To Study The Optimum Range For Hardness of Austempered Ductile Iron By Using Taguchi Method

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ABSTRACT

Austempered ductile iron commonly known as ADI is a type of ductile iron which has undergone a special heat treatment process of austempering. It has been emerged as a material of high interest because of its good combination of properties like high strength with good ductility, good wear resistance and good fatigue strength. The present study focused to find out the effect of heat treatment on hardness of austempered ductile iron. Taguchi Method is used as a design of experiment for analysis the different ranges of hardness. The results revealed that when austenitization temperature increases from 850 to 920 ˚**C** then hardness decreases from 43.31 to 40.82 HRC, and when the austenitization time increases from 60 to 120 mins, then hardness decreases from 43.33 HRC to 40.8 HRC. The results of austempered temperature showed that hardness decreases from 42.43 HRC to 41.7 HRC when temperature increases from 280 to 350 ^{0}C and when austempered time increases from 30 to 90 min hardness decreases from 42.91 HRC to 41.22 HRC. The maximum value of Signal-to-Noise ratio is 28.4, at austenitization temperature is 850 ^{o}C, austenitization time is 60 min, austempered temperature is 280^{o}C and austempered time is 30 min, hence this is optimum range of hardness.

KEYWORDS: Austempered ductile iron, Austenitization temperature, Austenitization time, Austempered temperature, austempered time.

1. INTRODUCTION

Austempered ductile iron, commonly known as ADI, is a type of ductile iron that has undergone a special austemper heat treatment process. In recent years, it has become a material of great interest due to its good combination of properties [5]. These include high strength with good ductility, good wear resistance and good fatigue resistance. This material has been used in a wide range of applications in automotive and other industrial components [7, 9]. ADI is the most versatile material for designers; It offers the design engineer an alternative to steel, iron and aluminium when high strength and low wear are required. It has the potential of up to 50% cost savings, as well as a general reduction in component weight, weighs 8-10% less than steel, compared to standard grades of ductile iron, exhibits more than twice the resistance For the same ductility value, it is stronger per unit weight than aluminium, as resistant to wear as steel [2,4]. When resistance is required, the ADI is particularly cost effective, fatigue resistance is 50% higher [1,6]. It has a high strength / weight ratio, high toughness, good thermal conductivity, good vibration damping and excellent wear resistance. In addition, all grades of ADI exceed the impact resistance with notches and the low temperature properties of cemented and hardened 8620 steel. In some applications, ADI with 42-46 RC has replaced 60 RC 8620 cemented and hardened steel [3, 14]. By varying the heat treatment parameters, the austerization time and temperature a specific set of properties can be achieved. Austempering was developed by Davenport and Bain in the 1920s while the steel was going out, they identified an intermediate phase, ultimately called bainite that had greater ductility than martensite with comparable hardness. In the early 1940s, Flinn applied this heat treatment to cast iron, namely gray iron. In 1948, the British Cast Iron Research Association (BCIRA) and the International Nickel Company (INCO) jointly announced the invention of ductile iron [11, 13]. The first step to apply treatment of heat on ductile iron was taken in the 1950s, but it remained a laboratory curiosity until 1972. After that, ADI components began to be produced in large quantities. It was commercially applied for the first time in 1972 when general engines had developed a lower ADI grade of bainite that had good enough properties to replace forged cemented steel for the manufacture of hypoid sprockets and ring gears for passenger cars [18, 2. 3] . Then it was used in different countries in various trucks for industrial applications. After some times, it is also being used in different types of light vehicles like cars etc. and the automotive industries of the United States considered it favourably [12, 16]. The majority of the main utilizations of ADI were identified with wear opposition. Today, ADI has discovered application in most tough merchandise businesses and in items extending from excavators, vehicle camshafts, control apparatuses, engine timing riggings and cleaning transports [15, 17]. It has been exposed that ADI is the cost efficient material which is utilized by most of the industries for various applications. The timing gears have been in continuous production since 1980's and have been interchanged due to its excellent qualities and properties. ADI gear teeth can just support about 80% of the greatest contact heaps of carburized steel; in most rigging plans the admissible contact of stress of ADI is adequate [21, 25]. Moreover, the graphite knobs in ADI gears produce a calmer rigging that guides the designer in tending to NVH issues. By the 1990's, ASTM A897-90 and ASTM A897M-90. Specifications for Austempered Ductile Iron Castings were distributed in the US while different particulars were created around the world. What's more, another term to depict the grid microstructure of ADI as "ausferrite" was presented [19, 22]. The majority of countries with a significant iron foundry industry are now involved in understand, develop and utilize ADI in a wide range of applications. The engineers worldwide are exploring ADI castings as a desirable alternative to other materials [20, 24].

