EFFECT OF CHEMICAL COMPOSITION AND AUSTEMPERING TEMPERATURE ON PROPERTIES OF CADI

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ABSTRACT

The abrasion wear resistance of 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 austenitization temperature of 975^{0}C for the period of 1hr and quenching in salt bath at temperature 400^{0}C for the period of 2hr,4hr respectively. The microstructure 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. Carbidic ductile iron (CDI) as-cast samples were taken as reference material to determine the relative hardness on 150kg load on C scale, micro hardness on 200 gm., X-ray diffraction (XRD), scanning electron microscope(SEM) and checking its wear properties on 2 kg load at 400rpm for 100 minutes and calculate weight reduce . The results obtained, allow to establishing a relationship between Cr content in the alloy, austempering parameters, microstructure and mechanical properties of CADI. It was found that increase in the CE, content in CADI increases the volume fraction of Carbides in an alloy which resulted in to enhancement in hardness and wear resistance.

***Keywords:* Abrasion, Austempering temperature, Ausferrite, Carbides, Carbidic austempered ductile iron, hardness, Microstructure, SEM, XRD.**

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. One of the methodologies commonly used to obtain a microstructure with as-cast carbides is to reduce the quantity of graphitizing elements (in particular Si), in order to promote the precipitation of ledeburitic carbides during solidification due to a closer interval between the stable and metastable diagrams[14]. A second option is to alloy the melt with carbide stabilizing elements, such as chromium, molybdenum or titanium [4],[5], which strongly reduce the interval between stable and metastable eutectic temperatures and promote total or partial solidification according to the metastable diagram[6]. It must be taken into account that an under cooling also affects the size and count of the solidification units, and therefore, the micro segregation.

The lower the cooling rate, the greater the micro segregation effect increasing the probability for carbide precipitation at the last to freeze zones[14], therefore, the formation of alloyed carbides. Then, the size and composition of carbides may vary, from typical unalloyed ledeburitic to thin plate shaped high-alloyed carbides, depending on the chemical composition and cooling rate [6], [7], [8], [9]. It was demonstrated that ledeburitic carbides produced either by controlling the cooling rate or the silicon level (non alloyed carbides) have a high tendency to dissolve during the austenitizing stage and are less stable than alloyed carbides. Alloyed carbides are stable no dissolution during heat treatment [16]. The objective of this work is to produce variants of CADI, studying their micro structural characteristics and evaluating the abrasion resistance, X-ray diffraction of material, scanning electron microscope and hardness testing.

II. EXPERIMENTAL PROCEDURE

2.1 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. Sample bars of size 15x15x200mm. CADI samples were obtained from heats alloyed with Cr after a heat treatment involving an Austenitizing stage of temperature 975°C in a muffle furnace for Tg-1h, followed by an austempering step in a salt bath at Ta 400°C during quenching time ta-2h,4h. Thus obtained test bars are sliced in 15mm long to test sample for micro structural characterization and hardness measurement. The wear samples Sliced of about 15x15x50mm long of 8mm diameter cut with EDM wire cut for as-cast, as well as for CADI wear samples preparation.

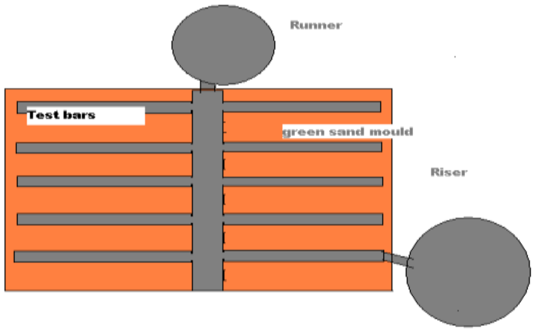

Fig.1(a)Sample Casting Green Sand Mould.

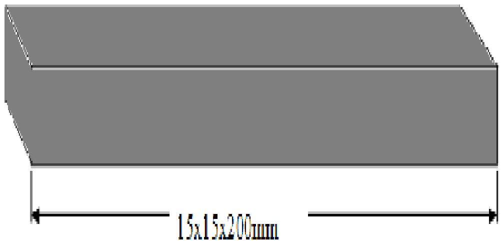

Fig.1(b) Sample Test Bars.

