Study on Effect of Austempering Temperature and Time on the Corrosion Resistance of Carbidic Austempered Ductile iron (CADI) Material

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Abstract— Corrosion 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). Six 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 325ºC and at 250ºC for a period of 1hr, 2hr and 3hr.The Corrosion Resistance was evaluated by using Salt Spray Fog test in accordance with ISO 9227 standard. Heat treatments affect the mechanical properties such as Bulk hardness and microhardness also the microstructure of the carbidic austempered ductile iron which can be characterized by optical microscope and SEM.

Key words: Austempering, Carbidic Austempered Ductile Iron, Microstructure, Optical microscope, SEM, Salt Spray Test, Corrosion Resistance etc

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 .A new type of DI, containing carbides immersed in the typical matrix of DI, called Carbidic DI. CDI with 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, surface finish, machinability of CADI but not the Corrosion resistance of 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. Since its introduction in the 1970s, the usage of austempered ductile iron (ADI) has constantly increased. ADI has been widely used as a structural material in the machine, automobile, and agriculture industries, due to its relatively low production costs coupled its excellent properties, including high tensile strength, satisfactory impact toughness and good fatigue resistance under dynamic loading conditions and excellent wear resistance [11]. But the properties of ADI do not satisfy the requirements in some working conditions. Carbidic austempered ductile iron (CADI) has emerged as a promising kind of engineering material to replace the ADI for the needs of higher wear resistance. Presently, CADI has attracted intensive attention in many areas such as railway, mining industry, and defence structures gears, pinions crankshafts, Centrifugal Pump Blades, transmissions, suspensions, earth-moving and construction equipment, railways etc. It induces interest in study the corrosion behaviour of the material in chloride media, bearing in mind that equipment made from this material may be in constant contact with such media[1].Corrosion rate can be measured by using different corrosion testing methods such as Electrochemical test, salt spray test, total immersion test etc. The choice of the corrosion testing methods as reported depends upon many factors such as nature of environment, nature of exposure, type of specimen etc.

Salt Spray Fog test is one of the corrosion testing methods, which involves the exposure of the specimens to fine spray as mist of a solution of sodium chloride at a specified temperature. The spray particles Settle upon the test surface (which is preferably inclined) and constantly replenish and replace the film of solution on the surface. The extent and nature of the corrosion of the metal or coated surface after a specified period of exposure serve as a measure of quality/corrosion resistance. To accelerate corrosion the temperature of the media or the pH of the media or the concentration of the media can be varied. The present systematic study was taken up for microstructure examination, assessment of mechanical properties, and corrosion Resistance of CADI for different Austempering temperature and Austempering time.

II. EXPERIMENTAL PROCEDURE

A. Material and Sample Preparation:

The pattern used in the present experiment was made of wooden with standard allowances and proper finishing, then by using; the prepared wooden pattern a mould is prepared with specified sand in the mould box. After removing the pattern from sand and drying the mould, remove the loose sand from mould, the mould is finished and the mould is ready to pour the molten metal in it, thus the standard square casting of 15x15x200mm long was produced in the green sand mould. Table1 gives the chemical composition of the carbidic ductile iron (as-cast). Six CADI samples obtained by casting undergoes heat treatment involving an austenitizing stage of temperature 975°C in a muffle furnace for 1hr, followed by an austempering step in a salt bath at Ta-325°C and Ta-250°C during quenching time ta-1hr,2hr and 3hr. Thus obtained test bars were sliced in 10mm long to test sample for microstructural characterization and hardness measurement. The bars were sliced of about 30x10x5mm long with EDM wire cut from as-cast, as well as CADI samples to conduct the Salt Spray fog test. Sample identification was done on the basis of chemical composition and heat treatment parameters as given in Table 2.

Alloying element	%
C	2.19
Si	2.21
Mn	0.58
S	0.0048
P	0.0179
Cr	2.09
Cu	0.60
Ni	0.45
Ti	0.013
Mg	0.043
CE	2.93

Table 1: Chemical composition of As-cast CDI

B. *Chemical and Micro Structural Examination*

The chemical composition of the alloys was measured by means of a spark emission optic spectrometer. Metallographic sample preparation for optical microscopy examination was conducted by using standard cutting and polishing techniques, and etching with 2%Nital. The magnification used to obtain data from a sufficiently large area was X20. Each reported value is the average of four measurements.