Synchronization gears have been in continuous production since the 1980s and have replaced with low-carbo Cr-M carburetted and hardened steel at important cost effective. This type of (ADI) gears can only support approximately 80% of carbide steel contact loads; In most of the gear designs, the permissible contact voltage of ADI is adequate [21, 25]. In addition, graphite nodes in ADI gears produce a quieter gear that helps the designer address NVH problems. During the 1990s, ASTM A897-90 and ASTM A897M-90 particulars for severe ductile iron foundries were distributed in the USA, While different details were created around the world. Moreover, another term was acquainted with depict the grid microstructure of ADI as "ausferrite" [19, 22]. Most countries with an important iron foundry industry are now involved in understanding, developing and using ADI in a wide range of applications. Engineers around the world are exploring ADI foundries as a desirable alternative to other materials [20, 24].

Therefore, ADI applications develop slowly but steadily. Be that as it may, the examination chip away at the hardness of ADI falls behind its application. ADI had a blended microstructure comprising of fine ausferrite created at low austempering temperatures and thick ausferrite delivered at high austempering temperatures. Many researchers have worked on different ADI characters, for example [20] considered the wear description of ADI in the circumstances of the jaw crushing, nail scratch and rubber wheel graze tests [24]. After that, the wear resistance properties of austempered ductile iron and the study of wear behavior of austempered ductile iron were studied [26]. This research has been carried out to study the hardness of the IDA under different austere temperatures..

2. CONCEPT OF DESIGN OF EXPERIMENT (DOE)

DOE is an organized and sorted out technique that is utilized to decide the connection between the various components that influence a procedure and the result of that procedure. Sir Ronald A. Fisher, the eminent mathematician and geneticist, built up this technique without precedent for the 1920s and 1930s. The design of experiment (DOE) comprises in understanding the effect of explicit changes on the procedure sources of info and afterward expanding, limit or standardize the outcome when taking care of the information. The DOE is a logical methodology that enables specialists to pick up information to all the more likely comprehend a procedure and decide how impacts (trait influence the leave reaction). The DOE procedure is isolated into three fundamental stages, which covers every single test draws near. These three stages are (1) Planning Phase (2) Conduction Phase (3) Analysis Phase.

2.1 PLANNING PHASE

In the planning phase, make the plan for the experimentation and for that choose L8 orthogonal array using Taguchi Method according to the factors and levels of the factors. In this experiment there are four factors and each factor has two levels.

Table 1. Samples with different parameters

Sample No.	**T_y, ^oC (F1)**	**t_y min (F2)**	**T_A, ^oC(F3)**	**t_A, min (F4)**
1.	850	60	280	30
2.	850	60	280	90
3.	850	120	350	30
4.	850	120	350	90
5.	920	60	350	30
6.	920	60	350	90
7.	920	120	280	30

8.	920	120	280	90

In Table 1, F1, F2, F3 and F4 are the factors and 1 and 2 are the levels of each factor.

Experiment is done according to Table 1.

F1-Austenitization temperature **(**T_y) having two levels 1st is 850 ^oC and 2nd is 920 ^oC.

F2-Austenitization time (t_y) having two levels 1st is 60 min and 2nd is 120 min .

F3-Austempered temperature (T_A) having two levels 1st is 280 ^oC and 2nd is 350 ^oC.

F4-Austempered time (**t_A)** having two levels 1st is 30 min and 2nd is 90 min.

One level is taken from the lower side and other is taken from the higher side of the range.

2.2 CONDUCTING PHASE

2.2.1 Material used

The ductile cast iron utilized in the present examination, was prepared as pieces of size 10 mm^3. The chemical composition of the same is exhibited in Table 2. The present structure was picked on the grounds that iron with comparable science had been utilized in our labs in past examinations, and accordingly, impressive information on microstructure, mechanical properties and sturdiness are accessible to the break. In this way, it was chosen to complete the hardness study likewise in ductile iron of similar compositions.

Table 2. Composition of the ductile iron used for the development of ADI

Element	Cu-iron	Element	Cu-iron
C	3.48	**Cu**	.6
Si	2.028	**Ti**	.04
Mn	.22	**Mg**	.04
P	.05	**Mo**	.033
S	.004	**Sn**	.0079
Cr	.050	**V**	.012
Ni	.016	**Al**	.02
Fe	Rest		

2.2.2 Heat Treatment Process

The heat treatment of ductile iron to develop austempered ductile iron (ADI) involves austenitization followed by austempering.