Table 1.Chemical Composition of As-cast CDI

Alloying elements %	C	Si	Mn	S	P	Cr	Cu	Ni	Ti	Mg	CE
C4	3.60	1.90	0.64	0.0122	0.0294	4.30	0.610	0.431	0.016	0.044	4.23

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 200x.

2.2 Chemical and Micro Structural Examination

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 X500.Each reported value is the average of six 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 (V200). 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 14325 meter, at 400rpm and track radius 57mm). The relative weight loss of CADI sample obtain by calculating initial weight and final weight of sample.

Fig.2 Show the Wear Samples of CADI 8mm Diameter and Counter Face Wear Base Plate.

2.4 X-Ray Diffracto Meter (XRD) OF CADI Material

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 of C4 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.

2.5 Scanning Electron Microscopy (SEM) of CADI Sample

SEM is done SCANNING ELECTRON MICROSCOPE (SEM),(JEOL 6380A), JEOL JSM-6380A Analytical Scanning Electron Microscope on C4 sample at different magnification from x500 to x2500 by secondary electron and photo micrographs are presented in the result and 10μm scale can be used to measure carbides, graphite and Ausferrite.

III. RESULT AND DISCUSSION

3.1 Chemical and Microstructural Characterization

Table 1 lists the chemical compositions of Carbidic Ductile Irons C4. It should be noted that C4 (CE=4.23%) nearly eutectic and alloyed with 4.30% Cr. All heats were alloyed with chromium in order to promote partial solidification according to the Fe–C metastable diagram [14]. This, in addition to the micro segregation effect, led to alloyed eutectic carbides formation. Fig 2a and 2b shows the microstructure of austempered sample C4 at 975^0c and quenched at 400^0c for 2 hr and Fig 3a and 3b shows the microstructure of austempered sample C4 at 975^0c and quenched at 400^0c for 4 hr. Following microstructures shows the carbides, graphite nodules and Ausferrite. In 2hr sample the carbides precipitated in grain boundaries and in 4 hr sample carbides are at random in thick net plate needle form. After austempering CADI samples, the matrix was ausferritic exhibiting the typical morphology, there is no change in the morphology and volume % of carbide. The carbide precipitated as a function of the Cr%, CE and Silicon.

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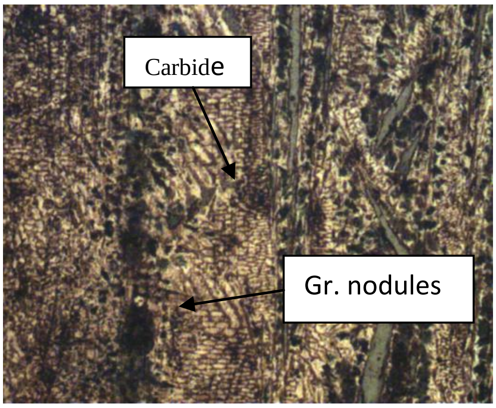

Fig. 3(a) C4-400^{o}c-2hr-200x shows carbides and Graphite nodules

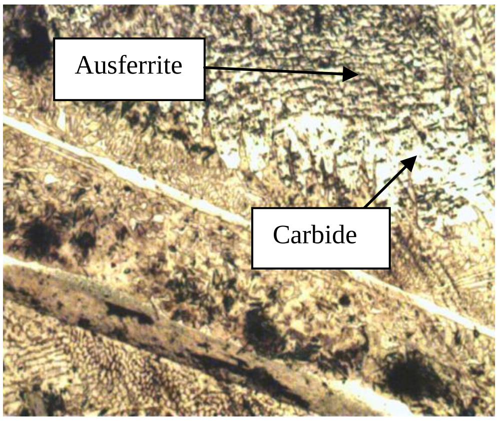

Fig.3(b) C4-400^{o}c-2hr-200x shows ausferrite.

