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EFFECT OF MICROSTRUCTURE ON WEAR BEHAVIOR OF CARBIDIC AUSTEMPERED DUCTILE IRON (CADI)

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ABSTRACT

The abrasion wear resistance of ductile cast iron is improved by the incorporation of an extra phase in the matrix, typically consist of carbides. The objective of the present work is to produce carbides in a ductile cast iron which is subsequently austempered, to obtain the carbidic austempered ductile iron (CADI). Two variants of (CADI) were produced by heating carbidic ductile iron (CDI) to a austenitization temperature of 975ºC for the period of 1hr and quenching in salt bath at temperature range 400ºC for the period of 2hr and 4hr. The microstructural characteristics of the produced CADI were evaluated by optical microscope. The abrasion wear resistance was evaluated by testing in accordance with ASTM G 99 standard. Heat treatment parameters affect the microstructure of the carbidic austempered ductile iron which can be characterized by optical microscope, XRD and SEM.

Keywords: Carbidic Austempered Ductile Iron, Optical Microscope, XRD, SEM, Austempering, Microstructure, Abrasion Wear.

I. INTRODUCTION

Austempered Ductile Iron (ADI) has been long recognized for its high tensile strength (over 1600MPa for grades 5 and 1, according to the ASTM A-834-95), replaced forged steels in many applications. It is also well known ability of this material to perform very well under different wear mechanisms such as rolling contact fatigue, adhesion and abrasion[1],[2],[3] . ADI has proved to behave in a different manner under abrasive conditions, depending on the tribosystem (lower high stress abrasion), but always possible to obtain a good performance in wear if the heat treatment parameters are selected properly. A new type of DI, containing carbides immersed in the typical matrix of DI, called Carbidic DI or CDI has been developed. A new type of CDI, containing carbides immersed in the typical ausferritic matrix, called carbidic ADI or CADI has been recently introduced in the market. The available literature of CADI shows only application examples and data about the response to abrasive wear but not the procedure to produce CADI. CADI is a ductile cast iron containing carbides, (that are induced either thermally or mechanically), that is subsequently austempered to produce an ausferritic matrix with an engineered amount of carbides. Methods of carbide introduction include: As-Cast Carbides: Internal (chemical or inverse) chill: Surface chill (limited depth, directional). Mechanically Introduced Carbides: Cast-in, crushed MxCy carbides; Cast-in, engineered carbides (shapes).Welded: Hard face

Weldment; Weldment with MxCy grains.[4],[5]. The presence of carbides promotes an increase in the abrasion wear resistance. The development of this material is possible; if heat treatment parameters, microstructure is controlled properly in order to obtain the maximum abrasion resistance. The objective of this work is to produce two variants of CADI, studying their microstructural characteristics and evaluating the abrasion resistance.

II. EXPERIMENTAL PROCEDURE

2.1 Material and Sample Preparation

The details of the pattern used in the present experiment is shown in figure 1(a) which was made from wooden with standard allowances with proper finishing, then by using the prepared wooden pattern a mold is prepared in the specified sand in the mold box then after removing the pattern from sand and drying the mold and removing the loose sand from mold, then the mold is finished and the mold is ready to pour the molten metal in it, thus the standard square casting of 15x15x200mm long, were produced in the green sand mold table1 gives the chemical composition of the carbidic ductile iron. Figure 1(a) shows the schematic diagram of the prepared sand mold used in the present investigation. The shape and dimensions of the model used to make the moulds for casting are shown in Fig. 1(a), it is of near net shape casting test bars of size 15x15x200mm. CADI samples were obtained from the same two heats alloyed with Cr after a heat treatment involving an austenitizing stage of temperature 1000°C in a muffle furnace for Tg-1h, followed by an austempering step in a salt bath at Ta-325°C during quenching time ta-2h,4h. Thus obtained test bars are sliced in 15mm long to test sample for microstructural characterization and hardness measurement. The wear samples Sliced of about 15x15x40mm long of 8mm diameter cut with EDM wire cut for as-cast, as well as for CADI wear samples preparation, CDI samples used as reference material.

