INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY

A PATH FOR HORIZING YOUR INNOVATIVE WORK

SPECIAL ISSUE FOR
NATIONAL LEVEL CONFERENCE
"Technology Enabling Modernization of Rural India (TMRI- 2018)"

LITERATURE SURVEY ON WHITE CAST IRON (LOW COST CORROSION RESISTANT FE-CR-MN-MO) DETAILED STUDY

DHIRENDRA AGARWAL[1], PROF. NEERAJ KUMAR[2], DR. A.K. BANSAL[3]

1. Ph. D. Scholar, Suresh Gyan Vihar University, Jaipur, Rajasthan.

2. H.O.D, Mechanical Engineering, Suresh Gyan Vihar University, Jaipur, Rajasthan.

3. S.G.V. Govt. Polytechnic College Jaipur, Rajasthan.

Abstract: Cast iron is iron or a ferrous alloy which has been heated until it liquefies, and is then poured into a mould to solidify. It is usually made from pig iron. The alloy constituents affect its color when fractured: white cast iron has carbide impurities which allow cracks to pass straight through. Grey cast iron has graphitic flakes which deflect a passing crack and initiate countless new cracks as the material breaks. Carbon (C) and silicon (Si) are the main alloying elements, with the amount ranging from 2.1–4 wt% and 1–3 wt%, respectively. Iron alloys with less carbon content are known as steel. While this technically makes these base alloys ternary Fe–C–Si alloys, the principle of cast iron solidification is understood from the binary iron–carbon phase diagram. Since the compositions of most cast irons are around the eutectic point of the iron–carbon system, the melting temperatures closely correlate, usually ranging from 1,150 to 1,200 °C (2,100 to 2,190 °F), which is about 300 °C (572 °F) lower than the melting point of pure iron.

Keywords: Cementite. Gray, Malleable, Nodular

Corresponding Author: DHIRENDRA AGARWAL

Access Online On:

www.ijpret.com

How to Cite This Article:

Dhirendra Agarwal, IJPRET, 2018; Volume 6 (8): 41-56

PAPER-QR CODE

INTRODUCTION

1) White cast iron

It is the cast iron that displays white fractured surface due to the presence of cementite. With a lower silicon content (graphitizing agent) and faster cooling rate, the carbon in white cast iron precipitates out of the melt as the metastable phase cementite, Fe_3C, rather than graphite. The cementite which precipitates from the melt forms as relatively large particles, usually in a eutectic mixture, where the other phase is austenite (which on cooling might transform to martensite. These eutectic carbides are much too large to provide precipitation hardening (as in some steels, where cementite precipitates might inhibit plastic deformation by impeding the movement of dislocations through the ferrite matrix). Rather, they increase the bulk hardness of the cast iron simply by virtue of their own very high hardness and their substantial volume fraction, such that the bulk hardness can be approximated by a rule of mixtures. In any case, they offer hardness at the expense of toughness. Since carbide makes up a large fraction of the material, white cast iron could reasonably be classified as a cermets. White iron is too brittle for use in many structural components, but with good hardness and abrasion resistance and relatively low cost, it finds use in such applications as the wear surfaces (impeller and volute) of slurry pumps, shell liners and lifter bars in ball mills and autogenously grinding mills, balls and rings in coal pulverizes, and the teeth of a backhoe's digging bucket (although cast medium-carbon martensitic steel is more common for this application

Table:-1 MECHANICAL AND PHYSICAL PROPERTIES OF C.G. IRONS

Property	Microstructure	
	Ferrite	Pearlite
Tensile strength N/mm2	310	420
Field strength N/mm2	270	345
Elongation%	4	2
Hardness	150	200
C.V.N. impact. J	5	3
Fatigue strength (N/mm2)	150	180
Elastic modulus GN/m2	165	165
Poisson's ratio	0.265	0.265
Thermal conductivity W/(mK)	44	36
Specific heat at 1000C	0.5	0.5
Coefficient of linear thermal expansion, X10-	11	13

6/0C		

A combination of high strength, good ductility and high thermal conductivity coupled with superior resistance to cracking and distortion, as compared to both gray and nodular cast irons, make compacted graphite iron an ideal choice as material for ingot moulds and similar applications. Due to good elevated temperature properties, these are being used for cylinder heads, gear pumps, eccentric gars, exhaust manifolds, brake drums, discs and piston rings.

