Life Improvement of Hadfield manganese steel castings

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***Abstract*: Austenitic manganese steel has a high toughness, high ductility, high strain hardening capacity and an excellent wear resistance. This grade of steel is mostly used in the mining industry for crushing and loading equipment. The present paper highlights the challenges and the life improvement of high manganese steel casting. Currently the challenges faces like rate of work hardening. This is due to the crushing efficiency of modern jaw and cone crushers. This limits the rate of work hardening produced on the surface of the metal thus resulting in low wear resistance. Due to this challenges faced, researchers were motivated to come up with innovative ideas and new development that will increase the hardness and wear resistance of the said steel, resulting in longer service life of the components. These developments include the introduction of a new heat treatment procedure, addition of alloying element in high manganese steel casting.**

***Index Terms* - *Austenitic Manganese steel, Wear resistance, Hardness, Application of manganese steel*.**

I. INTRODUCTION

Hadfield steel was invented by Sir Robert Hadfield in 1882. This type of steel with its austenitic matrix at ambient temperature has high toughness, high ductility, high strain hardening capacity and excellent wear resistance. As a result these casting parts have been widely used for many years in a variety of applications such as: earthmoving, mining, railways, quarrying, dredging and oil/gas drilling. Due to such application the hadfield manganese steel casting required long life. Had field manganese steel casting suffering from both impact load as well as wear. As we all know some application need high impact load and good wear resistance for example, Jaw crushers and cone crushers used for primary crushing equipment, while other applications needs moderate or no impact at all and high resistance to wear for the secondary and tertiary crushing equipment.

Heat treatment cycle for hadfield manganese steel casting

1. Raise the temperature from 200 to 700 °C @ 120°C per hour.
2. Hold at 700°C for 3 hours.
3. Raise the temperature from 700 to 1100 °C @ 120°C per hour.
4. 1 inch/1 hr + 1 hr =soaking time of individual castings.
5. After soaking, water quench immediately within 40 seconds inside the agitated water.
6. Water temperature should not rise above 40 °C and circulate cooling water.

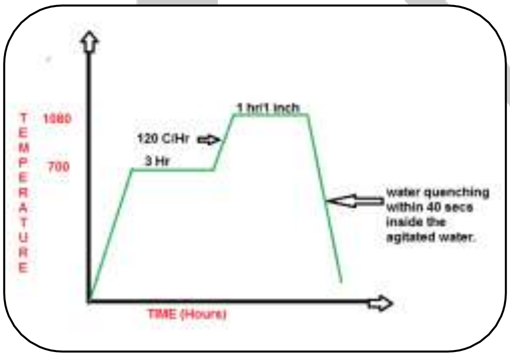


Fig -1 Heat treatment cycle of Hadfield Mn steel casting.

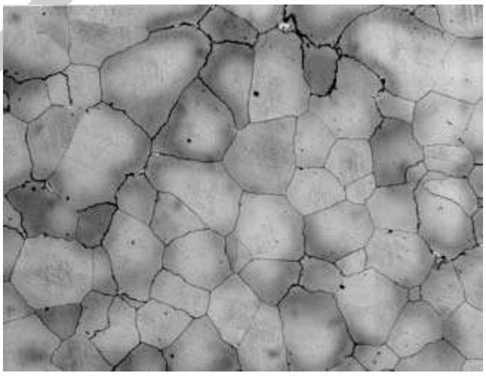


Fig -2 Microstructure of Hadfield Mn steel shows black dotte of Mn carbide and Austenitic Grains.

ELEMENT	PERCENTAGE
CARBON	1 TO 1.25 %
MANGANESE	12 TO 14 %
SILICON	O.06 MAX
SULPHUR	O.05 MAX
PHOSPHORUS	O.04 MAX
IRON	BALANCE

Fig -3 Chemical composition of Hadfield Steel

Properties of hadfield manganese steel can be influenced by following treatments

- Heat treatment
- Precipitation strengthening (ageing) Mechanism
- Pouring temperature
- Knock off period
- Effect of temperature
- Effect of section size
- Chemical composition

A. Heat treatment

A number of annealing cycles were designed in an attempt to find the optimum cycle, which results in an attractive combination of mechanical and formability properties of extra deep drawing quality steel. It was found that the cycle which involved an intermediate anneal at 600° C followed by soaking at 700° C resulted in the best combination of mechanical and formability properties. It was also found that the heating up to 600° C has to be done at a rate of 50° C /hr while the heating from 600° C to 700°C needs to be done at a marginally lower rate. The conventionally heat treatments for Austenitic Manganese Steel is Solution Annealing followed by quenching, which is performed by heating the steel between the temperature range of 1000° C to 1100° C held for enough time depending on the size of the steel and then cooled rapidly by quenching in water. This gives the Steel a Brinell number between 200 to 250. Which is low for effective wear resistance. Heat treatment involving solution annealing and quenching in water can enhance yield strength and abrasion resistance.