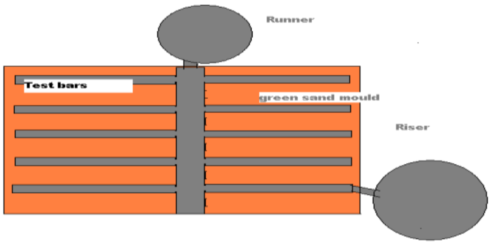

Figure 1(a). Sample casting green sand mould

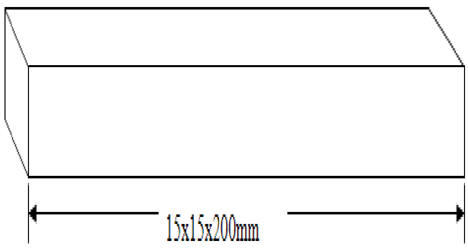

Figure 1(b). Sample Test Bars

Table1. Chemical composition of As-cast CDI

Alloying element %	C	Si	Mn	S	P	Cr	Cu	Ni	Ti	Mg	CE
C1	1.6	2.07	0.53	0.006	0.0249	2.17	0.680	0.458	0.008	0.041	2.29

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2.2 Chemical and Micro Structural Examination

The chemical composition of the alloys was measured by means of a spark emission optic spectrometer with a DV6 excitation source. Metallographic sample preparation for optical microscopy examination was conducted by using standard cutting and polishing techniques, and etching with 2% Nital. The volume fraction of carbides was measured by image analyzer. For this purpose, carbides were revealed by etching with 10% ammonium persulfate in aqueous solution. The magnification used to obtain data from a sufficiently large area was X20.Each reported value is the average of four measurements.

2.3 Mechanical Tests

Rockwell hardness was measured at 150 kg load (HRC) on C-scale. A hardness profile was obtained for each alloy. In order to determine the hardness of the carbides and the matrix separately, micro indentation tests were carried out by using a Vickers indenter at a 200g load (HV200). The abrasion wear resistance was evaluated by performing the ―Pin on disc Abrasion Test‖ the disc is of diamond ring having hardness of around 3000Hv and width of 10mm. According to the ASTM G-99 standard, and using the procedure A (test load 20N, distance travelled for 14450meter, at 400rpm and track radius 58mm).

Fig.2 Show the wear samples of CADI 8mm diameter and counter face wear base plate

2.4 SEM of CADI Sample

SEM is done SCANNING ELECTRON MICROSCOPE (SEM),(JEOL 6380A), JEOL JSM-6380A Analytical Scanning Electron Microscope on sample at different magnification, by secondary electron and photo micrographs are presented in the result.

2.5 XRD of CADI Sample

XRD is done on the machine X-RAY DIFFRACTO METER (XRD) with online UPS-15KVA MODEL MAKE: PHILIPS X-PERT PAN ANLYTICAL, SUPPLIER: M/s SPECTRA TECH (P) LTD MUMBAI, on CADI sample with excitation sources of copper k-α at 2θ position and various peaks of ferrite, Chromium iron carbide, Iron carbide and austenite are found which are indicated in the results.

III. RESULT AND DISSCUSSIONS

3.1 Chemical and Microstructural Characterization

Microstructure in Fig.3(c) shows rare white portion is carbide traces along the grain matrix, Dark spot shows the graphite nodule, Dark portion shows Ausferrite, which is conformed through hardness values, White portion in dark phase indicate retain austenite and dark line indicate free ferrite. While microstructure in Fig.3 (a) shows large amount of carbides is formed and dark portion is Ausferrite. Fig.3 (b) shows microstructure in which carbides are formed in circle form with thick boundries and dark portion is Ausferrite.