Table:-2 MECHANICAL AND PHYSICAL PROPERTIES OF COMPACTED GRAPHITE, GREY AND NODULAR IRONS

Property	Grey Irons	CG Irons	SG Irons
Tensile strength N/mm2	160-320	300-600	400-700
Ton / in2	11-20	20-38	26-45
Elongation %	Nil	3-6	6-25
Modulus of elasticity 1b/in2	14-16 x 10-6	20-23x10-6	25-27x10-6
Charpy impact (J) at room temperature	Nil	3-7	17
Thermal conductivity Cal/cm 0C/sec.	0.11-0.14	0.10-0.12	0.08-0.09
Damping capacity	13.2x10-4	4-6x10-4	2-5x10-4
Fatigue limit untouched ton/in2	7-8	15-20	12-18
Machine ability	Very good	Very good	Good
Corrosion Resistance	Moderate	Intermediate	Good

The micro structural features of gray, malleable, nodular and compacted graphite cast irons. The typical properties and principal applications of each of the grads have been discussed in detail by Gillbert [1]. The basis of deciding whether to select an ordinary gray iron, or an S.G. iron or a malleable iron for an end application comprises the economic and the technical consideration. Gray irons offer the lowest cost in cost option of producing sound casting. It is, however, not easy to choose between the remaining ones, namely, between the S.G. and the malleable irons. Malleable irons are more difficult to cast because the starting micro structure is that of a white was iron. This automatically introduces section size limitations. Moreover, the cost incurred in.

ALLOY CAST IRONS

1. SILAL

Silal [1-2], the trade name given to silicon alloyed iron, is one of the earliest heat resistant irons developed by Norbury and Morgan of the British Cast Iron Research Association (BCIRA). The silicon content of this silicon alloyed gray iron varies from 4 to 6%. Microstructure of Silal comprised of graphite flakes distributed in the ferritic matrix. Heat and oxidation resistance of silal primarily depend on the size and the distribution of the graphite flakes. Finer the graphite flakes, better is the heat resistance.

In order to retain a hypoeutectic composition and avoid primary graphitization, the carbon content of Silal is controlled by the silicon content. For example, a 5 percent silicon bearing Silal can have a maximum carbon content of 2.7 percent. Lower the carbon content, better are the mechanical properties. It can be attributed to the reduction in the amount of graphite.

The oxidation resistance of Silal is due to the presence of a oxide and silicate film of the surface, Such a film checks the transport of oxygen atoms into the metal and to the diffusion of metal atoms towards the surface. Silicon, being a ferrite stabilizer, reaises the ferrite to austenite transformation temperature and thus enhances the temperature range to which it can be used in service without undergoing growth.

The useful service temperature range of Silal is governed by its silicon content. Work carried out by White, Rice and Elsea [3], and Maitland and Huges [4] explains it best. Resistance against scaling and growth get enhanced by increasing the silicon content. For optimum combination of properties, the silicon content is kept in between 4.5 - 6.5%. Such a composition is very well suited for temperatures ranging from room temperature up to 9000C. For use at service temperatures exceeding 9000C, the silicon content of silal is increased up to about 11%. However, higher silicon content makes the iron weak and brittle at room temperature. The inherent brittleness of silal is not a problem at temperatures above 2600C. These irons have been used successfully for furnace and stoker parts, for burner nzzles, and for trays used in heat treating other metals.

Chromium, copper and nickel additions enhance the mechanical properties of silal. Chromium increases the strength significantly and makes the microstructure more uniform. Small amounts of copper and nickel in the presence of chromium further enhance the mechanical properties and heat resistance.

