

A STUDY ON THE TRANSFORMATION OF VARIOUS MATRICES OF S. G IRON INTO AUSTEMPERED DUCTILE IRON

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ABSTRACT

Austempered Ductile Iron (ADI) can be made by the austempering of spheroidal graphite (S. G) iron. Austempering changes the matrix nature of ferrite or pearlite to ausferrite (austempered) plus retained austenite. The austempered matrix has better mechanical properties as compared to ferritic or pearlitic matrix of S.G iron. Therefore, austempered ductile iron can be of great importance in our agricultural industry. In the present work, commercially used grades of S. G iron with ferritic matrix (denoted by A) and pearlitic matrix (denoted by B) were austempered to produce a tempered austenite matrix of ductile iron. Both S.G irons (A) and (B) were austenitised to 950 °C. Ferritic matrix S. G iron (A) was austempered to 250 °C and 300 °C for 15, 30, 45, and 60 minutes, respectively. Whereas pearlitic matrix S. G iron (B) was austempered at 300 °C and 400 °C for 15, 30, 45 and 60 minute, respectively. Austempering of S. G iron with ferritic matrix at 250 °C and 300 °C shows almost same hardness. However, austempering of S.G iron of pearlitic matrix at 250 °C shows higher hardness values at all holding times as compared to austempering at 400 °C. It can be concluded that the S. G iron(A) of ferrite matrix is less responding to austempering as compared to the pearlitic matrix (B). Thus, better mechanical properties such as high hardness/wear resistance can be achieved by using S. G iron (B) of pearlitic matrix less responding to austempering as compared to the pearlitic matrix (B). Thus, better mechanical properties such as high hardness/wear resistance can be achieved by using S. G iron (B) of pearlitic matrix.

1. INTRODUCTION

It is well known that heat treatment cycle for austempering of ductile iron consists of austenitising it between 850- 950 °C, followed by fast quenching into a low temperature and held isothermally in the austempering range 200-400 °C for a specified length of time to complete the transformation and then air cool/quench [1, 2]. The processing window for austempering temperature was also determined on the basis of the mechanical properties as required by ASTM A897M-03 standards [3]. During the austenitisation of ductile iron carbon from the nodules may dissolve in the austenite to attain its equilibrium concentration. This austenite is then quenched rapidly at slightly above the martensite start transformation temperature to avoid the formation of pearlite/ferrite [4].

S. G iron is austenitised either using a high temperature salt bath or a controlled atmosphere furnace. It is established by many workers [4-6] that initial austenitising time and temperature (850 – 950 °C) must be controlled to form fine grain austenite and uniform carbon contents in the matrix.

It has been observed [1, 5, 6] that during austempering ferrite is nucleated and grows from the parent austenite.

At the same time the carbon rejected from the growing ferrite diffuses into surrounding austenite enriching the carbon content of austenite rather than forming the carbide.

Many researchers [1, 5, 6] suggested that the austempering reaction in ductile iron over the temperature range 200-400 °C occurs in two stages. During 1st stage transformation starts by the nucleation of bainitic ferrite at the inter phase and grain boundaries, and then grows into austenite. This is associated with the carbon rejection from growing ferrite plates into the surrounding austenite. The carbon enrichment of austenite occurs during holding time and enrichment of austenite takes place up to 1.8-2.2 % C. The structure of first stage is called upper bainite which consists of relatively coarse bainitic plates plus retained austenite in the matrix. This product is also known as upper ausferrite.

During 2nd stage with extended austempering period, high carbon stable austenite further decomposes into more stable fine bainitic ferrite and carbide, nominally called

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lower bainite or lower ausferrite. It has been observed by many workers [6, 7] that the undesirable 2nd stage of austempering reaction, where austenite decomposes to form ferrite and carbide, occurs much more readily when austempering at high transformation temperatures. Some new terminologies are being introduced to illustrate the above mentioned differences in austempering reaction at low and high transformation temperatures [1, 7].

The austenite transformed at higher austempering temperatures which can result in the formation of carbide free ferrite and stabilized austenite is called as "austempered ductile iron". The fine ferrite, carbide and stabilized austenite structure, formed at lower austempering transformation temperatures, is known as "austempered/bainitic ductile iron". It is reported [4] that the structures obtained from austempering of ductile iron and steel are quite different; therefore, they are appropriately termed as ausferrite and bainite, respectively. It is well known that austempered ductile irons are used where both high toughness and strength is required, while austempered bainitic ductile irons are employed when highest strength and wear resistance is needed.