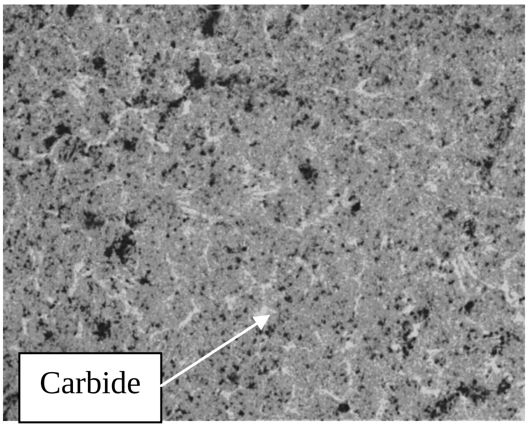

Fig 3(a) C1 975ºC-1h 400ºC-2h-200X

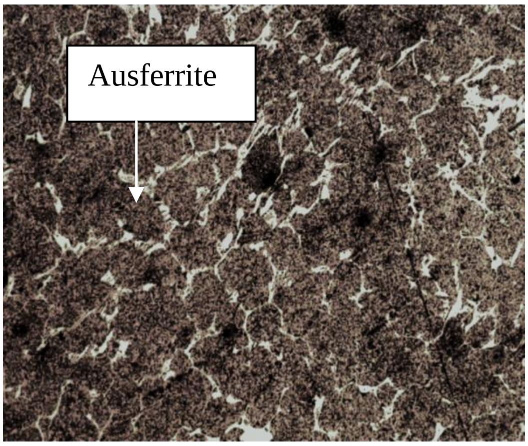

Fig 3(b) C1 975ºC-1h 400ºC-4h-200X

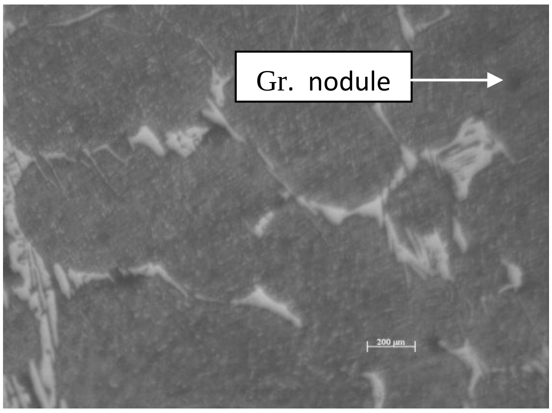

Fig 3(c) C1 900ºC-1h 400ºC-2h-500X

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3.2 Mechanical Properties

3.2.1 Hardness Tests

The Rockwell hardness on C-scale was determined for samples C1 bulk hardness was determined as average of five measurements. The results of the austempering temperatures and two quenching durations in salt bath are determined. The Vickers micro hardness was determined as the average of three measurements in each alloy in a region of carbide and ausferrite. Micro-hardness of Carbide phase is found around 608HV200 to 622HV200 and for other than Carbide phase i.e for ausferrite around 453HV200 to 589HV200.

3.2.2 Scanning Electron Microscope

SEM of Fig.4 (a) shows greyer portion is carbides while grey portion in small pieces is austenite and dark line indicates ferrite. In Fig.4 (b) the amount of carbides is reduced and these carbides are induced into Ausferrite. Fig.4(c) large amount of carbides are formed and dark spot is graphite nodules.