2. NICROSILAL

Nicrosilal is a heat resistant alloy cast iron developed by BCIRA in 1930. It contains 1.6 - 2.2% total carbon, 4.0 -4.5% silicon, 0.6 - 1.2%, manganese, 18.0 -22.0% nickel, 2.0-4.0% chromium and 0.1 - 0.5% phosphorus. The basic purpose of the development of Nicrosilal [5] was to have a cast iron with superior or at least equivalent heat resistance to that of silal but with better ductility and toughness. This was achieved through alloying with nickel an chromium and 0.1 - 0.5% phosphorus. The basic purpose of the development of Nicrosilal [5] was to have a cast iron with superior or at least equivalent heat resistance to that of silal but with better ductility and toughness. This was achieved through allowing with nickel and chromium.

The general microstructure of Nicrosilal comprises of graphite in a predominantly austentic matrix. Better mechanical properties and resistance against oxidation is attained with finer graphite, preferable under-cooled. Chromium bearing carbides are also present when chromium content exceeds about 1.8 percent. Optimum properties are obtained at 4.5-5.0 percent silicon. Lower the silicon content, lesser is the heat resistance. Higher silicon content, on the other end, lowers the stability of austenite and favours the formation of silico-ferrite which is a brittle phase. Stability of austenite can be restored to a desired level by addition of nickel (austenite stabilizer).

Since both silicon and nickel decrease the carbon content in eutectic, the carbon content of these cast irons rerely exceeds 1.8 to 2.0 percent. Nickel content exceeding 18 percent is required for acquiring a stable austenitic matrix. A minimum of 1.8 percent chromium is also always present. The major part of chromium is present as carbide and only a small fraction of chromium amount goes into the austenite. Thus it increases strength. Enhanced wear and heat resistance can be obtained by increasing the chromium content up to about 4 percent.

At elevated temperatures (400-700oC), austenite becomes unstable and formation of martensite takes place. As a result, Nicrosilal gets hard and brittle, and becomes magnetic. Dimensional changes causing distortion and embrittlement leading to cracking are the another evil features exhibited on cooling to room temperature from this temperature range. By raising nickel contents, this problem can be encountered.

3. HIGH SILICON IRON

The silicon content of high silicon cast irons [5-7] ranges in between 14-16 percent. These, most probably, are the cheapest corrosion resistant irons showing maximum resistance against acids.

These resist well both oxidizing and non-oxidizing acids. As a result, these are also referred as acid-resisting cast irons.

High silicon irons containing up to 15.2 percent silicon have a microstructure comprising of silico-ferrite (a solid solution of silicon in ferrite) and finely distributed graphite flakes [8]. Increasing the silicon content above 15.2 percnt makes the iron brittle. This is essentially due the formation of brittle phases, namely, n and e phases [7]. This is why, the silicon content is normally restricted within the range 14.25 to 15.25 percent. However more is th silicon contnt, better is the corrosion resistance particularly against hydrochloric acid.

Composition and properties of the high silicon irons are given in the Tables.5 & 6 [9].

High silicon irons are inherently low strength brittle materials showing poor thermal and mechanical shock resistance. An attempt has been made to produce high silicon iron with a nodular graphite structure for improving the mechanical properties [10]. However, nodular graphite silicon irons did not exhibit any improvement as the low strength and brittleness of high silicon irons is attributed to the brittle matrix rather than the graphite form.

Since high silicon contents are responsible for inherent brittleness, mechanical strength and shock resistance of these irons can be improved by lowering the silicon content to about 12 percent. As such a reduction lowers the corrosion resistance significantly, it restricts the utility of the allowy. High silicon irons with lower silicon contents are used under those service conditions where the loss in corrosion resistance has a minimal effect on service life or is offset by the benefit derived from better properties [6].