Sr. No.	Process parameter	Sample ID
1	Austempered at 250°C for 1 Hrs.	A1
2	Austempered at 250°C for 2 Hrs.	B1
3	Austempered at 250°C for 3 Hrs.	C1
4	Austempered at 325°C for 1 Hrs.	A2
5	Austempered at 325°C for 2 Hrs.	B2
6	Austempered at 325°C for 3 Hrs.	C2
7	Composition C2, As-Cast-CDI	D

Table 2: Identification of Sample according to process parameter

C. *SEM of Samples*

Scanning Electron Microscope Jeol Jsm-6380A was used for scanning of samples at different magnification and photo graphs are presented in the result.

D. *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).

E. *Salt Spray Fog Test*

Corrosion resistance of samples were investigated by Salt Spray Fog test for the dimensions of all specimens 10mm x10mm x 5mm.and the test was conducted as per ISO 9227 Standard. Before testing the Specimens, WMW MICROMAT SFW 200×600 surface grinding machine was used for surface grinding of samples for getting same surface finish to all samples.

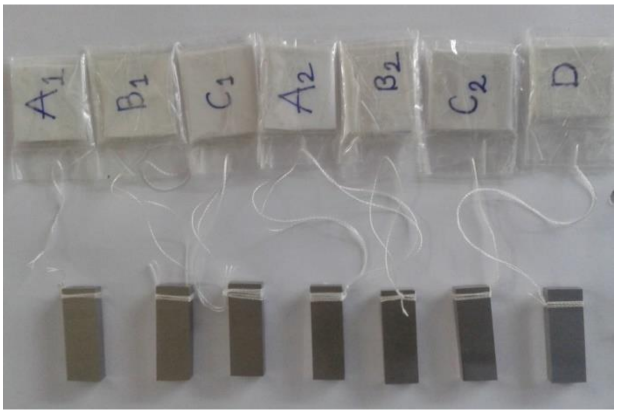

Fig. 1: CADI Samples prepared for Salt Spray Fog test.

The specimens were placed in salt spray chamber for the duration of 480hrs (21 days) as per ISO 9227 and cleaned by using mechanical method as per ISO 8407:1991.Finally the corrosion rate of 7 samples were evaluated by using weight loss method as per ASTM G1-03.

III. RESULT AND DISCUSSIONS

A. *Micro Structural Characterization*

Microstructure in Fig.2.d shows rare white portion is carbide traces along the grain matrix. Microstructure in Fig.2.b shows dark portion that is ausferrite. Microstructure Fig.2.f shows black spot in circle mark shows the graphite nodule. All the six microstructure shows carbide traces, ausferrite and graphite nodules. It is the indication of formation of CADI.