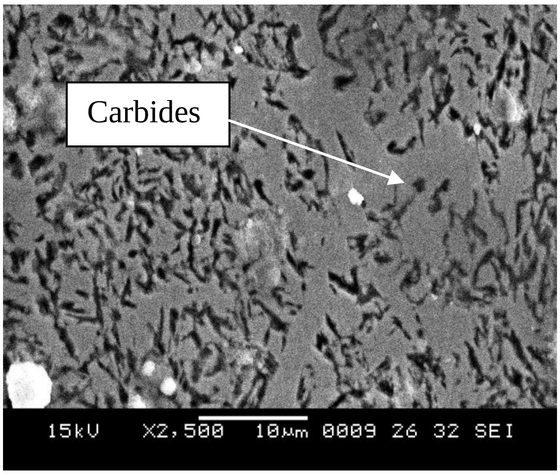

Fig 4(a) C1 975°C-1h 400°C-2h-2500X

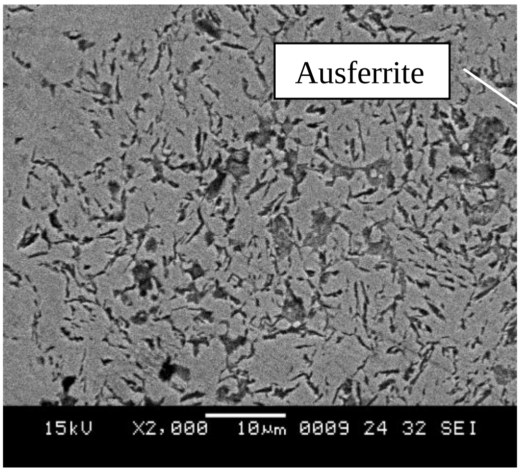

Fig 4(b) C1 975°C-1h 400°C-4h-2500X

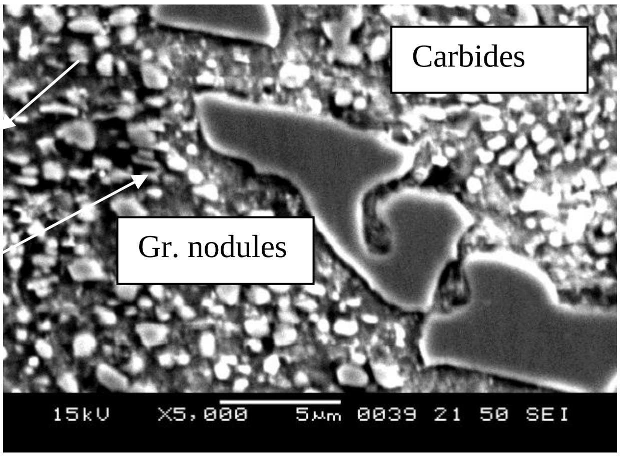

Fig 4(c) C1 900°C-1h 400°C-2h-5000X

3.2.3 X-Ray Differaction

XRD of Fig.5 (a) shows the peak of Austenite at 200,311, iron carbide at 213, ferrite at 200, chromium iron carbide at 911 and martensite at 101,110 planes. While Fig.5 (b) shows the peak of martensite at 101, 110, austenite at 311, iron carbide at 213 and ferrite at 200 and chromium iron carbide at 531 planes. The XRD in Fig.5(c) shows that the peaks of Austenite at 111,200 and ferrite peaks at 200, 211,220 and iron carbide peaks at 131 and chromium iron carbide at 511 planes.

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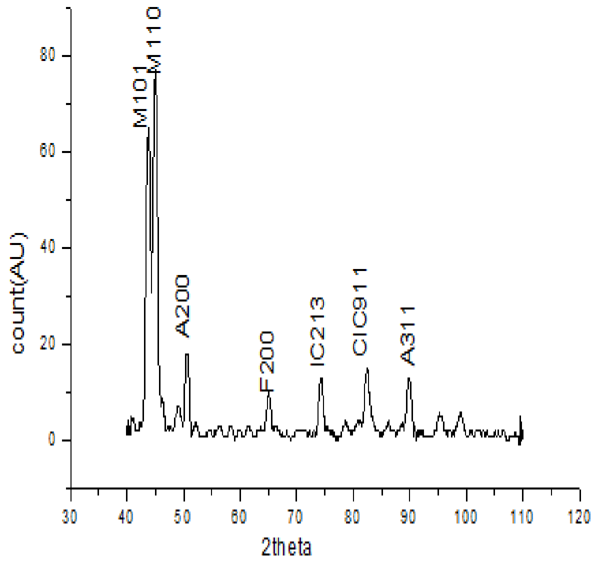