S. G iron is mainly employed for the production of parts which are mostly utilized in automobile and agricultural industries, where wear resistance/ high hardness and toughness are the basic requirements. These parts of S. G iron are mostly produced using gas fired furnaces. This S. G iron is not as clean as is required for the austempering [8]. However, in the present work an effort has been made to improve the properties particularly hardness of this indigenously produced S. G iron by austempering.

2. EXPERIMENTAL WORK

Two types of S. G irons, produced by employing a gas fired furnace, were selected for the present study. The compositions of S. G iron "A" and S. G "B" are given in the Table 1. Both the S. G irons were austenitised at 950 °C and then austempered at two different temperatures for a various length of times. Individual temperature and time span for austempering of both S. G irons 'A' and 'B' is shown in Figures 1 and 2, respectively

Table 1: Composition of S. G irons A and B.

Elements	% C	% Si	% Mn	% P	% S
S.G. Iron "A"	3.4	1.85	0.24	0.004	0.005
S.G. Iron "B"	3.7	2.5	0.35	0.004	0.004

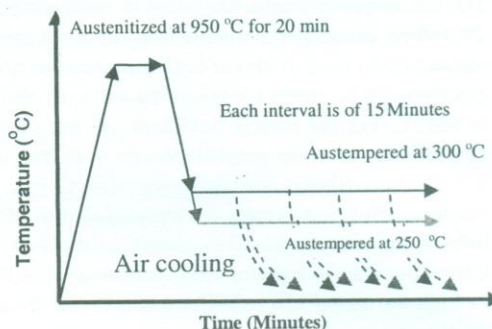


Figure 1: Schematic representation of Austempering of S.G Iron 'A' at various temperatures and times.

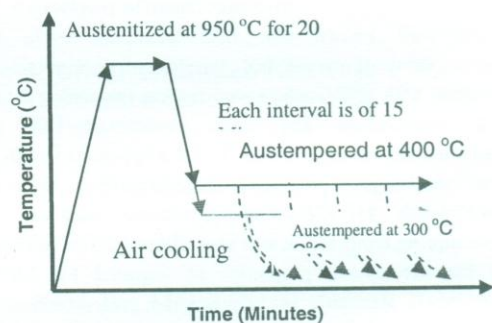


Figure 2: Schematic representation of Austempering of S.G Iron 'B' at various temperatures and times.

Cubic shaped samples of S. G iron "A" having dimensions approximately 1.5 cm were austenitized in a muffle furnace at 950 °C for 20 minutes. One of the austenitized samples at 950 °C for 20 minutes was taken out from the furnace and immediately quenched in the water. Another austenitized sample was held in air for 10 seconds (which was the time taken in moving samples from one furnace to another furnace) before quenching in water. Remaining austenitized samples were immediately transferred to other muffle furnaces which were maintained at 300 °C and 250 °C, respectively, for

austempering. At these temperatures, austempering was carried out for 15, 30, 45 and 60 minutes, respectively and then these austempered samples were quenched in water. Various samples of S.G iron "B" having dimensions similar to S. G iron "A" were also austenitized at 950 °C for 20 minutes. One of the austenitized specimen was taken out from the furnace and immediately quenched in the water. Remaining samples were austempered in muffle furnaces at 400 °C and 300 °C for 15, 30, 45, 60 minutes, respectively and then quenched in water. The temperatures of the furnaces were monitored by Chromel/Alumel (T1/T2) thermocouple. Prior examination had shown that depth of the surface layer damaged by decarburization was less than 0.5 mm. Therefore, these heat treated specimens were ground to remove 1mm of material. The micro structural studies of polished and etched samples (2% nital) were carried out using an Olympus PME 3 inverted Metallurgical Microscope. Hardness values of all heat-treated and as received samples were measured by using a Brinell hardness testing machine.

3. RESULTS & DISCUSSIONS

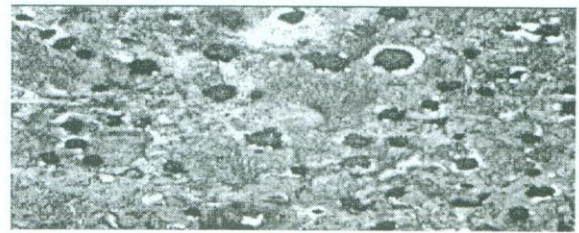
The microstructure of a sample of as cast S. G iron "A" containing approximately 80% ferrite is shown in Figure 3. It can be seen in Figure 3 that graphite nodules are surrounded by ferrite rings and dark areas other than nodules in the matrix are pearlite. This type of structure is called a bull's eye structure [9].

Figure 4, is a representative microstructure of as cast S. G iron "B" which shows more pearlitic areas (approximately 80%) in the matrix as compared to S.G iron "A". This more pearlitic area in the microstructure of S. G iron "B" as compared to "A" may be due to more carbon in S. G. iron "B". Ferrite rings around the nodules can also be observed in the Figure 4. However, the size of the ferrite rings in case of S. G iron "B" is smaller as compared to S.G iron "A".