B. Precipitation strengthening (ageing) Mechanism

Ageing at 700 ° C for two hours gives us the optimum hardness in the experiment. This shows that the carbide inclusion can be used to strengthen Austenitic Manganese Steel if not allowed to exceed the optimum size that can impede dislocation movement and also not allowed to diffuse into the grain boundaries which might lead to embrittlement. Since the precipitated carbide has led to an increase hardness of the steel, and from the relation between wear resistance and hardness we can say the precipitation strengthening can be used in improving the wear resistance of Austenitic Manganese Steel for service condition where abrasive loading is more than impact loading.

***C.* Pouring temperature**

For uneven, inconsistent wear rate and pattern of the steel pouring temperature should between 1400° C to 1440°C. For thick part pouring temperature should be 1300°C. The practice in most manganese steel melting furnace is to raise the melting and pouring temperatures to 1500°C and above so as to enhance fluidity of the molten metal and ease removal of slag. High temperature promotes micro and macro carbide segregation of alloy elements and formation of embritting transformation products. The presence of segregation at the grain boundaries, acts as barrier to dislocation movement. This could be responsible. The pouring temperatures of 1400 - 1450 ° C will promote uniform dispersion of carbide particles within the structure and thereby enhancing the wear property of the jaw crusher. However, the low pouring temperatures diminish the fluidity of the molten metal and results in casting defects, low yield put and high operational.

D. Knock off period

Mould knock off period for different parts of hadfield Mn steel is given below.

SR NO	JOBS	DESCRIPTION	KNOCKOUT TIME
1	Mn steel Jaw Plate	Up to 500 Kg	After 12 Hours
2	Mn steel jaw plate	Above 500 Kg	After 48 Hours
3	Mn steel concave	Up to 500 Kg	After 12 Hours
4	Mn steel Concave	Above 500 Kg	After 48 Hours

Fig-4 Mould Knock off Period

E. Effect of temperature

The effects of temperature on mechanical properties (in both tension and compression) have been well documented. The general trend for changes in flow stress versus temperature is shown in Fig. 5 for both tension and compression. There is an increase in yield strength with decreasing temperature with a corresponding drop in ductility and ultimate tensile strength.

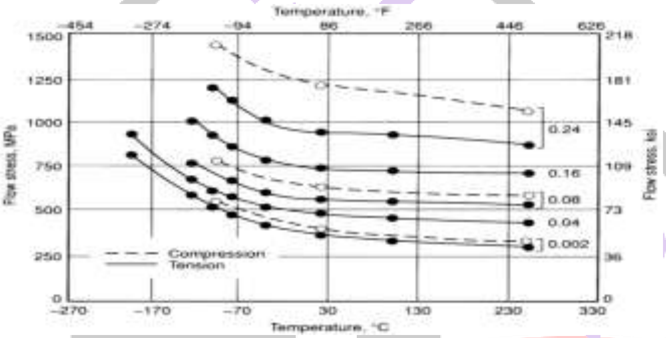


Fig- 5 Effect of temperature on Mechanical properties.

E. Chemical composition

The different elements are like carbon, manganese , silicon , molybdenum , phosphorous , sulphur, effect on the properties of had field Mn steel. The effects of different elements on the properties had field Mn steel given below,

<u>CARBON:-</u>

As carbon is increased it becomes increasingly difficult to retain all of the carbon in solid solution, which may account for reduction in tensile strength and ductility. Nevertheless, as the carbon increases above 1.2 %, the abrasion resistance increases, while, the ductility is lowered. The carbon content is usually below 1.4 % and 13 % manganese due to the difficulty of obtaining an austenitic structure sufficiently free of grain boundary carbides, which are detrimental to strength and ductility .

<u>MANGANESE:</u>

Manganese contributes a vital austenite-stabilizing effect. It sharply depresses the austenite-ferrite transformation and thus helps to retain 100% austenite structure at room temperature after water quenching. Manganese within the range of 10 to 14%, has almost no effect on yield strength, but it does benefit tensile strength and ductility. Below 10% Mn the tensile properties decline rapidly to perhaps half the normal level at about 8% Mn. For critical requirements 11%Mn is desirable as a minimum; though the improvement over 10% is slight. The maximum is rather arbitrary and probably depends more on the cost of the alloy than on metallurgical results, since acceptable properties may be produced up to at least 20% Mn.