Fig 5(a) C1 975ºC-1h 400ºC-2h

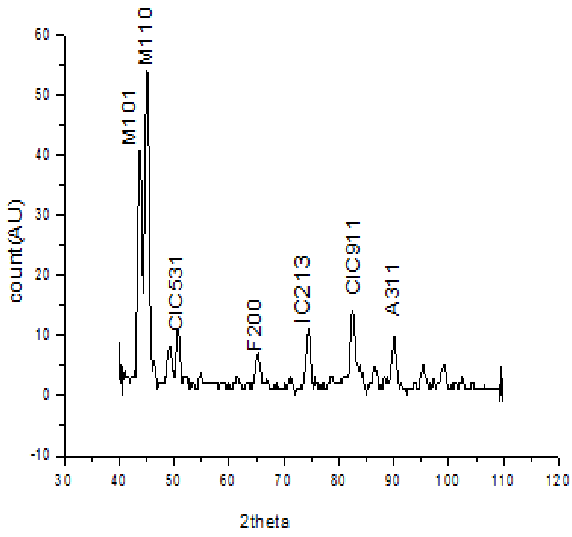

Fig 5(b) C1 975ºC-1h 400ºC-4h

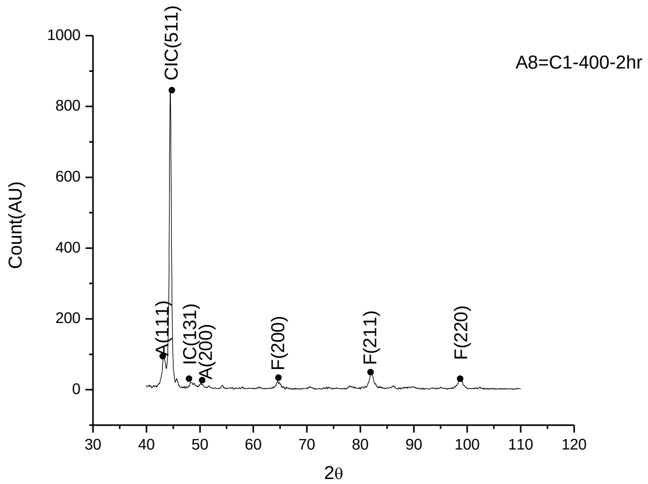

Fig 5(c) C1 900ºC-1h 400ºC-2h

3.2.4 Wear Resistance

The Pin on disc wear test is conducted in accordance with ASTM G-99 standard. The weight loss values for CADI samples measured on pin of 8mm diameter 40mm long and Diamond ring disc. Weight loss is the functions of the chromium content, carbon equivalent, austempering heat treatment parameters and microstructure matrix .The Maximum wear resistance is obtained on sample C1 975ºC-1h 400ºC-3h as its weight loss is minimum. Austempering at 400ºC-3h the reinforcement effect of carbide and ausferrite is matched to the hardness values which are higher, reported in the graph of figure 5 and accordingly the wear resistance is more, which is indicated in Table 2. Weight loss for sample C1 900ºC-1h 400ºC-3h is calculated with the formula:

$$Y - Y1 = \frac{Y2 - Y1}{X2 - X1}\,(X - X1) \text{ …….. Eq 1}$$

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Where, Y= weight loss in gram(3h)