2.2.2.1 Austenitization

The samples of size 10 mm^3 were heat treated, muffle furnace was used for austenitization. In order to achieve complete and homogeneous austenitization, the furnace was optimized accordingly. The alloyed samples were soaked in a muffle furnace at T_y= 850°C and 920 °C for 60 and 120 min.

2.2.2.2 Austempering

The samples were held in austempering salt bath at T_A =280°C and 350°C for t_A =30 and 90 min. The austenitized samples were immediately quenched in a salt bath maintained at the required austempering temperature. The samples were held in the bath for a predetermined time in order to carry out the austempering transformation, followed by quenching in water. A cylindrical steel pot of 10 liters capacity was used as a salt bath in a box type resistance furnace with the top door and well-insulated walls. The austempering salt bath was made of potassium nitrate, sodium nitrate and sodium nitrate in ratio of 50:40:5. The bath was continuously stirred. The bath temperature was controlled to ± 5°c. All the samples were quenched in water immediately after being austempering.

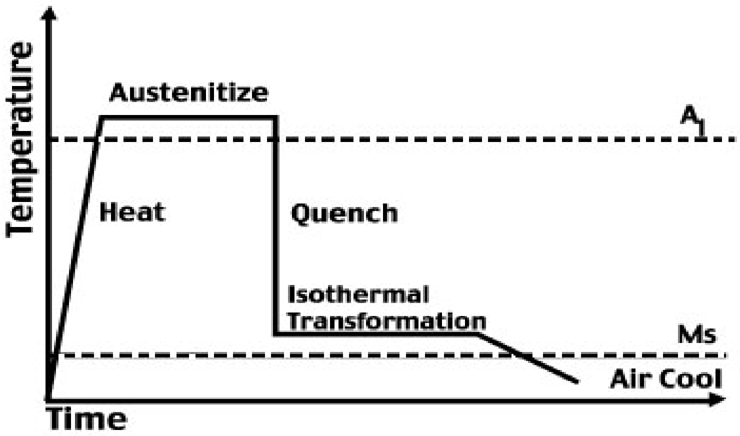

Figure1. Representation of heat treatment process

2.2.2.3 Sample preparation for testing

After quenching, the specimens were prepared for further testing. In this the specimens were cleaned by emery/sand paper to remove the scaling and scratches. The grit sizes of sand paper used for cleaning purpose are 220, 320, 400 and 600 respectively. The Samples were rotated perpendicularly after using each sand paper. After removing all the scratches samples were then polished with the help of fine polishing machine. For getting scratch free polished surface.

2.2.2.4 Hardness Testing

The Hardness study was conducted on polished surface of specimens. Three readings are taken from a single specimen. Hardness testing was carried out on a rockwell hardness testing machine.

2.3 ANALYZING PHAASE

S/N ratio analysis (Signal-to-Noise ratios) from Taguchi method is used for the final results. In this Larger, The-Better is used for the hardness, because generally more hardness is required in most of the applications.

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Table 3. Austenitization and austempering temperatures and time used in experiment

Sample No.	**T_y, °C**	**t_y min**	**T_A, °C**	**t_A, min**	**Av. Hardness (HRC)**	**S/N Ratio**
1.	850	60	280	30	45.6	28.4
2.	850	60	280	90	44.2	28.1
3.	850	120	350	30	42.4	27.7
4.	850	120	350	90	40.9	27.4
5.	920	60	350	30	42.3	27.7
6.	920	60	350	90	41.0	27.4
7.	920	120	280	30	41.2	27.5
8.	920	120	280	90	38.6	26.9

3. RESULTS AND DISCUSSIONS

In Table 3 austenitization temperature has two levels 1st is 850 °C and 2nd is 920.In the same way austenitization time also has two levels 1st is 60 min and 2nd is 120 min. Austempered temperature has two levels 1st is 280 °C and 2nd is 350 °C. Two levels of austempered time are 30 and 90 min.

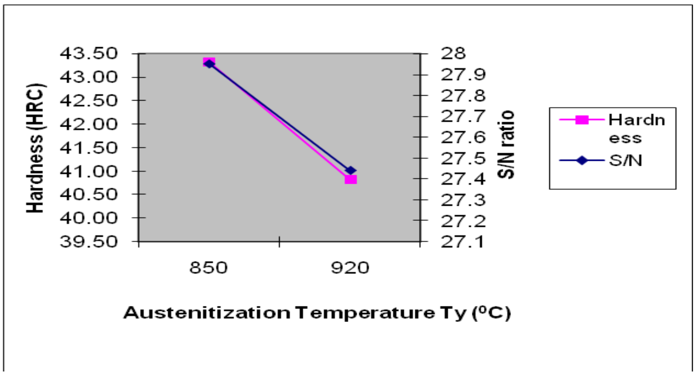

Figure 2. Variation in hardness and S/N ratio with austenitization temp. Ty = 850 ^{0}C, 920 ^{0}C