<u>SILICON:-</u>

The misuse of Silicon has had a more damaging effect upon the reputation of manganese steel. silicon may be used up to 2% to moderately increase yield strength without significantly effecting toughness. This may be true for 25mm test bar data, but when we talk about heavy section castings, silicon can have a disastrous effect on toughness. Show in figure 6, below Even with 0.6 to 1.0% silicon, toughness is adversely affected with increasing carbon content

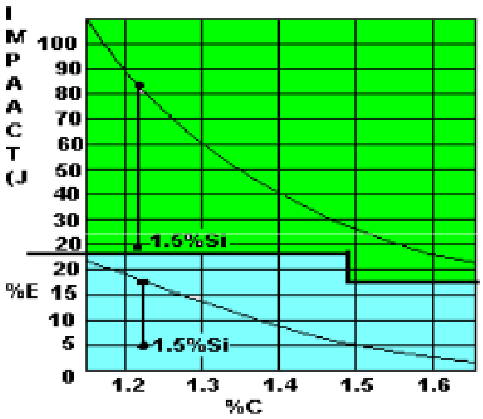
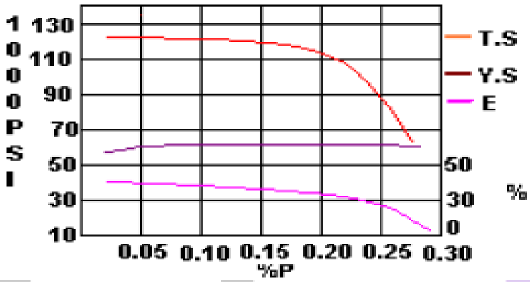


Fig .6 Effect of 1.5 % silicon upon izod impact energy and tensile strength of 150mm section Mn steel (13%Mn , 0.6%Si , 0.035%P)

PHOSPHORUS

Phosphorus content of 0.08% is permitted in specifications, experienced foundry men will hold phosphorus to much lower levels. The most serious problem faced with high phosphorus contents is the effect upon "in plant cracking" rather than the effect on the mechanical properties .However, statistical analysis of crusher performance data has indicated significant relationship between phosphorus content and toughness.



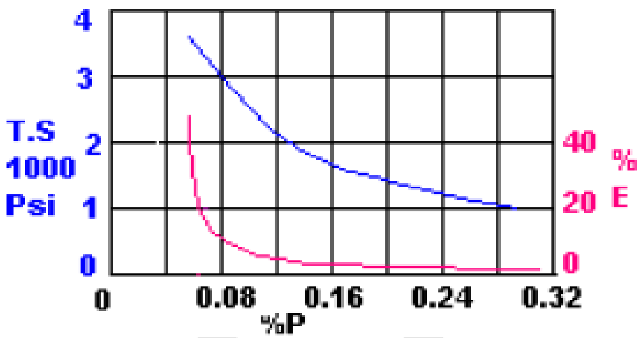
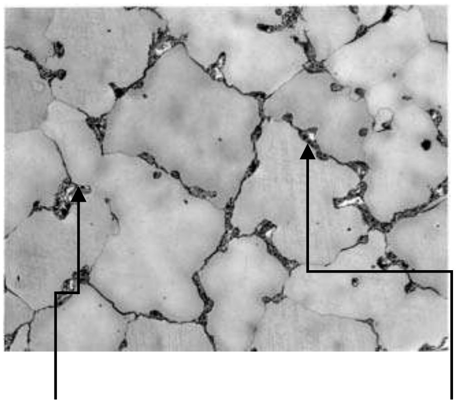


FIG. 7 Effect of phosphorus on tensile and FIG.8 Effect of phosphorus on strength properties at room temperature tensile and elongation at 1149°C.

The degree of embitterment was influenced by other factors such as thickness, carbon, silicon content and other alloy additions, but the clear message is that phosphorus should be held as low as practically and economically possible. Phosphorus above 0.02% progressively promotes inter granular cracking in manganese steels as in austenitic stainless steels. Above 0.06%, the high temperature plasticity of manganese steel is severely reduced and the steel becomes extremely susceptible to hot tearing. At such a high phosphorus level, micro structural evidence of grain boundary films of phosphide eutectic can be observed. Below 0.06% phosphorus, no micro structural evidence can be observed but phosphorus still effects the hot tearing propensity. The maximum tolerable phosphorus content is depended upon the severity of the stress system which is related to casting design, size and riser location. For massive, complex castings it is advisable to hold the phosphorus below 0.04%.