The excellent corrosion resistance of high silicon irons is largely due to the presence of silica-like oxide film. This film is a corrosion product which forms during exposure to the environment. This film prevents further corrosion in many media. On initial exposure to a corrosive medium, the iron is attacke by aggressive ions an iron atoms are leached out of the silico-ferrite lattice; the corrosion rate is high during initial exposure. The silicon atoms remaining in the matrix of the iron are oxidized to form silicon-oxygen compounds which react with water at the metal surface to form an adherent film. The film continues to develop and harden with time thereby improving the usefulness of the protection it imparts [2]. The maximum advantage of protective film is achieved at silicon contents >14.25% [10]. Hydrofluoric acid is capable of dissolving this film and thus the material offers no resistance to hydrofluoric acid. Also the resistance to sulphurous acid is very poor.

High silicon irons exhibit good resistance to sulphuric, nitric and mixed (sulphuric and nitric) acids at all concentrations and temperatures. The resistance to hydrochloric acid is somewhat inferior but can be improved upon by increasing the silicon content to levels of 16 to 18 percent, a modification which causes the irons to become more brittle. Resistance to attack by hydrochloric acids can also be improved by adding 3 to 4 percent molybdenum or 3 to 5 percent chromium to the basic composition. These additions also tend to increase the brittleness of the iron. The improved corrosion resistance of molybenum bearing high silicon irons may be attribute to the formation of extremely stable complex carbides with the consequent elimination of graphite [8]. Chromium also gives a similar beneficial effect. Goo corrosion- erosion resistance is primarily due to its high inherent hardness.

High silicon cast irons are highly resistant to solutions of organic acids at all concentrations an temperatures but inferior to ordinary gray irons in their resistance to alkali attack [8].

High silicon cast irons are use extensively in equipment for the production or sulphuric and nitric acid; for fertilizer, textile, and explosives manufacturer; for sewage disposal and water treatment; for handling mineral acids in petroleum refining, and in metal cleaning or picking; in electroplating; for processing of paper, beverages, an paints and pigments; and as anodes for the impressed current, catholic protection of iron pipes or other ferrous vessels buried in the soil. Specific casting of high silicon irons include pump rotors, agitators, kettles, evaporators, separator towers and Rachid rings, tank outlets, crucibles, insolvable anodes and pipe and fitting for plumbing in chemical laboratories of hospitals, colleges, and industry.

4. NI-RESIST CAST IRONS

It is possible to stabilize austenite at room temperature by raising the nickel contents of the irons. Ni-Resist iron is a trade name given for a family of high nickel bearing cast irons having austenitic matrix. These irons are therefore tough, heat-resistant and corrosion resistant. In fact, these irons show excellent corrosion resistance against many corrosive fluids. These irons have a thin, losely adhering film of rust which prevents further corrosion. This film does not flake off and hence does not contaminate the product handled [11].

The nickel and chromium contents of Ni-Resist irons range from 14 to 36 percent and 1.6 to 6.0 percent respectively. Up to about 1 percent molybdenum is also present. Such a composition imparts good resistance against corrosion and erosion. Additionally, these alloy contents make the Ni-Resist irons suitable for service conditions involving moderately high temperatures. Better toughness, good cast ability and mach inability of Ni-Resist irons further enhance their utility range [11].

There are two main classes of Ni-Resist, the copper containing and the copper free (Table.6) [6, 12]. Both the types contain chromium which imparts hardness and stiffness to the material. Presence of chromium also ensures good machinability which is otherwise poor due to greater toughness of the austenitic matrix.

Microstructure of Ni-Resist irons comprises of graphite flakes in an austenitic matrix. Presence of carbides would depend upon the presence of chromium [5].

Though the Ni-Resist irons are tougher and more resistant to shock than conventional gray cast irons, the fact that the graphite is present in the same weakening flake form inhibits possible improvements. Much better strength and impact properties can, however, be obtained by treating the iron so that the graphite appears in the appears in the spheroidal form whose weakening effect on the austenitic matrix is negligible. Theses Ni-Resist irons, having graphite as spheroids, have better mechanical properties than their versions having flake type graphite [11].

In order to differentiate the spheroidal graphite Ni-Resist irons from the flake ones, the prefix D has been used. The composition ranges of some Ni-Resist irons are given in Table 7 [12].

