacity of 29.4 KN. 10 mm diameter

steel ball indenter is used in this process. Test is conducted at four different places; average value is considered. CharpyImpact toughness test is done as per ASTM E 23 standard with 300 Joules hammer capacity and 4.5ms^{-1}striking velocity. Tests are done on unnotched test samples of size 10x10x55 mm.

2.3.3. Wear

Abrasion wear of the material is measured as per ASTM standard G99-05 using pin-on-disk wear testing machine. HRC – 65 disk hardness, load of 98.1N is applied to the specimen, with a velocity of one m/s and 10,000m travel distance of is considered. 0.01 mg precision scale is used to measure the weight loss values of the specimens.

3. Results and Discussion

3.1. Microstructure

The microstructure of DI, ADI and Carbidic Ductile Iron materials are shown in Figure 3. The microphotograph of [Figure 3A] DI contains bull’s eye structure. Graphite spheroids are surrounded by the ferrite phase. The ADI microphotograph austenized at 900°C and austempered at 300°C contains lower ausferrite matrix [Figure3B] with evenly distributed graphite spheroids of same size.

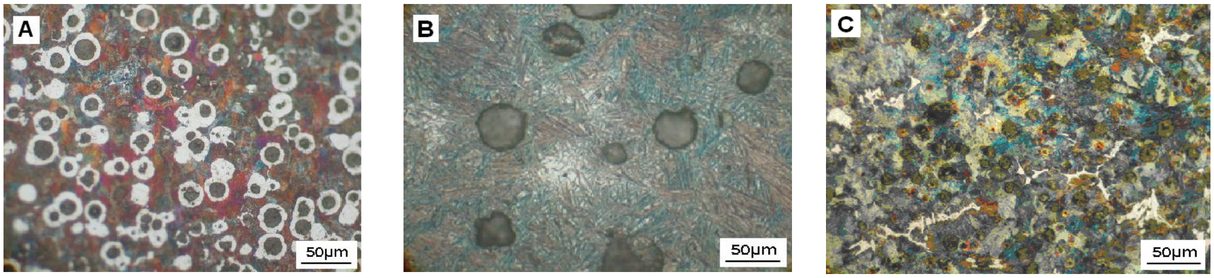

Fig. 3: Microstructures of base metal DI, ADI & 1 % CrCDI

The white regions in the figure 3C are alloy carbides;they are formed because of chromium addition. Here, sizes of the spheroid graphite are same as DI and the carbides is evenly distributed in pearlite matrix with small amount of ferrite is also seen.Microstructures of CDI specimensaustempered at various temperatures and time are given in Figure 4 to 7. All photographs contain spheroids and carbides in ausferrite matrix. This shows that carbides are retained after austempering treatment.Matrix of the shorter austempering shows coarse ausferrite whereas longer austempering forms fine ausferrite. Higher austemped temperature forms upper ausferrite, while the lower temperature austempering forms lower ausferrite. The lower ausferrite has very fine ferrite needles within the austenite regions. The ferrite needles in the upper ausferrite are long, broad and thick. Fine ferrite matrix has seen in those samples austempered at longer time.