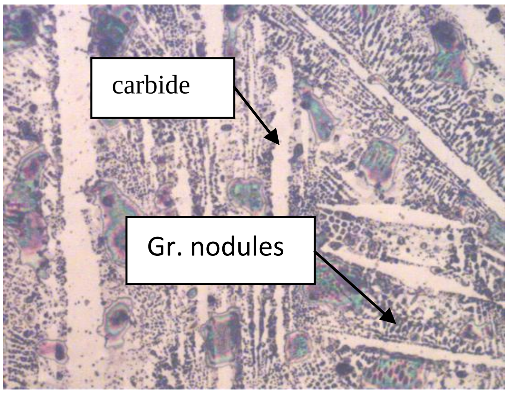

Fig. 4(a)C4-4hr-200x shows carbides and Ausferrite.

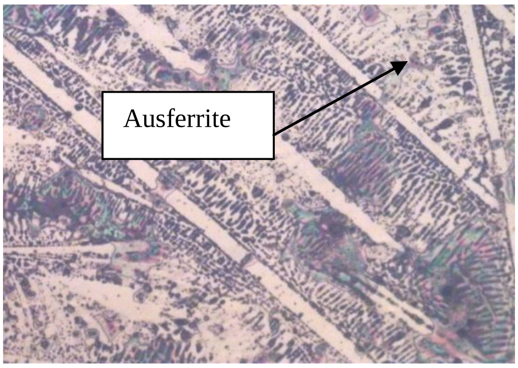

Fig.4(b)C4-400^{0}c-4hr200x shows carbides and Graphite nodules.

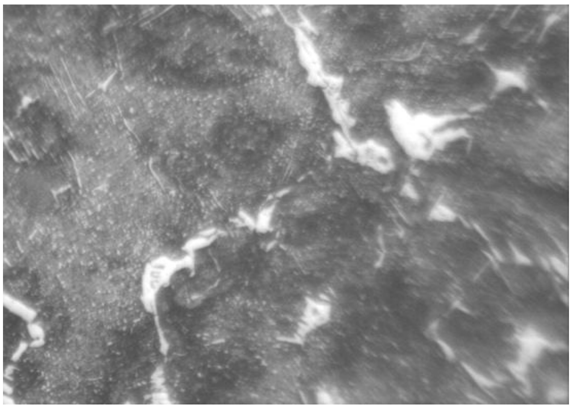

Fig.5 Show Microstructure of Austenitized at 900°C Austempered at400°C-2h at 500X.

3.2 Mechanical Proporties

3.2.1 Hardness Tests

The Rockwell hardness foe 150 kg load on C-scale was determined for samples C4-400^{0}c-2hr and C4-400^{0}c-4hr bulk hardness was determined as average of three measurements. The bulk hardness of 2 hr sample is 60 HRC and bulk hardness of 4 hr sample is 54 HRC. The results of the one austempering temperature and two quenching durations in salt bath are determined. The reinforcing effect of carbides increases with the chromium content and the reinforcing effect of carbides on hardness was varies with the austempering temperature. The Vickers micro hardness was determined as the average of three measurements in each alloy. Carbides are randomly precipitated throughout the sample. Micro-hardness on of Carbide phase is found around 593.3HV200 to 632.6HV200 for 2 hr sample and 527.3HV200 to632.9HV200 for 4 hr sample. From the wear resistance results it is observed as the hardness decreased the wear increased and hardness increased the wear decreased.