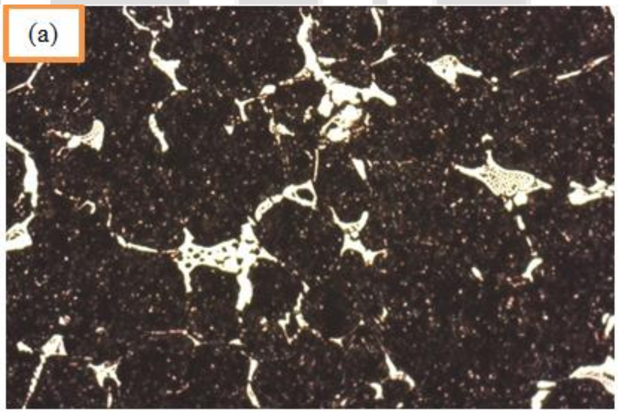

Fig. 2: (a) A1-250 ^{0}C 1Hrs-200X

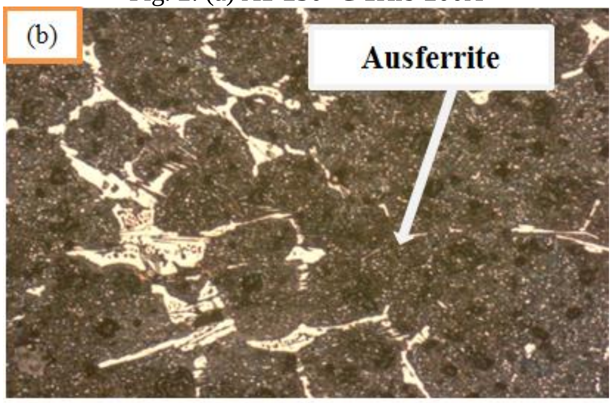

Fig. 2: (b) B1-250 ^{0}C 2Hrs-200X

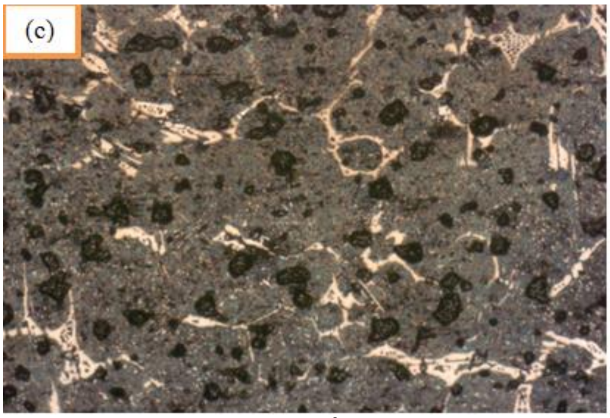

Fig. 2: (c) C1-250 ^{0}C 3Hrs-200X

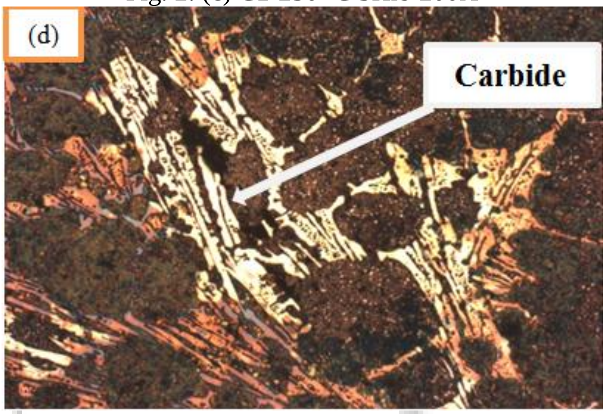

Fig. 2: (d) A2-325 ^{0}C 1Hrs-200X

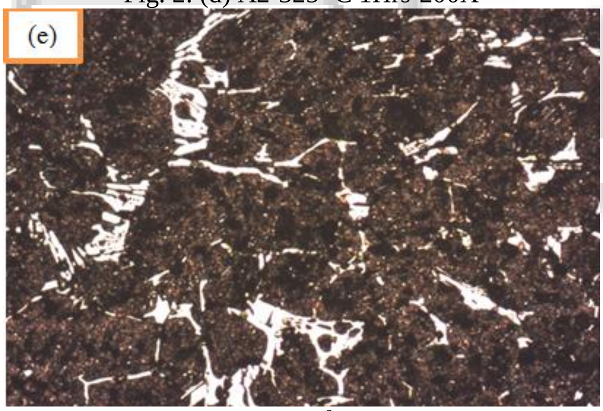

Fig. 2: (e) B2-325 ^{0}C 2Hrs-200X

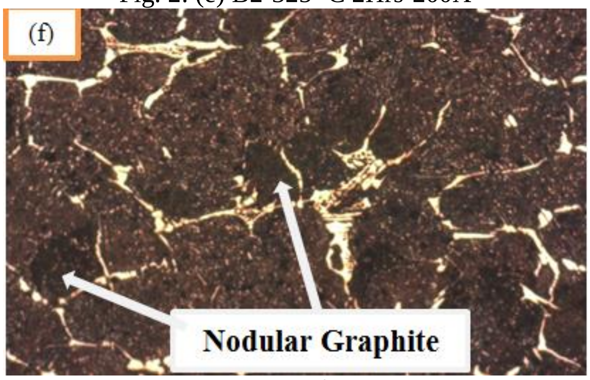

Fig. 2: (f) C2- 325 ^{0}C 3Hrs-200X

B. Scanning Electron Microscope

After austempering CDI samples, the matrix was ausferritic exhibiting the typical morphology i.e. reinforcement of carbide and ausferritic matrix is found in the SEM microstructure. SEM of Fig.3.b shows more grey portion is carbides while grey portion in small pieces is Retained austenite and dark needle like structure indicates ausferrite. Fig.3.a shows large amount of carbides and dark spot in circle mark is graphite nodule.