X= time in hour = 3h

Y1= weight loss in gram(2h) = 0.135

X1= time in hour = 2h

Y2= weight loss in gram(4h) = 0.107

X2= time in hour = 4h

Putting this values in eq^n 1,

$$Y - 0.0.135 = \frac{0.107 - 0.135}{4 - 2}(3 - 2)$$

Y= 0.174 gm

Therefore weight loss for sample C1 1000ºC-1h 325ºC-3h is 0.174gm

Table 2, Pin on disc Wear testing results of various CADI

Sample Name	Weight loss in gram
C1 975 ºC-1h 400 ºC-2h	0.135
C1 975 ºC-1h 400 ºC-3h	0.174
C1 975 ºC-1h 400 ºC-4h	0.107
C1 900 ºC-1h 400 ºC-1h	0.266
C1 900 ºC-1h 400 ºC-2h	0.0853
C1 900 ºC-1h 400 ºC-3h	0.0856

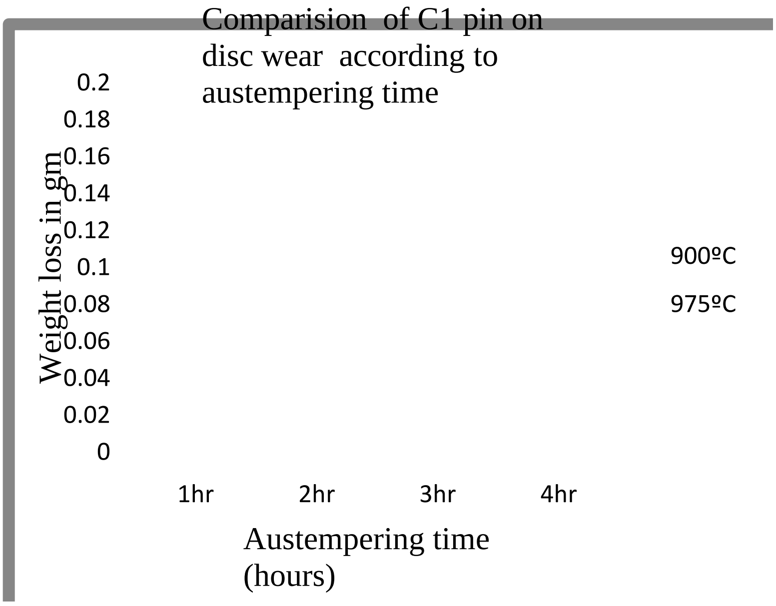

Fig.6 Wear Resistance is Maximum at 400ºC-3 h

IV. APPLICATIONS OF CADI IN REAL PARTS

The application of CADI under ideal conditions, Material handling equipments, like conveyor, chute, In power plant Ash handling equipment, cattle feed extruder, cam shaft of IC Engine, Earth mover component, soil aerator, centrifugal pump component, cylinder liner, agricultural and mining machinery[13], Equipment bucket loader, pipes the use of a material for a new application should be evaluated through field tests, even with their associated difficulties such as higher cost, sample tracking, machine shut downs, etc. The performance of wheel loader bucket protection plates made of CADI containing 1.0 and 2.0% Cr and austempered at 300ºC is currently being assessed by field tests, using a conventional ADI also austempered at 300ºC as reference material. This type of solicitation was deliberately chosen in order to get abrasive conditions different to that evaluated in the lab [13].

V. CONCLUSIONS

It is possible to obtain Carbidic ADI (CADI) with different amount of carbides using Cr as the main alloying element. The carbide contents are obtained by alloying with Cr between 2 and 2.5%. All most all carbide was stable during the austenitizing stage of the austempering and the amount of dissolved carbides was nil and negligible. The presence of carbides in the microstructure increase the wear resistance, after austempering the wear resistance was increased; this is due to reinforced matrix of three phase's ferrite, ausferrite and carbides. Under the present experimental conditions in the alloys containing 2.17% Cr precipitates the thick circular form carbides significant reinforcement of the matrix with respect to abrasion. The highest wear resistance was obtained for sample C1 900ºC-1h 400ºC-3h, with the chromium content (2.17% Cr) and CE=2.29.

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