Corrosion resistance of Ni-Resist irons is ue to high nikel content and not due to the presence of an inert oxide surface film [6, 12]. Ni-Resist irons exhibit very good corrosion resistance against sulphuric acid. However, these do not perform well when exposed to hydrochloric acid and cannot be exposed to nitric acids. Ni-Resist irons possess excellent corrosion resistance against caustic soda over a wide range of concentrations and temperature. Though the mechanical properties considerably (the latter one having superior properties), the corrosion behavior of the two varieties is nearly similar.

A perusal of these Tables and Figures revealed that:

• Volume fraction of the massive carbides (VMC) in the as-cast condition was maximum for the alloy A1 and minimum for the alloy A3, however, the difference in the magnitude of massive carbides is not massive carbides is not much for the alloy A2 and A3.

• For all alloys, neglecting few exceptions, volume fraction of the massive carbides decreased with an in the heat treatment temperature/time.

• At 800oC, alloy A1 and A3 showed only marginal decrease in the volume fraction of massive carbides. Alloy A2 showed a gradual and comparatively marked decrease in the volume fraction of massive carbides.

- At 850oC, all alloys showed only marginal decrease in the volume fraction of massive carbides.

- At 900oC, the behavior of all alloys is similar to that observed at 850oC.

- At 950oC, the alloy A1, that was showing only marginal decrease up to 900oC, showed a sharp decrease in the volume fraction of massive carbides was pronounced only above 6 hours soaking periods. There was only marginal decrease in the volume fraction of massive carbides for alloy A3.

- At 1000oC, allow A3 maintained the same trend (marginal decrease). Alloy A1 and A2 showed a marked and continuous decrease with increasing soaking periods.

- For alloy A1, up to 8 hours soaking periods, volume fraction decreased only marginally up to 900oC. For 10 hours soaking period, a marked and continuous decrease in the volume fraction was found. The same temperature was shown by A2 and A3 with some exceptions.

Table – 3 Compressive Strength (Alloy A1) (CS of as cast = 1798.39 MPa)

S.No.	Temperature, deg. C	Time, hrs.	
		6	10
1	900	2082.86	2426.13
2	950	2234.59	2607.88
3.	1000	2525.03	2712.03

Table – 4 Compressive Strength (Alloy A2) (CS of as cast = 1863.82 MPa)

S.No.	Temperature,deg. C	Time, hrs.	
		6	10
1	900	2379.37	2498.06
2	950	2446.62	2663.17
3.	1000	2693.90	2845.30

Table – 5 Compressive Strength (Alloy A3) (CS of as cast = 1908.72 MPa)

S.No.	Temperature, deg. C	Time, hrs.	
		6	10
1	900	2552.19	2599.22
2	950	2609.22	2867.84

3.	1000	2806.56	2938.07

CORROSION STUDIES

The alloys were characterized for their corrosion behavior. In fact, development of corrosion resistant white coast iron was one of the main aim of present work. Corrosion behavior was studies with the help of weight loss method due to its reliability and reproducibility. Corrosion data have been summarized in Tables 6-8.

Table: 6 Effect of heat treatment on corrosion rate (Alloy A1) (As cast CR 23.588 mdd at 168 hrs. & mdd at 720 hrs.)

S.No.	Temperature deg. C	2 hrs. SP		6 hrs. SP		10 hrs. SP	
		168 hrs.	720 hrs.	168 hrs.	720 hrs.	168 hrs.	720 hrs.
1	800	23.53	20.900	23.114	20.923	23.212	20.075
2	850	21.789	19.293	21.594	19.106	20.168	18.047
3	900	20.768	18.407	20.342	17.903	20.101	17.803
4	950	18.534	17.013	17.611	15.202	16.918	14.812
5	1000	16.052	14.334	16.019	13.792	15.823	13.372

Table: 7 Effect of heat treatment on corrosion rate (Alloy A2) (As cast CR 22.966 mdd at 168 hrs. & mdd at 720 hrs.)