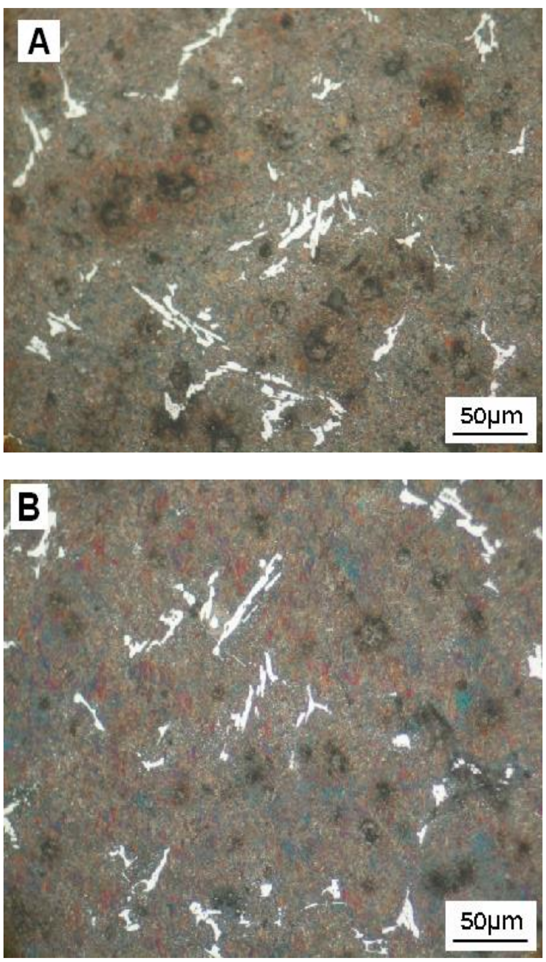

Fig. 4: Microstructure of CADI Austempering Temperature
250°C @ 2 & 4 Hrs

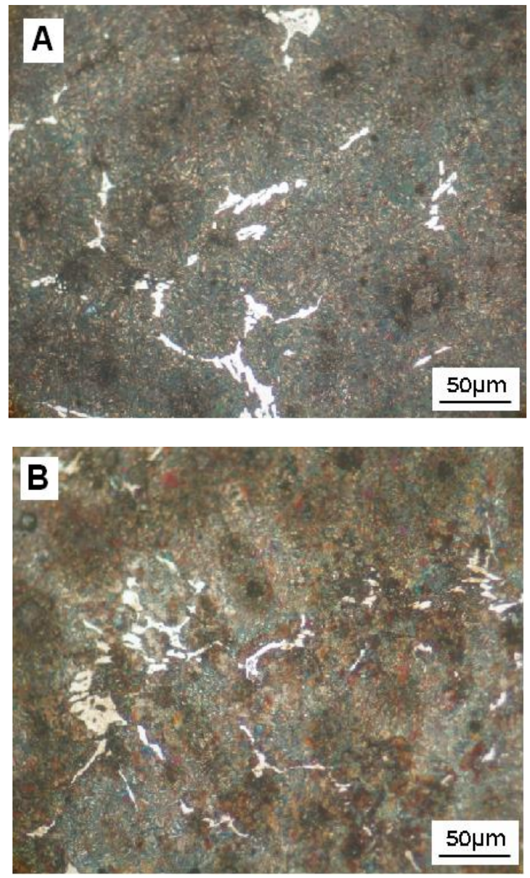

Fig. 5: Microstructure of CADI Austempering Temperature 300°C @ 2 & 4 Hrs

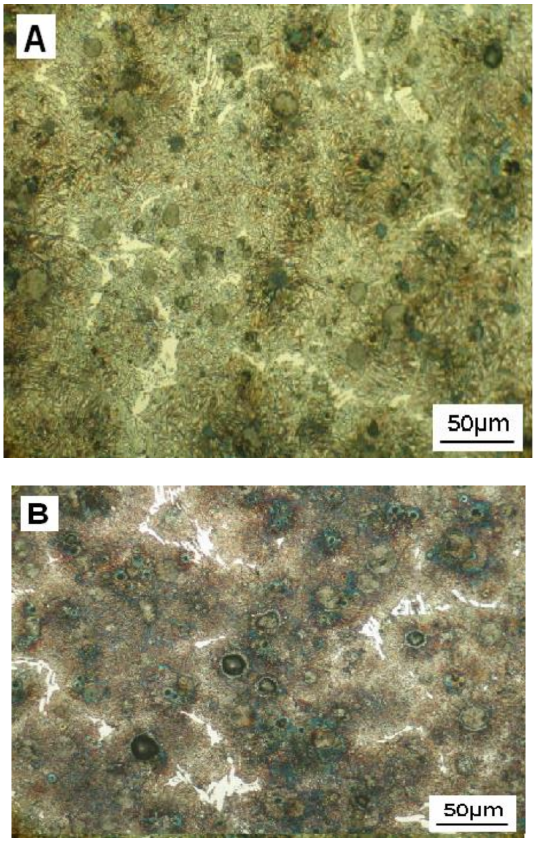

Fig. 6: Microstructure of CADI Austempering Temperature 350°C @ 2 & 4 Hrs

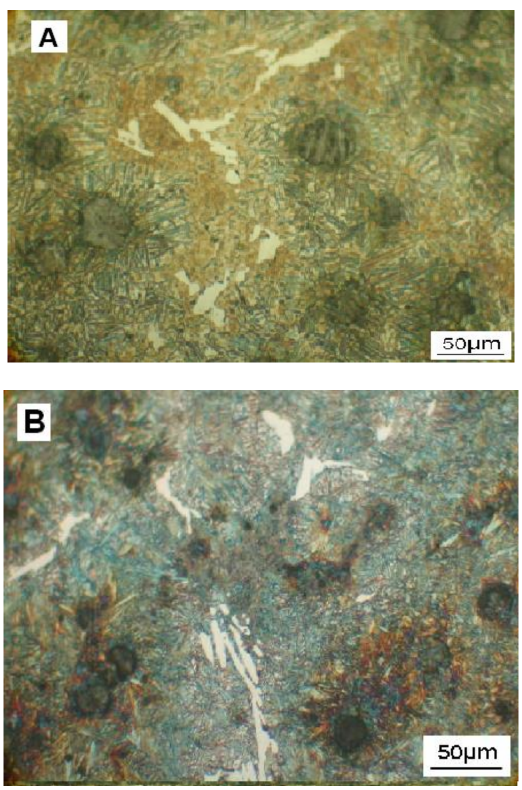

Fig. 7: Microstructure of CADI Austempering Temperature 400°C @ 2 & 4 Hrs

3.2. Mechanical Properties

Mechanical properties of the metal are given in Figure 8. CADI is 177% harder, its resistance to wear is 515 times higher and its impact toughness is also good compared to ADI. High resistance to wear and hardness is created by the carbides in the matrix. The low hardenabilty base metal composition produces only lower ausferrite matrix during austempering. Lower ausferrite matrix posses high hardness and wear resistance.