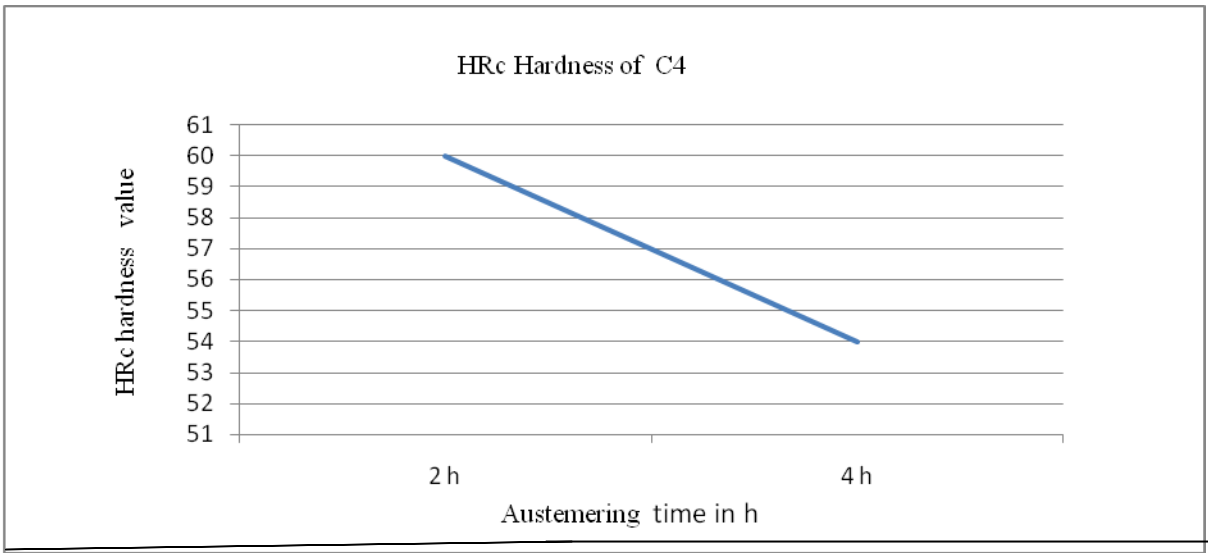

Fig.6 Variation of Bulk Hardness with Austempering Time of C4

3.2.2 Wear Resistance

The Pin on disc wear test is conducted in accordance with ASTM G-99 standard [11]. Table 2 shows the weight loss values for the sample C4-975^{0}c-400^{o}c-2hr and C4-975^{0}c-400^{o}c-4hr measured on pin of 8mm diameter 40mm long and Diamond ring disc. The least wear resistance is obtained in C4-975^{0}c-400^{o}c-4hr and Maximum wear resistance is obtained in C4-975^{0}c-400^{o}c-2hr.Figure 4 shows the graph of weight loss values obtained from samples at the austempering temperatures 400^{0}C and two quenching times 2hr and 4hr. The weight loss obtained of two samples by evaluating the initial weight and final weight of the pin. Weight loss is the functions of the chromium content, carbon equivalent, austempering heat treatment parameters and microstructure matrix. In case of C4-975^{0}c-400^{o}c-2hr; the Cr% is 4.30% it has been shown more wear resistant. As evaluating the hardness value of samples, it is found that more the hardness value less is the wear of material and less hardness value more wear occurred .The result will shown in graph . Weight loss for sample C4 975ºC-1h 400ºC-3h is calculated with the formula:

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

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

X= time in hour = 3h

Y1= weight loss in gram(2h) = 0.008

X1= time in hour = 2h

Y2= weight loss in gram(4h) = 0.029

X2= time in hour = 4h

Putting this values in eq^n 1,

$$Y - 0.008 = \frac{0.029 - 0.008}{4 - 2}(3 - 2)$$

Y= 0.0185 gm

Therefore weight loss for sample is C4 975ºC-1h 400ºC-3h 0.0185gm.