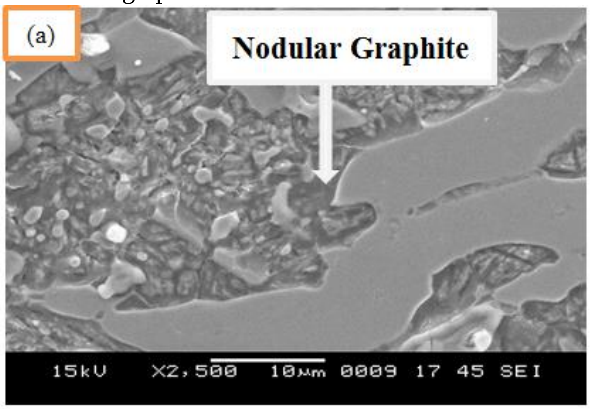

Fig. 3: (a) A1 250ºC-1hr-2500X

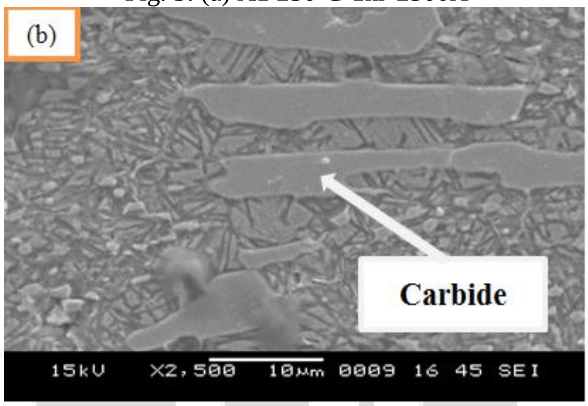

Fig. 3: (b). B1 250ºC-2hr-2500X

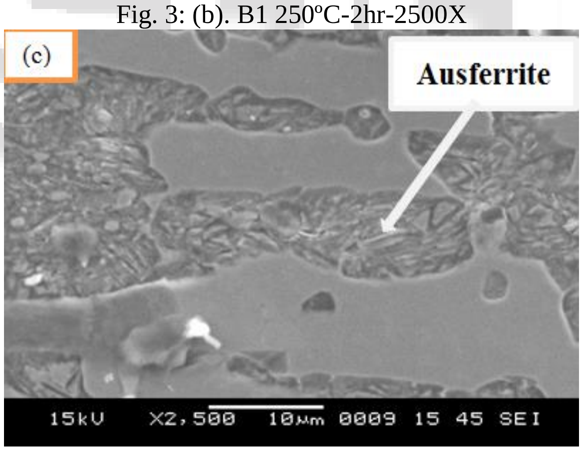

Fig. 3: (c). C1 250ºC-3hr-2500X

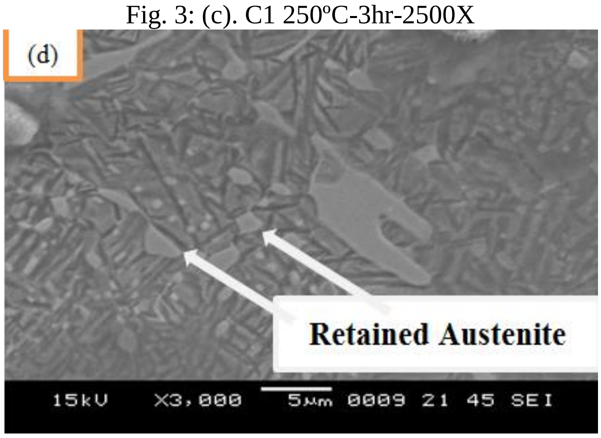

Fig. 3: (d). A2 325ºC-1hr-3000X

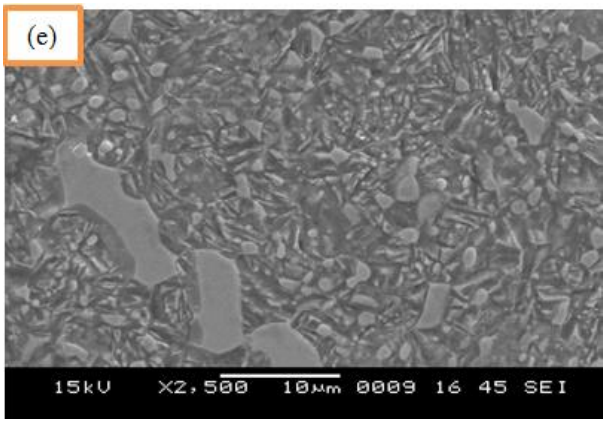

Fig. 3: (e). B2 325ºC-2hr-2500X

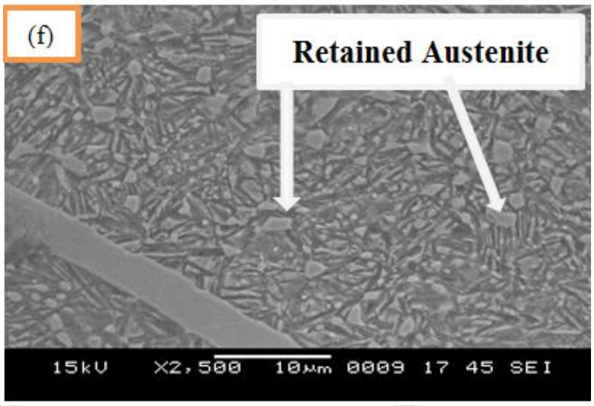

Fig. 3: (f). C2 325ºC-3hr-2500X

C. Comparative Graph of Rockwell Hardness of Samples

Higher austempering temperature (325ºC) results in coarser ferrite and also higher amount of high carbon austenite, which in turn reduces the hardness of the specimen as well as lower austempering temperature (250ºC) results in finer ferrite and lower amount