CARBIDE & PHOSPHURUS
AT GRAIN BOUNDRY
(THIS MICROSTRUCTURE IS NOT ACCEPTABLE)

FIG. 9 Microstructure of phosphorus contain more than 0.5 % Hadfield Mn steels

SULPHUR

Increased sulfur content lowers transverse ductility and notch impact toughness but has only a slight effect on longitudinal mechanical properties. Weldability decreases with increasing sulfur content. This element is very detrimental to surface quality, particularly in the lower-carbon and lower-manganese steels. For these reasons, only a maximum limit is specified for most steels. The only exception is the group of free-machining steels, where sulfur is added to improve Machinability; in this case a range is specified "Machinability of Steels" . Sulfur has a greater segregation tendency than any of the other common elements. Sulfur occurs in steel principally in the form of sulfide inclusions. Obviously, a greater frequency of such inclusions can be expected in the re- sulphur grades

CHROMIUM:-

It may be more prudent to identify chromium as an impurity to manganese steel since misuse of this element has generated huge losses for both producers and users. Chromium increases yield strength and flow resistance, which can be useful in certain applications: however, on the other side of the ledger, chromium is very detrimental to toughness and is extremely sensitive to section size variation.

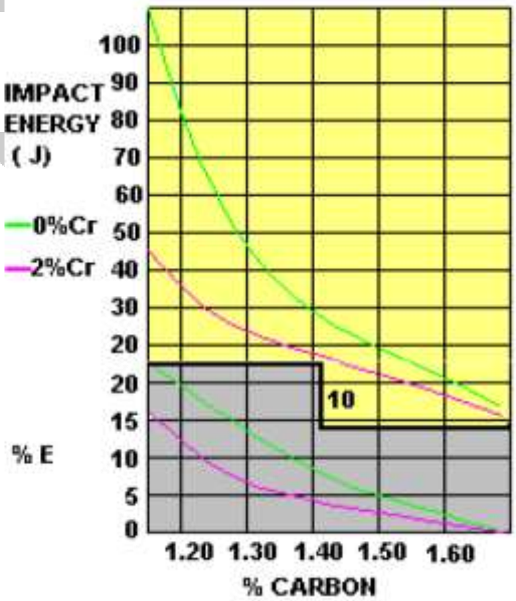


FIG. 10 Effect of chromium on impact energy and elongation of 150 mm Mn steel.(13% Mn , .06% Si , 0.035 % P)

NICKEL

It has been shown that adding nickel to plain austenitic manganese steel decreases the tensile strength, slightly increases the ductility but has no effect on yield strength. However, nickel improves the toughness of such steel by inhibiting the precipitation of grain boundary carbides during reheating and cooling. This produces a steel less susceptible to hot tearing and more amenable to welding. It has been shown that adding nickel to plain austenitic manganese steel decreases the tensile strength slightly increases the ductility but has no effect on yield strength. However, nickel improves the toughness of such steel by inhibiting the precipitation of grain boundary carbides during reheating and cooling. This produces a steel less susceptible to hot tearing and more amenable to welding. Another beneficial effect of nickel is that it improves low temperature impact strength.

MOLYBDENUM:-

An important contribution made by molybdenum additions is the significantly improved as cast mechanical properties and the enhanced resistance to carbide embitterment which occurs if manganese steel is re-heated. In foundry terms, this translate into easier shop handling with reduced propensity for cracking, especially during the removal of gates and risers, arc air flushing and weld repair. For this reason, molybdenum (usually a 1% addition) is a valuable contributor to the production of massive crusher castings. However, it is very important to remember that carbon is the embritteling element and these beneficial effects for large casting production are only of practical significance at lower carbon contents.

TITANIUM:-

Titanium has been added to conventional austenitic manganese steel in amounts ranging from 0.03% to 0.24% in order to refine grain size of jaw crusher castings and consequently increase their life by minimizing cracking. In heavy sections the grain refining effect is not prominent, but the titanium ties up carbon and in effect, makes the steel equivalent in ductility and yield strength to a lower carbon grade of manganese steel.

VANADIUM:-

Vanadium has been added to austenitic manganese steel in order to increase the initial hardness of the steel and thereby make it more wear resistance under conditions of low stress abrasion.