100X

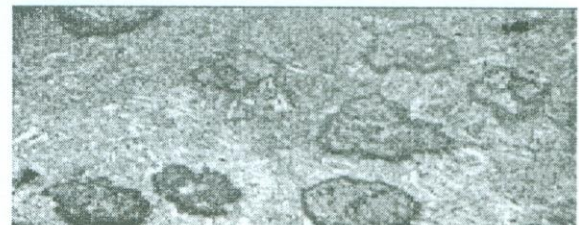
Figure 3: As cast S.G iron "A".



100X

Figure 4: As cast S.G iron "B".

The microstructure of the S. G iron "A" austenitized at 950 °C for 20 minutes and quenched in water is shown in Figure 5. The matrix has been converted to austenite when heated at 950 °C and quenching of that austenite transforms it into martensite. The highest hardness number of this sample also verifies that during quenching austenite matrix has transformed in to harder product i.e. martensite.



250X

Figure 5: Austenitized at 950 °C and quenched in water.

Figure 6 shows the microstructure of S. G iron "A" austenitized at 950 °C and held in air for 10 seconds (the time required for shifting the sample to another furnace for austempering) and then quenched. It can be seen that whole of the austenite transformed to martensite. Thus, it can be concluded that the transferring time from austenitization furnace to austempering furnace does not allow the transformation of austenite to softer products (ferrite or pearlite).



250X

Figure 6: Austenitized at 950 °C held in air for 10 seconds and quenched

The microstructure of S. G iron "A" austenitised at 950 °C for 20 minutes and austempered at 250 °C for 15 minutes shows almost complete transformation to ausferrite, i.e. an intermediate phase between pearlite and martensite Figure 7. Similar microstructure (ausferrite) after austempering was produced by some other workers [10, 11]. The hardness values of the specimens as cast, quenched and austempered at various temperature for different times are given in Table 2. This shows that hardness values of as cast S. G iron is BHN 172 whereas hardness of the quenched sample is BHN 440. The S.G iron "A" austenitized at 950 °C for 20 minutes and austempered at 250 °C for 15 minutes shows hardness BHN 265 .Which is in between the hardness values of as cast and quenched samples. The comparison of hardness values as mentioned above also indicates that the austempering transformation, i.e., (ausferrite) is an intermediate phase between pearlite and martensite.



400X

Figure 7: Austempered at 250 °C for 15 minutes "A".

Table 2: Brinell Hardness Number (BHN) for S. G iron "A".

Condition	BHN	Austempered at 300 °C		Austempered at 250 °C	
		Time (Min)	BHN	Time (Min)	BHN
As Cast	172 ± 1.4	15	265 ± 1.5	15	265 ± 1.5
		30	240 ± 1.4	30	231 ± 1.7
Austenitised and Water Quenched	440 ± 2.3	45	249 ± 1.7	45	249 ± 1.5
		60	239 ± 1.3	60	244 ± 1.6

The microstructure of S.G iron "B" austenitised at 950 °C for 20 minutes and austempered at 400 °C for 15 minutes is shown in Figure 8. This Figure shows that the whole matrix has transformed to ausferrite. The same material (S. G. Iron B) was also used for austempering by another

worker [12]. Figures 9 (a) and (b) are SEM microstructures of austenitised specimens at 900 °C for 2 hours and austempered at 300 °C for one hour [12]. These microstructures verified that this indigenously produced S. G iron has transformed to ausferri.



400 X

Figure 8: Austempered at 400 °C for 15 minutes "B"

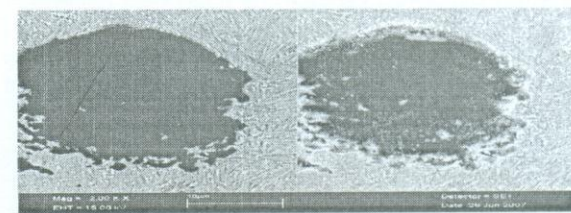


Figure 9 (a): SEM micrograph of ADI showing carbon nodules, right: secondary electron image and left: backscattered image, S. G iron "B" [12].

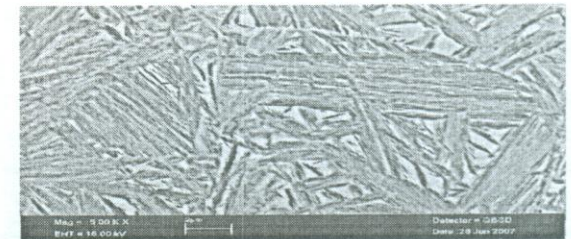


Figure 9 (b): SEM micrograph of bainite sheaves with retained austenite, S. G iron "B" [12].