S.No.	Temperature deg. C	2 hrs. SP		6 hrs. SP		10 hrs. SP	
		168 hrs.	720 hrs.	168 hrs.	720 hrs.	168 hrs.	720 hrs.
1	800	23.014	20.719	22.729	20.041	21.913	20.013
2	850	21.896	19.127	20.929	18.613	20.167	18.016
3	900	20.202	18.147	19.833	17.292	19.546	17.017
4	950	18.222	16.631	17.782	15.414	17.131	14.912
5	1000	16.597	14.791	16.093	14.103	16.101	13.901

Table: 8 Effect of heat treatment on corrosion rate (Alloy A3) (As cast CR 23.010 mdd at 168 hrs. & 20.346 mdd at 720 hrs.)

S.No.	Temperature deg. C	2 hrs. SP		6 hrs. SP		10 hrs. SP	
		168 hrs.	720 hrs.	168 hrs.	720 hrs.	168 hrs.	720 hrs.
1	800	21.726	20.129	20.898	19.477	20.504	19.328
2	850	20.538	18.916	20.186	18.001	19.291	16.768
3	900	18.622	15.311	18.407	14.878	17.099	14.173
4	950	17.736	14.235	16.616	13.401	16.074	13.389
5	1000	16.104	13.404	15.904	13.171	15.740	12.989

A perusal of the Table and figure revealed that:

• The corrosion resistance even in the as-cast state was satisfactory. Alloy A1 showed maximum corrosion rate. There was not much differentiae in the corrosion rate of A2 and A3.

• On heat treating from 800°C , the corrosion rate matched with the corrosion rate of the as-cast A1 and A2 alloys. Corrosion rate of A3 was considerably different (lower) form that of as-cast A3 alloy.

• Corrosion rate decreased considerably for alloys at and above 900oC at all soaking periods.

• The maximum resistance against corrosion was at 10 hours soaking period and/or for 1000oC heat treatment temperature.

• Alloy A3 exhibited best corrosion resistance.

The surfaces of the specimens after corrosion testing were examined under a scanning microscope. No pitting or any other form of corrosion was revealed. Surface was attacked uniformly. Corrosion product was non-adherent.

DISCUSSION

1. GENERAL BACKGROUND

Prior to analyzing the results, it is essential to understand the behavior of alloy under consideration. The microstructure of the alloys in the as-cast condition as well as in heat treated conditions should be explainable on the basis of the chemical composition and relative solubility of various alloying elements in the matrix phase/and carbides. In addition to this, nature of alloying element will be responsible for the generated microstructures.

Carbon content of the alloy tends to combine with a relatively large concentration of alloying elements. As a result of it, more the carbon lesser is the amount of overall alloy content of the matrix and more is the amount of carbides.

A matrix having lesser amount of alloying elements has a natural tendency to transform to marten site and on air cooling there are fair chances that marten site will be present in the microstructure along with austenite.

Micro structural features observed in the heat treated condition can be explained by considering the changes on heating in the phases present in the as-cast alloy followed by considering the changes during cooling to room temperature.

On heating, a reduction in the volume fraction of the massive carbides will occur due to the presence of silicon and/or copper which promote the graphitizing tendency. Reduction in the volume fraction of the massive carbides results in the availability of allowing element which on dissolution in austenite enhances the stability of austenite.

Graphitizing effect of silicon and copper along with the rise in temperature will generate discontinuous massive carbides with a tendency towards rounding off the edges. Austenite with increased stability can possibly precipitate carbides with increase in heat treating temperatures and saking period. An increase of either heat treating temperature for soaking period or of a soaking period for a heat treating temperature will not only coarse the dispersed carbides but also may promote the dissolution of dispersed carbides but also may promote the dissolution of disperesd carbides and may/may not transform to martensite.

The changes that take place on heating can be summarized as:

- Austenite precipitates dispersed carbides and austenite plus disperesed carbides are obtained. The transformed austenite will contain lesser alloy contents.

- Massive carbides will get discontinuous and their volume fraction will get reduced. Such a transformation will be accompanied by rejecting interstitial and substitution solute elements.