TUNGSTEN:-

Additions up to 3% tungsten to austenitic manganese steel have been studied. Such steels are given the dispersion hardening treatment to obtain a higher initial hardness value than would be obtained from applying the water quenching treatment to the conventional composition. Steels containing 2 and 3% tungsten work harden more rapidly than the conventional manganese steel, but not as rapidly as a dispersion treated 2%Mo steel.

Second stage of Heat treatment cycle (Precipitation strengthening)

Austenitic Manganese Steel was machined to nine pieces of dimension 15mm by 15mm by 15mm. The samples were then austenitized at 1000^{o}C for thirty minutes before quenching in water. Thereafter the samples were subjected to a second stage heat treatment which involved ageing at two different temperatures of 600^{o}C and 700^{o}C for holding times ranging between one and three hours before air cooling. Three samples were used as control samples.- two were austenitized at 1000^{o}C for thirty minutes and one was air cooled while the other was furnace cooled. The third sample was left in the as – machined condition. Hardness measurements utilizing the Rockwell Hardness Tester (HRB) and micro structural examination were utilized for characterization of various heat treatment structures produced.

Temperature ^{0}C	600			700		
Sample	A1	A2	A3	B1	B2	B3
Holding time(HOURS)	1	2	3	1	2	3

Table.1 second stage hardening heat treatment.