of high carbon austenite, which in turn raises the hardness of the specimen. Figure 4 shows the hardness values which are higher than as-cast. The bulk hardness (HRc) was determined as an average of five measurements.

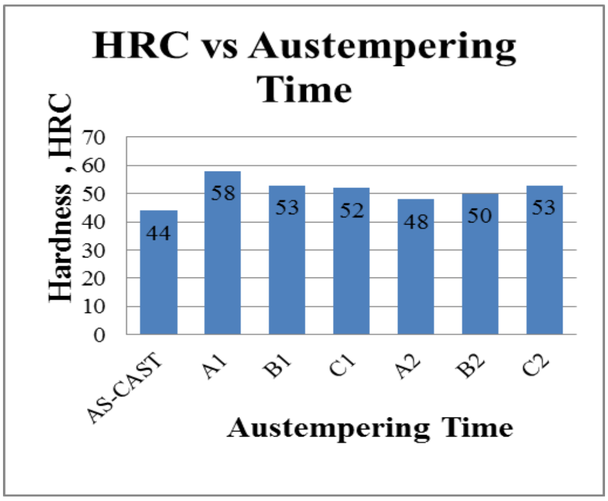

Fig. 4: Comparative graph of Bulk Hardness

D. Micro Hardness of Samples:

The Vickers micro hardness was determined as the average of six measurements in each alloy in a region of carbide and ausferrite. Carbides are randomly precipitated throughout the sample. Micro-hardness of Carbide phase is found around 700HV200 to 985HV200 and for other than Carbide phase i.e. for ausferrite around 350HV200 to550HV200.

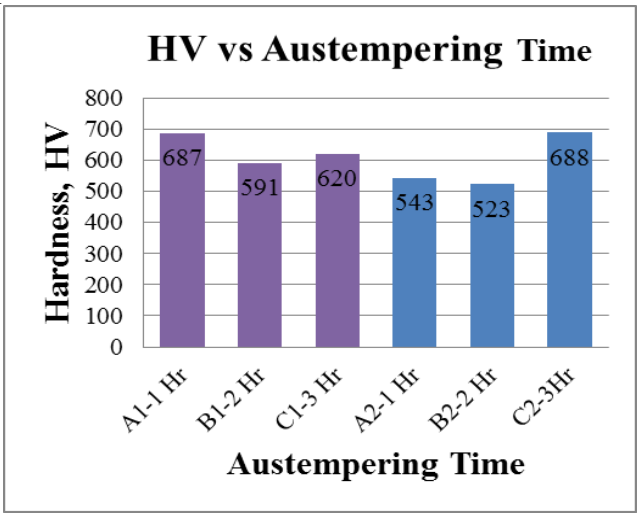

Fig. 5: Comparative graph of Micro-Hardness.