- Massive carbides will get converted to other types of carbides.

- Interstitial and substitution solute atoms available as a result of reduced volume fraction of massive carbides will go to austenite. This will give rise to formation of austenite having enhanced stability.

- Asutenite having enhanced stability, on raising the heat treatment temperature or time, will precipitate dispersed carbides by lowering its stability.

- Dispersed carbides will increase with increase in temperature/time and finally will get coarsen. Another possibility also exists i.e. dispersed carbides may get dissolved into austenite at higher temperatures.

Since manganese and copper partition essentially to austenite and some chromium will also partition to austenite, there is fair possibility of transforming austenite to marten site on air cooling from lower heat treatment temperature, such a possibility is very less on air cooling from higher temperatures due to enhanced stability of austenite.

Carbide precipitation during cooling mainly occurs because of the decrease in the solid solubility of carbon with temperature in the austenite.

Similar to on heating, the possible structural changes on cooling can be explained as:

- On slow cooling, some austenite will be transformed to marten site and a mixed structure containing austenite and marten site will result. Massive carbides will remain unaltered. Resultant microstructure will comprise of austenite, martensite and martensite and massive carbides.

- On cooling from lower heat treatment temperature (800 and 850°C), austenite will reject dispersed carbides and a mixed microstructure comprising of austenite and dispersed carbides will be obtained. Some austenite will get transformed to marten site. Massive carbides may undergo transformation to some other carbides. Dispersed carbides will get coarsened. Resultant microstructure will comprise of austenite, martensite, massive carbides and dispersed carbides.

- On cooling from higher heat treatment temperatures (900 and 950°C), austenite will remain stable. Dispersed carbides will get coarsened. Massive carbides volume fraction will be reduced and they may undergo transformation to some other carbides. Resultant microstructure will comprise of austenite, massive carbides and disperse carbides.

On cooling from still higher heat treatment temperatures, austenite will remain stable. Dispersed carbides will get coarsened. These may also undergo dissolution. Massive carbides volume fraction will be reduced significantly and they may undergo transformation to some other carbides or else may get aligned/rounded. Resultant microstructure will comprise of austenite and massive carbides.

2. MICROSTRUCTURE AND HARDNESS

The high hardness of the alloys in the as-cast can be attributed to the presence of large proportion of massive carbides and martensite. Variation in the hardness values of the three alloys is consistent with the microstructural features.

The structural changes in the heart treated condition are responsible for variation of the hardness. Carbides get precipitated from the austenite during soaking and hence a reduction in the volume fraction of MCs and/or rounding off of the massive carbides observed. Martensite also gets decomposed on heating.

For all the alloys at 800oC, the matrix was comprised of martensite and austenite. Hardness is independent of soaking period for A1 and A3 alloys. The same trend has been shown by volume fraction of massive carbides. It justifies the hardness results. For alloy A2, both hardness and massive carbide data follow the same trend i.e. both decrease relatively faster at soaking periods more than 4 hours and justify the results.

On heat treating at 850oC, formation and coarsening of DCs and DSPs (needle/plate) takes place. The coarsening tendency will be more at higher soaking periods. This explains the results obtained. Volume fraction of massive carbides follow the same trend as the of hardness.

In a similar manner, hardness, volume fraction and microstructure can be correlated for other heat treatment temperatures. Matrix is now austenite.

3. COMPRESSIVE STRENGTH

The compressive strength data can be expand in terms of initial volume fraction of massive carbides, the effect of heat treatment temperature and soaking period on the volume fraction of massive carbides, morphology of massive carbide as influenced by the heart treatment temperature and soaking period on the volume fraction of massive carbide as influenced by the heat treatment temperature and soaking period, formation of needle like carbides/dispersed spherical carbides and influenced on their coarsening tendency/interlinking either with massive carbides or amongst themselves, and morphology of these carbides as affected by the heat treatment temperature and soaking period. Matrix structure also play a significant role.