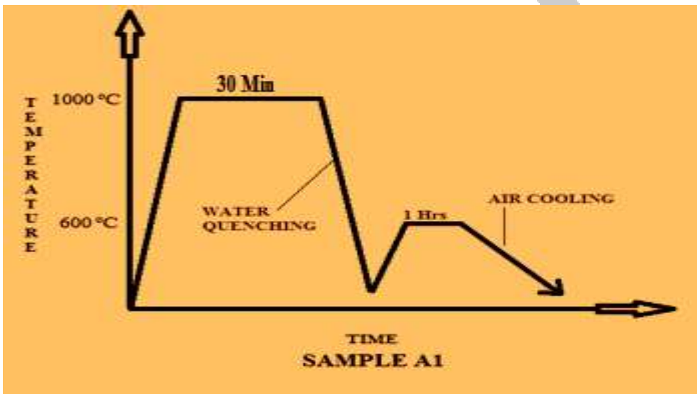


Fig.11 sample A1

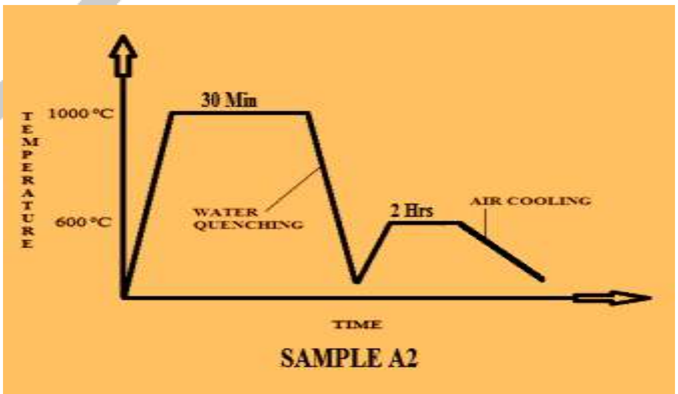


Fig.12 sample A2

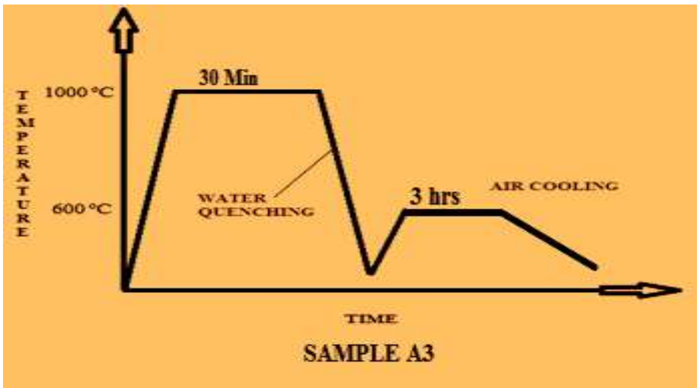


Fig.13 sample A3

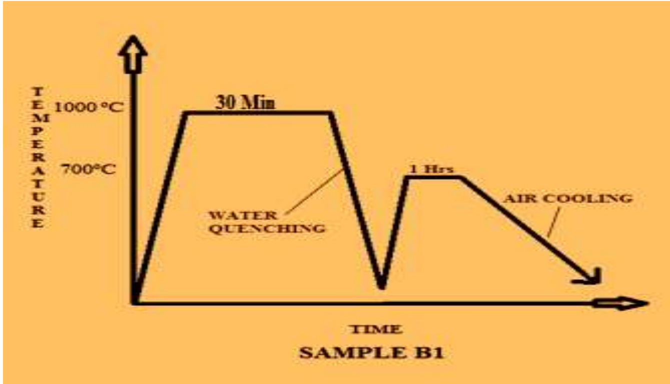


Fig.14 sample B1

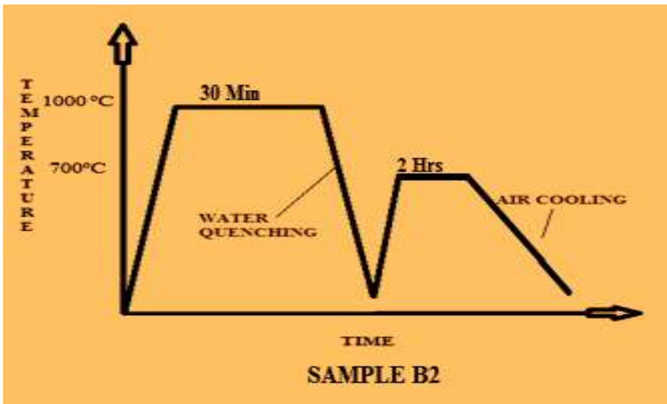


Fig.15 sample B2

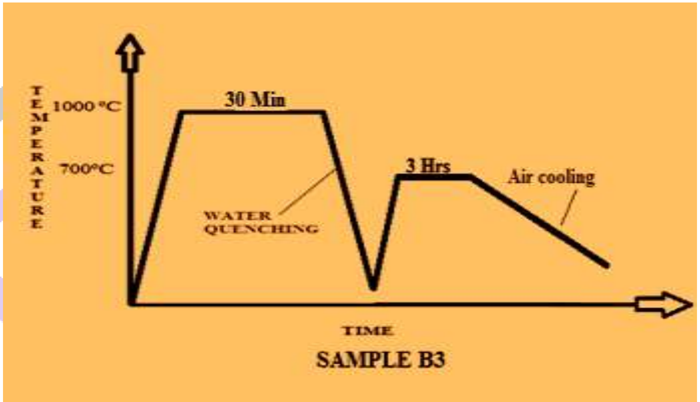


Fig.16 sample B3

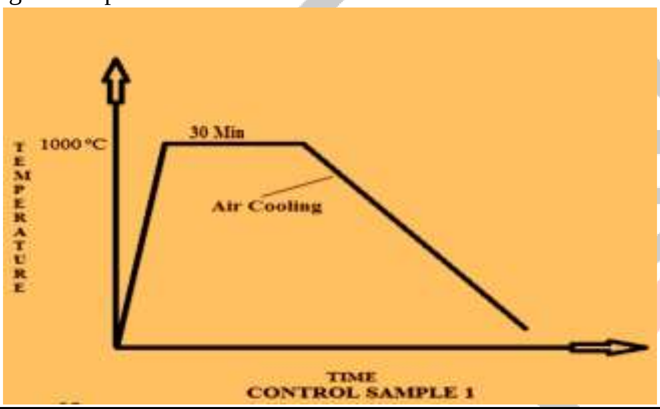


Fig.17 control sample 1

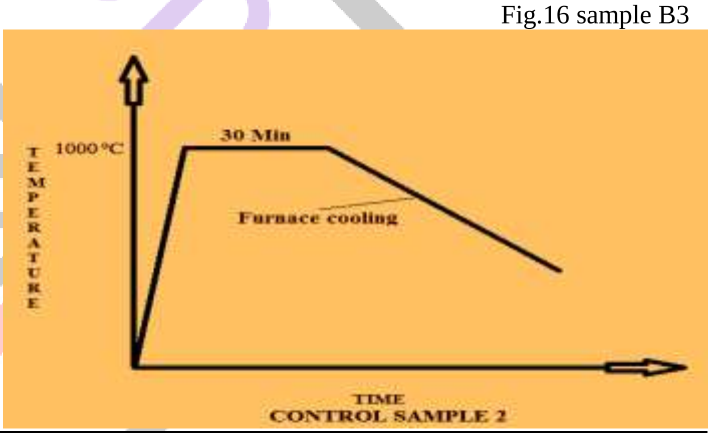


Fig.18 control sample 2

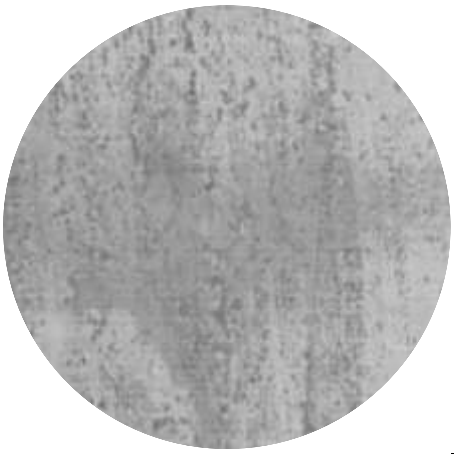


Fig.19 Microstructure of the Sample Heated to 700 °C and Held for 2 Hours, Etch with 2% Nital, Magnification X400

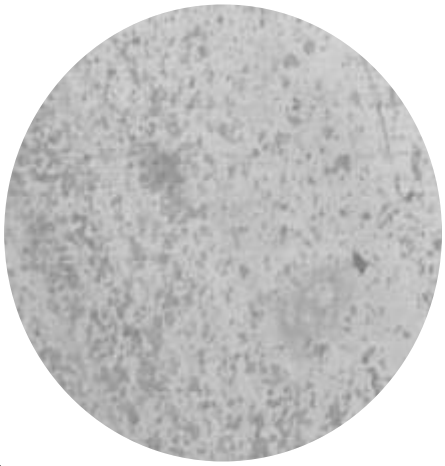


Fig.20 Microstructure of the Sample Heated to 700 °C and Held for 3 Hours, Etch with 2% Nital, Magnification X400

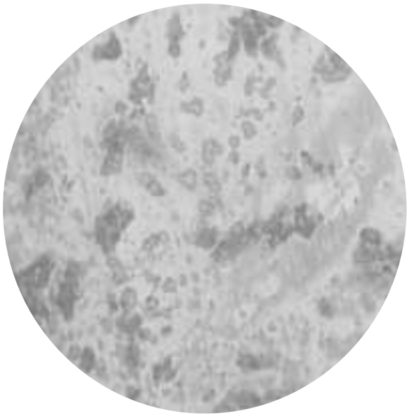


Fig.21 Microstructure of the Sample Heated to 700 °C and Held for 3 Hours, Etch with 2% Nital, Magnification X400

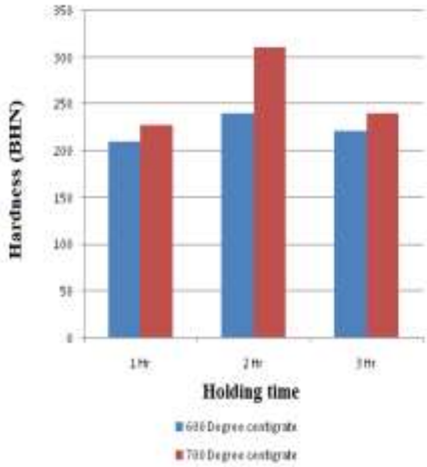


Fig.22 Chart of Variation Hardness with Ageing Time and Temperature