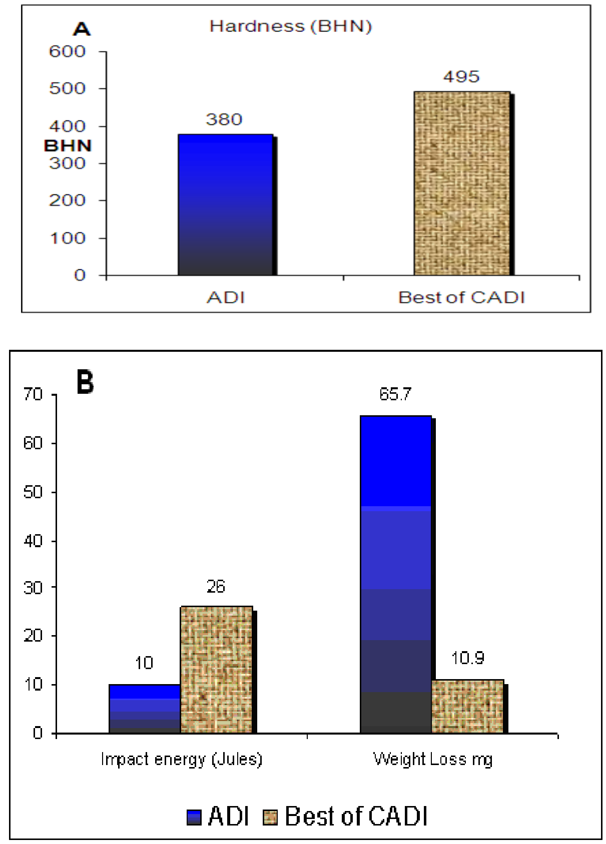

Fig. 8: Properties of ADI and CADI

3.2.1. Hardness

Hardness variations of 1% Cr alloy are shown in Figure 9. Variation in hardness due to change in austempering temperature is low because hardness lines are very close to each other. Maximum hardness value of 495 BHN has attained at 250ºC austempering temperature at two and three hours time. Higher austempering temperature and time reduces the hardness. One hour austempering reveals higher hardness values. These samples have upper ausferrite microstructure. The nucleation of ferrite needles starts at the initial stages of austempering and because of long time availability in the long austempering process produces upper ausferrite. The broad retained austenite of upper ausferrite and carbides in these matrixes combination gives higher hardness of CADI.