As-cast alloys (inherently brittle white case irons) due to the presence of martensite as matrix, platy massive carbides and complex microstructural (highly heterogeneous system) exhibit poor compressive strength. Martensite is also present in alloys heat treated from lower heat treatment temperatures (say up to = 900oC). Role of needle like carbides/dispersed spherical

carbides is two-fold. These can either strengthen or embrittle the alloy depending on their favorable/adverse morphology. At higher temperatures/soaking periods. Somewhat favorable effect is due to coarsening and reduction in their volume fraction. Similarly, reduced volume structure at elevated temperatures enhance the compressive strength of the alloy. In fact, at higher temperatures, volume fraction of needle like carbides/dispersed spherical carbides is of less importance. Here the strength will be governed by the volume fraction, distribution and morphology of massive carbides. Based on these reasoning, the compressive strength data can be explained with reasonable good accuracy. Fortunately, the data generated for all alloy are explainable on the basis of above stated facts.

4. CORROSION STUDIES

In general, all alloys showed reasonable good corrosion resistance in the as-cast condition and much better in heat treated state particularly heat treated state particularly heat treated from high temperatures. This can be attributed to the presence of completely austenitic matrix and favorable morphology of massive carbides. For specimens heat treated from relatively lower temperatures, the corrosion rates were lower than the as-cast alloys in spite of the fact that the carbides in the form needles and DSP are present. It is a point of much satisfaction that this so called adverse morphology did not enhance the corrosion rate.

Variation in corrosion rates of all the alloys is explainable on the basis of alloy chemistry and micro structural features such as unevenness of the matrix (heterogeneity) and agglomeration/alignment of massive and dispersed carbides. Chemical heterogeneity, associated with the matrix, reduces the corrosion resistance of specimens heat treated from

REFERENCES

1. Sain, P. K., C. P. Sharma, and A. K. Bhargava. "Microstructure Aspects of a Newly Developed, Low Cost, Corrosion-Resistant White Cast Iron", *Metallurgical and Materials Transactions A, 2013.*

2. Metals HandBook, Vol.1, 9th edition, ASM, Metals Park, Ohio, 1978, p. 3-9 & 75-96.

3. Angus, H.T., Cast Iron- Physical and Engineering Properties, Butterworths, London, 1976, p. 53, 161-253 and 286-354.

4. INCO, Engineering Properties and Applications of Ni-Hard Cast Irons, International Nickel Co., Inc., New York, 1978, p. 2-15.

5. Patwardhan, A.K., Singh, S.S., and Jain, N.C.; Tool and Alloy Steels, October 1987, p. 369-377.

6. Barton, R.; Special Cast Irons, Report No. 576, BCIRA Journal, Nov.1960, Vol. 8, No. 6.

7. Ohide, T., and Ohira, G.; British Foundry, Vol. 76, Part 1, January 1983, p. 9.

8. INCO.; Ni-Resist Austenitic Cast Irons – Properties and Applications, International Nickel Co., Inc., 1965, p. 1-21.

9. Stefanescu, D.M., Mitea, D., and Cracium, S.; AFS International Cast Metal Journal, June 1976, Vol. 1. No. 2, p. 19-26.

10. Battelle, B.L., Minkoff, I. And Mollard, F.; Editors, The Metallurgy of Cast Irons, Proc. of 2nd International Symposium, Geneva, Switzerland, May 1974, p. 29-31.

11. Henon, G.; Properties and Uses of Irons Alloyed with Nickel, Copper and Chromium, Foundry Trade Journal, March 1966, p. 507-519.

12. Bansal A.K., M.E. Dissertation, 1999 Malviya Regional Engineering College, Jaipur, University of Rajasthan.

13. Srinivasan, T., M.E. Dissertation, University of Roorkee, Roorkee. 1975.

14. Sharma, C.P., M.E. Dissertation, University of Roorkee, Roorkee. 1976.

15. Sudan, A.S., M.E. Dissertation, University of Roorkee, Roorkee. 1976.

16. Singh, S.S.; Ph.D. Thesis, University of Roorkee, Roorkee.1981.