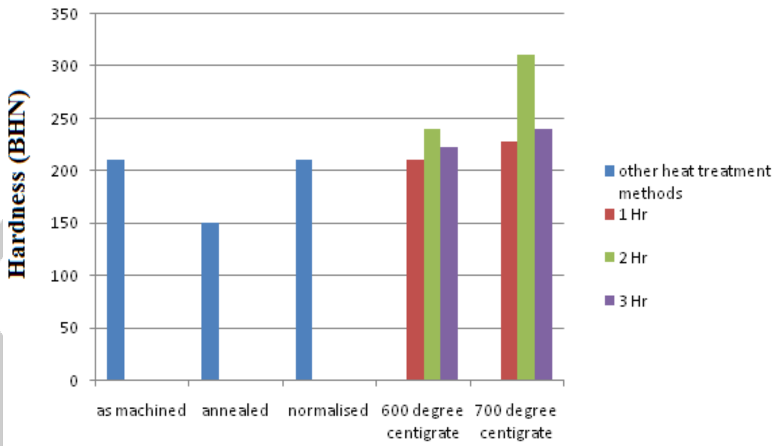


Fig.23 Chart Comparing Values for Aged Samples and those of Other Heat Treatment Methods

DISCUSSION

Comparing the average hardness of the samples as machined, as normalized, annealed and water quenched, it is observed that the sample as machined has the highest hardness but the difference from the water quenched sample is marginal. This confirms the fact that wear abrasion actions on Austenitic Manganese Steel do not increase the hardness considerably as it would be desired for long service life in application for only abrasion without impact action. When the steel was aged at 600^0C it shows improvement in hardness. The hardness increases as the holding hour increases from the first hour to the second hour but the hardness dropped at the third hour. Ageing at 700^0C has a similar result to those mentioned above, but the hardness at the second hour is higher than the one recorded at 600^0C. It shows that the best hardness is attained when the steel is aged at 700 ^{0}C for 2 hours.