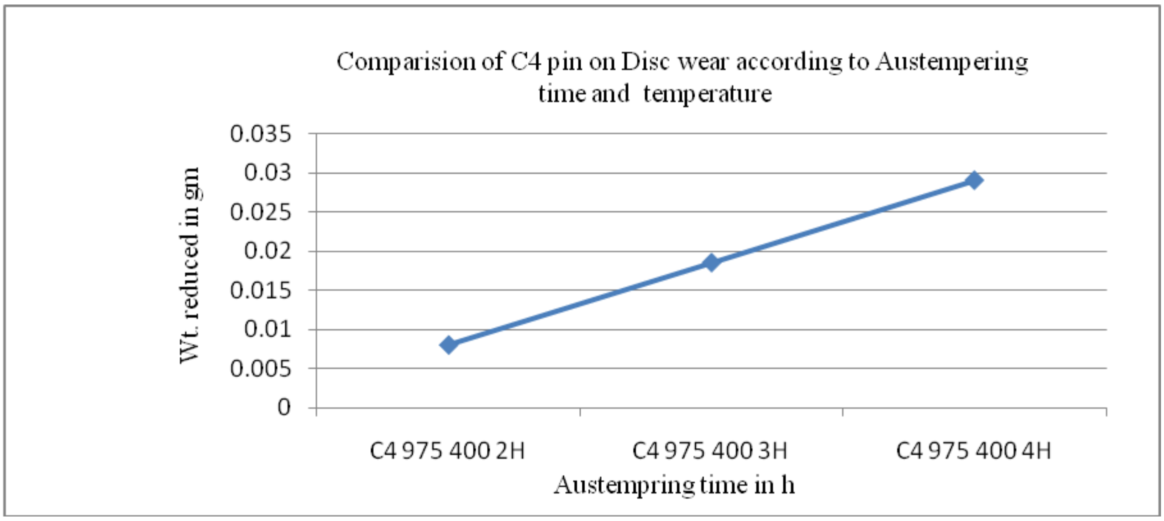

Fig 7.wt. Reduced in gm Vs. austempering time in h.

Table 2. Pin on Disc Wear Testing Results of Samples

Sr. No.	sample name	Wt.loss in gm.
1	C4-975^{0}c-400^{o}c-2hr	0.008
2	C4-975^{0}c-400^{o}c-3hr	0.0185
s3	C4-975^{0}c-400^{o}c-4hr	0.029

3.3 XRD and SEM of CADI Material

3.3.1 XRD and SEM of sample C4-975^{0}c-400^{o}c-2hr

The microstructure shows above the carbide in the form of variable thickness net immersed in the matrix and the matrix consist of ferrite and Austenite, the same is observed in the SEM image which is taken at 2500X magnification, which shows the carbide is immersed in the ferrite and Austenite matrix. XRD shows iron carbide peaks at 220, 321, Austenite peaks at 200, Martensite peaks at 211 planes and ferrite peaks at 220 plane. Due to alloying with Cr; the graphite nodule formation is poor.

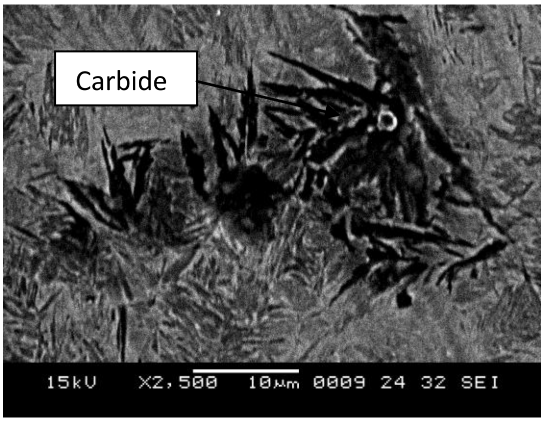

Fig.8(a) show SEM of C4 at 2500x.

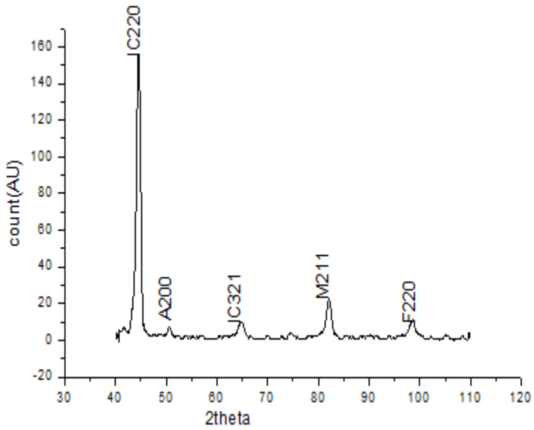

Fig.8(b) show as XRD of C4.

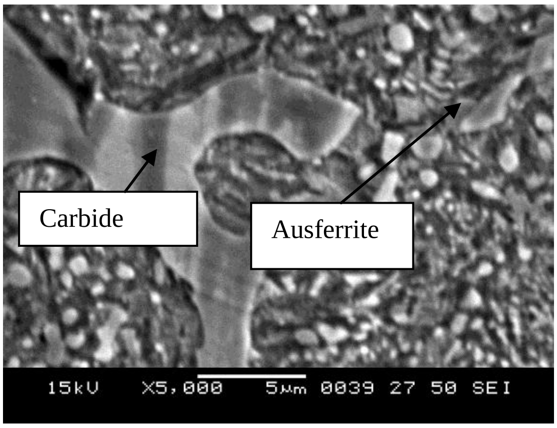

Fig. 9(a)Show SEM image 900^{0}c 400^{0}c 2h at 5000X.