The hardness of as received and heat treated samples of S. G iron "A" and "B" are given in Tables 2 and 3. It can be seen in Table 2 that S. G iron "A" which was austempered at 250 °C and 300 °C indicates almost same values of hardness at all holding times. The hardness of austempered S. G iron of similar composition and microstructure as of S.G. iron "A" produced at 400°C were measured by Ajmal et. al [13]. It can be observed that that hardness values of ADI produced by Ajmal et. al at 400 °C were almost similar to the hardness of ADI produced by austempering of S. G iron "A" at 250°C and 300°C in present experimentations.

Table 3: Brinell Hardness Number (BHN) for S. G iron "B".

Condition	BHN	Austempered at 400 °C		Austempered at 300 °C	
		Time (Min)	BHN	Time (Min)	BH N
As Cast	199 ± 1.5	15	249 ± 1.7	15	265 ± 1.5
		30	240 ± 1.5	30	254 ± 1.6
Austenitised and Water Quenched	454 ± 2.5	45	270 ± 1.4	45	283 ± 1.7
		60	254 ± 1.7	60	249 ± 1.5

The hardness values of S. G iron "B", austempered at 400 °C and 300 °C, are higher than the S. G iron "A" at all holding times, Table 3. It was also observed that higher values of hardness can be achieved if the S. G iron "B" is austempered at 300 °C for 45 minutes. This higher value of hardness of S. G iron "B" austempering at lower temperature, i.e., 300 °C for 45 minutes has been also verified by many workers [10, 11, 13].

4. CONCLUSIONS

1. Austempering of S. G iron "A" at 300 °C and 250 °C shows almost same values of hardness.
2. Austempering of S. G iron "B" at 300 °C yields higher values of hardness at all holding times as compared to austempering at 400 °C.
3. Maximum hardness was achieved in S. G iron "B" austempered at 300 °C for 45 minutes.

REFERENCES

1. R. Elliot, "Cast Iron Technology", Butterworth & Co. Ltd., New York, 1988.
2. O. Erić, et. al., "Determination of Processing Window for ADI Materials Alloyed With Copper", Association of Metallurgical Engineers of Serbia, MJoM, Vol. 16, No.2, pp. 91-102, 2010.
3. M. Erdogan, V. Kilicli, and B. Demir, "Transformation Characteristics of Ductile Iron Austempered from Intercritical Austenitizing Temperature Ranges", J. Mater. Sci., Vol. 44, No.5, pp. 1394-1403, 2009..
4. H. K. D. H. Bhadeshia, et. al., "Stress induced transformation to bainite in Fe-Cr-Mo-C pressure vessel steel", Materials Science and Technology, Volume 7, Number 8, pp. 686-698, 1991.
5. H. K. D. H. Bhadeshia, "Bainite in Steels". The institute of Materials, London, pp. 117-121, 1992.
6. N. Darwish and R. Elliot, "Austempering of low manganese ductile irons", Materials Science and Technology, Vol. 9, pp. 572-585, 1993.
7. H. Bayati. and R. Elliott, "Austempering process in manganese alloyed ductile cast iron", Materials Science and Technology, Vol. 11, pp. 118-129, 1995.
8. C. K. Lin and J. Y. Wei, "High-Cycle Fatigue of Austempered Ductile Irons in Various-Sized Y-Block Castings", Materials Transaction, JIM, Vol. 38. No. 8, pp. 682-691, 1997.
9. H. K. D. H. Bhadeshia and D. V. Edmonds, "The Mechanism of Bainite Formation in Steel", Acta Metallurgica, Vol. 28, pp. 1265-1273, 1980.
10. R. C. Thomson, J. S. James and D. C. Putman, "Modelling microstructural evolution and mechanical properties of austempered ductile iron", Materials Science and Technology, Vol. 16, pp. 1412-1419, 2000.
11. R. Kazerooni, A. Nazarboland and R. Elliott, "Use of austenitising temperature in control of austempering of an Mn-Mo-Cu alloyed ductile iron", Materials Science and Technology, Vol. 13, No. 12, pp. 1007-1015, 1997.
12. A. Gulzar, et.al., "Microstructure evolution during surface alloying of ductile iron and austempered ductile iron by electron beam melting", Applied Surface Science, Vol. 255, Issue 20, , PP. 8527-8532, 2009.
13. M. Ajmal and F. Nazir, "Mechanical properties of austempered ductile iron austenitised at different temperatures", Advanced Materials-2005, Dr. A. Q. Khan Research Laboratories, Pakistan, pp 321-324, 2005.