Table 4. Range of hardness and S/N ratio

T_y ^{0}C	Hardness(HRC)	S/N ratio
850	43.31	27.95
920	40.82	27.44

In figure 2, hardness is varying with the change in temperature. This shows that hardness decreases with the increase in temperature. Low temperature results in fine acicular dispersion and thus high hardness and wear structure. The high temperature results in coarser acicular structure low hardness. The carbon content of the matrix decreases as the silicon content increases. The hardenability depends to a significant degree on the carbon content of matrix. In this comparison of level 1st i.e 850 ^{0}C and 2nd 920 ^{0}C shows the variation in hardness due to change in the temperature.With the change in hardness S/N ratio also changes. Larger valve of S/N ratio shows better result.

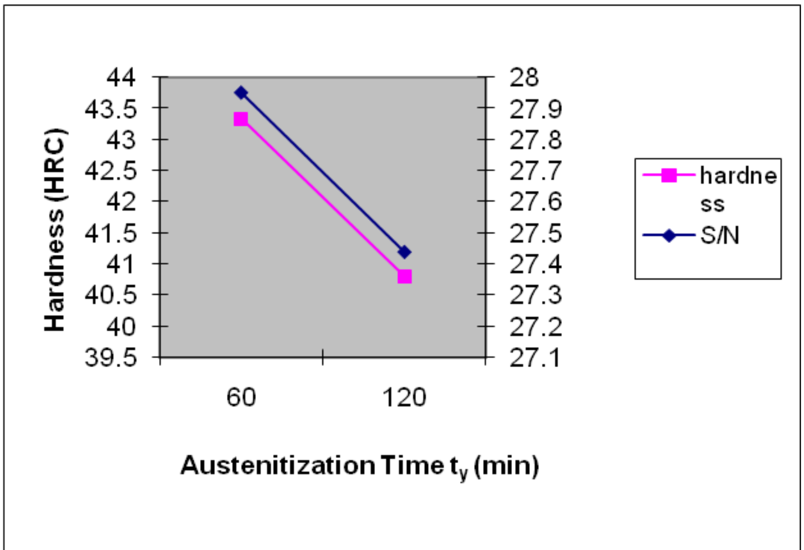

Figure 3. Variation in hardness and S/N ratio with austenitization time t_y = 60 and 120 min

Table 4. Range of hardness and S/N ratio

$t_{y(min)}$	Hardness(HRC)	S/N ratio
60	43.33	27.95
120	40.8	27.44

Figure 3 shows the changes in hardness due to change in austenitization time, when time increases hardness and S/N ratio decreases. Too low time may cause entire matrix to transfer to austenite but the carbon distribution may not be homogenized, but hardness increases due to fine stutrure.

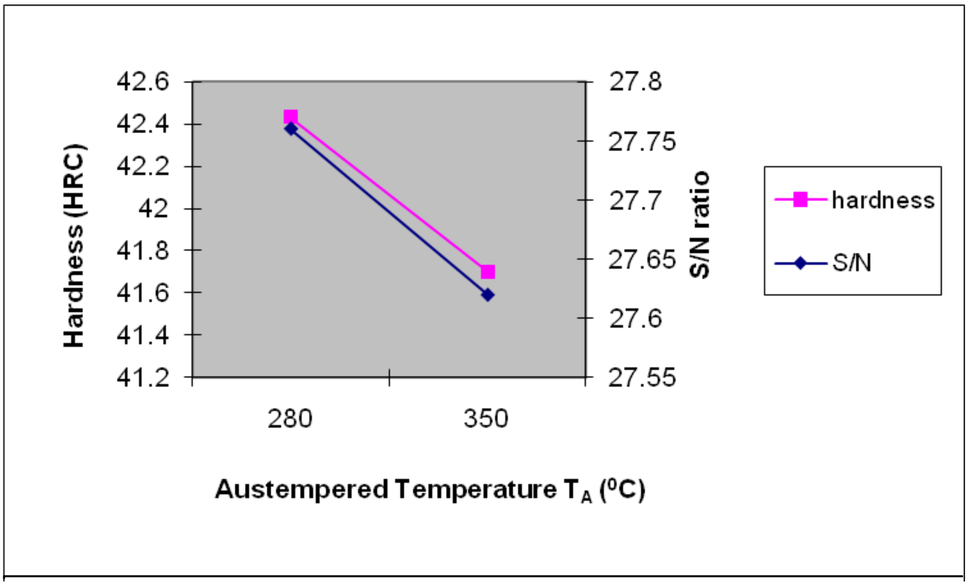

Figure 4 Variation in hardness and S/N ratio with austempered temp. T_A = 280 ^{0}C & 350 ^{0}C