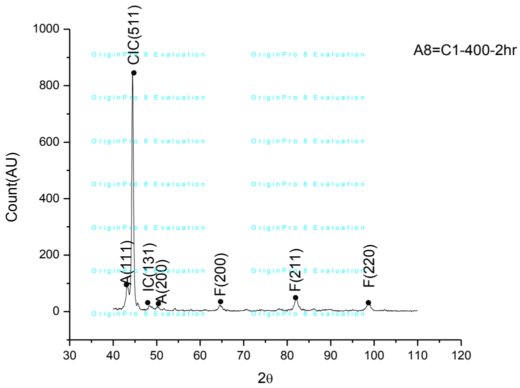

Fig.9(b) Show XRD of 900^{0}c 400^{0}c 2h.

3.3.2 XRD and SEM of sample C4-975^{0}c-400^{o}c-4hr

The microstructure shows above the carbide in the form of variable thickness net immersed in the matrix and the matrix consist of ferrite and Austenite, the same is observed in the SEM image which is taken at 2500X magnification, which shows the carbide is immersed in the ferrite and Austenite matrix. XRD shows iron carbide peaks at 221, 212,060 plane, Chromium iron carbide peaks at 511 planes and ferrite peaks at 200,211,220 plane. Due to alloying with Cr; the graphite nodule formation is poor.

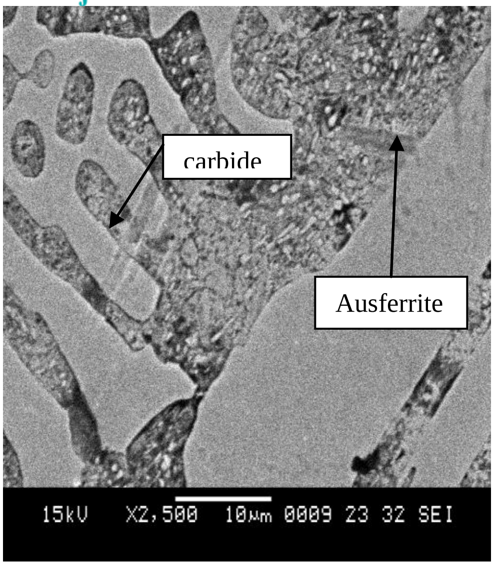

Fig.10(a)show SEM of C4 at 2500x.

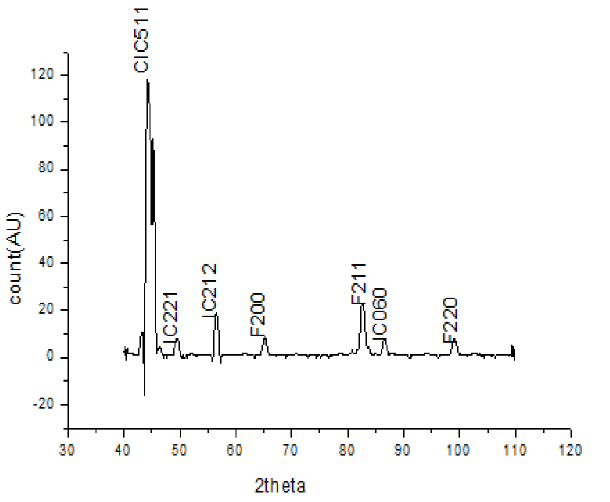

Fig. 10(b) show as XRD of C4.

IV. APPLICATION 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 3000C is currently being assessed by field tests, using a conventional ADI also austempered at 3000C 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. CONCLUSION

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 4.30%. 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 4.30% Cr precipitates the thick circular form carbides significant reinforcement of the matrix with respect to abrasion. The highest wear resistance was obtained for sample C4 975ºC-1h 400ºC-4h, with the chromium content (4.30% Cr) and (CE=4.23%) the austempering temperature (400ºC-4hr).The hardness of the material is relative to the wear resistance properties. As the hardness of material increases the wear resistance properties increase and vice versa.

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