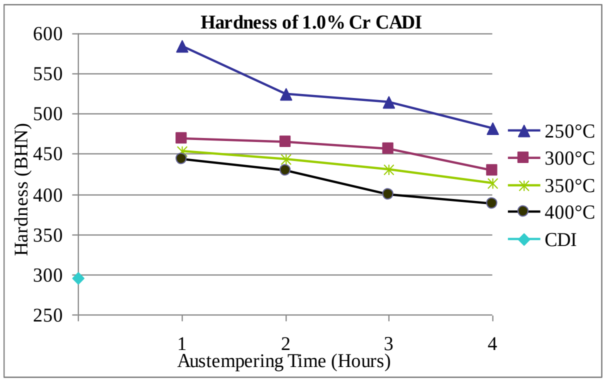

Fig. 9: Hardness

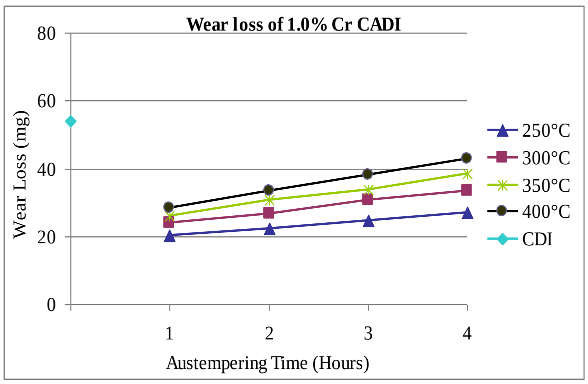

Fig. 10: Weight loss

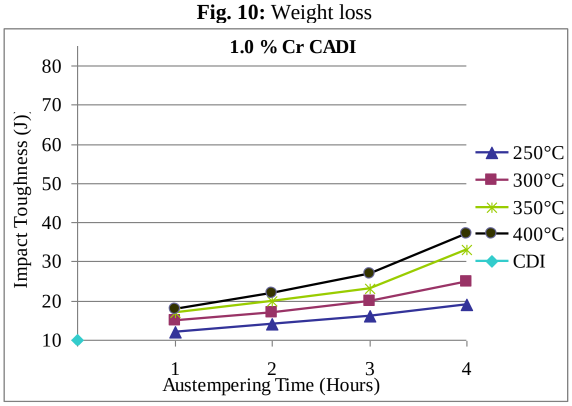

Fig. 11: Impact Toughness

3.2.2. Wear

Wear change of carbidicaustempered ductile iron is shown in Figure 10. The specimen treated at 250°C has higher wear resistance whereas specimensaustempered at 400°C offers low wear resistance. Resistance to wear is low if austempered for four hours. Larger austempering produces long ferrite needles and austenite. This austenite contains more enriched carbon. This enriched carbon induces the hardening effect due tostrain in this material. This hardening effect due to strain produces high wear resistance surface. It is known that the carbide present in the matrix resists the wear. So the known carbides along with hardening effect due to strain of austenite posses higher resistance to wear. This self induced hardness resist the wear of the material. The samples with higher carbide content have better wear resistant.

3.2.3. Impact Toughness

Charpy impact toughness tests are conducted, three samples are for each catogery and the values reported are average of these tests. Variation of impact toughness is in Figure 11. Impact toughness specimens treated at 400°C offer higher values compared to others. Lower temperature austempering gives lower impact toughness compared to higher austempering temperature. This is because of the upper ausferrite present in it. Carbidicaus tempered ductile iron having lower ausferrite microstructure has better toughness than with upper ausferrite matrix. Lower austempering temperature produces high carbon in the austenite. This is in relation to the lower kinetic energy of carbon atoms in the austenite at the lower austempering temperature. This austenite with high carbon and small ferrite needles shows better impact toughness. Variation of impact toughness at shorter austempering is higher compared to longer austempering.

4. Conclusion

- The CADI production is not a highly complicated process. However, there are important considerations to be successful. High quality ductile iron and proper alloy addition is the necessary ingredient for heat treatment.
- The austempering time effect on mechanical properties of CADI is studied. Shorter austempering corresponds to higher hardness (495 BHN) and resistance to wear but variations of mechanical properties are higher while comparing to longer austempering.
- Carbidesavailable in the basic alloy is retained after heat treatment. Carbide content, ausferritematrix makes the property variation.
- Higher temperature of austemperingforms of upper ausferrite microstructure. This upper ausferrite produces better impact toughness.
- Maximum impact toughness is at 400ºCaustempering temperature and 4 hours of tempering.

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