E. Corrosion Rate of CADI Samples:

Salt Spray Fog Test is qualitative method for identifying Corrosion behaviour of metals and their alloys.[9] The corrosion was identified as localized type of corrosion. Photographs of CADI Samples shown in Fig. 6 indicate that holes and pits were present on metal surface that means Pitting type of corrosion takes place. Corrosion Rate of each sample was evaluated as per ASTM G1-03 by using Corrosion rate calculation.

Fig.6: Corroded CADI samples.

Corrosion rate = $\frac{K\times W}{A\times T\times D}$ mm/year [10].

Where,

K = Constant = 8.76×10^4

W=Weight loss in grams.

A= Corroded Surface Area, cm^2

T=Time of exposure in Hrs.

D=Density of CADI material in gm. /cm^3

Sr. No	CADI Samples	Corrosion Rate (mm/year)
1	AS-CAST	0.2646
2	A1(250◦C-1Hr)	0.2094
3	B1(250◦C-2Hr)	0.2162
4	C1(250◦C-3Hr)	0.2543
5	A2(325◦C-1Hr)	0.2381
6	B2(325◦C-2Hr)	0.2562
7	C2(325◦C-3Hr)	0.2604

Table 3: Corrosion Rate of CADI Samples.

The experimental evidence indicated that corrosion rate of CADI depends on Austempering temperature and time. Lower nodular graphite quantity and more retained austenite content could provide better corrosion resistance [1].Austempering Temperature and Time effects very sensitively over quantity of graphite nodule and retained austenite formation. Table 3 shows the comparisons of corrosion rate of As-cast with CADI. Again it is proved that shorter the Austempering time corrosion resistance should be quite high [8]. Experimental results of CADI Sample shows same nature that is Corrosion rate of CADI increases with increasing austempering time.

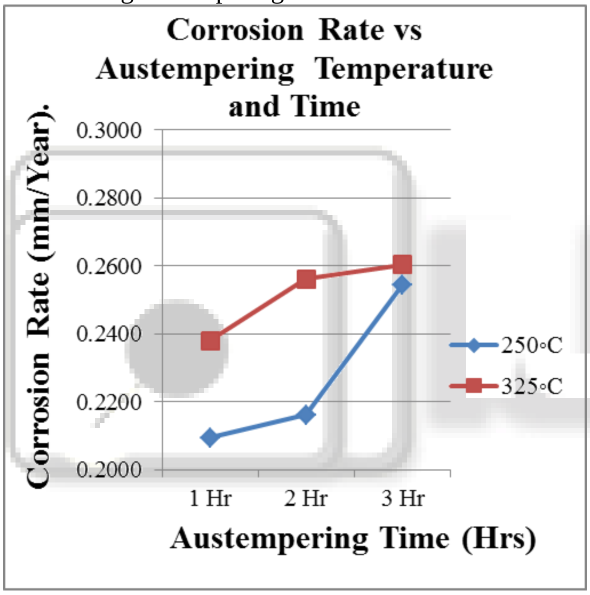

Fig. 7: Austempering Temperature and Time effect on corrosion Rate of CADI Samples.

When Austempering temperature is high the driving force for nucleation of Acicular ferrite is very less and diffusion rate of carbon in austenite is very high which form carbon enrich austenite that means retained Austenite quantity is less. At lower Austempering temperature the diffusion rate of carbon in Austenite is very less which produces more Retained Austenite [2]. It was proved that at 250^{0}C, corrosion rate of CADI is less than that of 325^{0}C Austempering temperature as shown in Fig 7.

IV. Conclusions

An attempt was made to study the effect of austempering temperature and time on Corrosion resistance of CADI material the major concussions derived from this experimentations are:

1) It can be concluded that the samples austempered at higher austempering temperature had significantly higher Corrosion Rate that means less resistance to the Corrosion.
2) CADI samples at lower austempering temperature of 250ºC had more resistance to corrosion as compared with CADI samples at 325ºC.
3) At higher austempering temperature of 325ºC, the Corrosion resistance decreases with increase in austempering time. A2 has high Corrosion resistance among A2, B2 and C2.
4) It can be concluded that out of 6 CADI samples CADI at 250 ºC - 1 Hrs. (A1) sample has best Corrosion resistance than others.
5) All CADI sample have more corrosion resistance and Hardness than As-cast.
6) Corrosion Resistance and hardness of CADI samples was found to be directly proportional.

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