Figure 15 helped to further show that ageing at 700^0C for 2 hours is the best and will be recommended for ageing of the steel for industrial applications where only wear abrasion action is present and also to improve the hardness of the Steel for other applications. The heat treatment cycles of these various treatments are shown from Fig 11 to 18. They helped to throw more light on how different ageing treatments affect the hardness of each of the samples. The micrograph of the as-machined sample shows inclusion of small sized carbide particles which explain why the Steel show high hardness as compared to the annealed and normalized samples. The micrograph of these other treatments showed that the carbide has formed large carbide network connected through the whole microstructures and this has caused the austenite phase to transform to ferrite bringing about the reduction in hardness.

The microstructure of the annealed samples shows the carbide covering the whole structure. The normalized samples also show the carbide forming a network round the austenite phase in the Structure. During annealing there will be enough time for carbide network breakdown explaining why the hardness value for the annealed sample was low compared to the normalized samples. Microstructures of the 700^0C treatment show continuous increase in the carbide forming as inclusion in the austenite phase throughout the treatment of the steel explaining the continuous rise in hardness. Plates 19, 20 and 21 give a clear picture of this.

The carbides were small and sparingly distributed in the austenite phase after the first hour. After the second hour the carbides have spread all over the austenite phase and they are fine. By the third hour of holding the carbides have grown to bigger size but were still well spread in the matrix of the austenite. This trend also took place at 600^0C, but for 600^0C treatment the carbide inclusions were not as dispersed at the second hour as in the 700^0C treatment. It should be noted that the carbide grew after the second hour in both cases; the size of the carbide must have exceeded the optimum size that can effectively cause further increase in hardness as the carbide formed at 700^0C after two hours of ageing.

Ageing at 700^0C for two hours gives us the optimum hardness in the experiment. This shows that the carbide inclusion can be used to strengthen Austenitic Manganese Steel if not allowed to exceed the optimum size that can impede dislocation movement and also not allowed to diffuse into the grain boundaries which might lead to embrittlement.

Since the precipitated carbide has led to an increase hardness of the steel, and from the relation between wear resistance and hardness we can say the precipitation strengthening can be used in improving the wear resistance of Austenitic Manganese Steel for service condition where abrasive loading is more than impact loading.

CONCLUSION

It has been established that Precipitation Strengthening (ageing) Mechanism can be used to improve the hardness and invariably the wear rate of the Hadfield Steel. The micrographs show that the treatment was able to cause precipitates in the matrix of the austenite phase and the hardness results show that the precipitates were able to increase the hardness of Austenitic Manganese Steel and that the ageing at 700^0C for 2 hours gave the best result.

References

[1] Aver, H. S., 1981, *"Austenitic Manganese Steel: Metal Handbook",* 8th Edition
[2] Higgins, R. A., 1993, "Engineering Metallurgy Part 1: Applied Physical Metallurgy", 6th Edition, ELBS, Cornwall, Page (s): 50-56, 190-215 and 230-235.
[3] Katella, R., 1994,"Austenitic Wear Resistant Steel and Method for Heat Treatment", Patent Paper.
[4] Cyril Wells, Metal Research Laboratory. Carnegie Institute of Technology, Pittsburgh. "Constitution of Ternary Alloys"
[5] Howard S. Avery, American Brake Shoe Company, N.J. & M.J.Day, Carnegie- Illinois Steel Corporation, Chicago, "Austenitic Manganese Steel"
[6] J. Tasker, The Frog, Switch and Manufacturing Co. U.S.A., "Austenitic Manganese Steel – Fact and Fallacy"
[7] George E. Dieter, Jr. "Mechanical Metallurgy"
[8] Mats Hillert and Mats Waldenstrom, The Royal Institute of Technology, Sweden, "Isothermal sections of the Fe-Mn-C system in the temperature range 873K – 1373K"