Table 5. Range of hardness and S/N ratio

T_A ^{0}C	Hardness(HRC)	S/N ratio
280	42.43	27.76
350	41.7	27.62

Figure 4 shows the variation in hardness due to change in austempered temperature from 280 ^{0}C to 350 ^{0}C, when temperature increases hardness and S/N ratio decreases. At low temperature, fine acicular dispersion of ferrite, hence more hardness and at high temperature, coarser acicular dispersion of ferrite, hence less hardness.

Figure 5 shows the changes in hardness due to change in austempered time, when time increases hardness and S/N ratio decreases. Too low time may cause entire matrix to transfer to austenite but the carbon distribution may not be homogenized, but hardness increases due to fine stutrure. This figure shows the better results in 30 min.

Fig 2 shows the effect of austenitization temperature on the hardness of ADI samples, when Ty 850˚C and 920˚C. From the graph it is evident that the hardness of ADI samples decreases from 43.31 to 40.82 HRC, when austenitization temperature increases from 850 to 920˚C. The high temperature results in coarser acicular structure low hardness. The carbon content of the matrix decreases as the silicon content increases. The hardenability depends to a significant degree on the carbon content of matrix. It is evident from figure 3, that the hardness decreases with the increase of austenitization time. Too low time may cause entire matrix to transfer to austenite but the carbon distribution may not be homogenized, but hardness increases due to fine stutrure. When time increases from 60 to 120 min then hardness decreases from 43.33 HRC to

40.8 HRC. It is evident from figure 4, that the hardness decreases with the increase of austempered temperature. When temperature increases from 280 to 350 ^{0}C then hardness decreases from 42.43 HRC to 41.7 HRC. It is evident from figure 5, that the hardness decreases with the increase of austempered time.

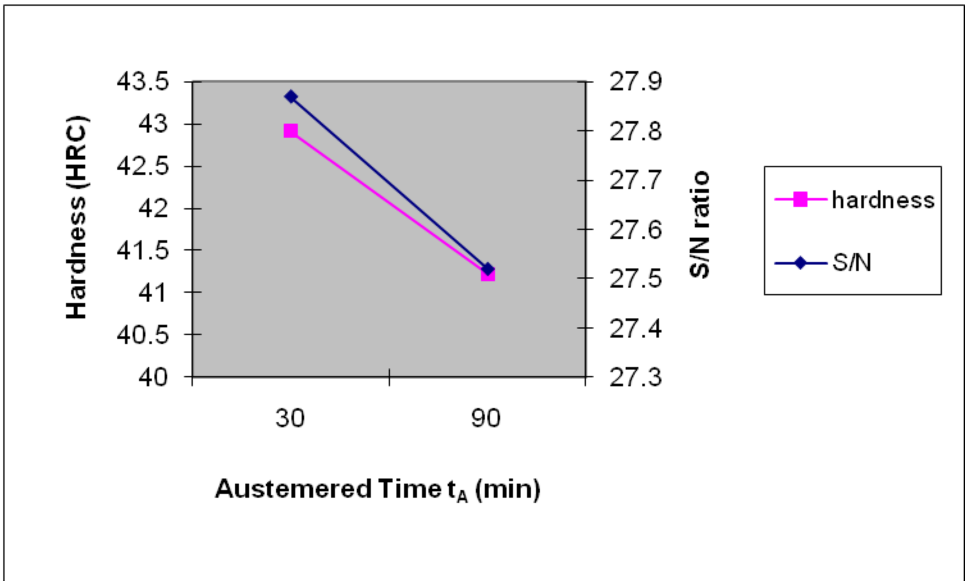

Figure 5 Variation in hardness and S/N ratio with austempered time t_A = 30 and 90 min.

Table 5 Range of hardness and S/N ratio

$t_{A(min)}$	Hardness(HRC)	S/N ratio
30	42.91	27.87
90	41.22	27.52

When time increases from 30 to 90min, then hardness decreases from 42.91 HRC to 41.22 HRC. For the optimum results for hardness, Larger-The-Better type S/N ratio is used and accordingly the maximum value of S/N ratio i.e 28.4. so the optimum range of parameters for hardness is T_y=850 °C, t_y=60 min, T_A = 280 °C and t_A = 30 min.

4. CONCLUSIONS

In this work copper alloyed ductile iron was austenitizated and austempered at 850˚ C, or 920˚ C and 280˚ C, or 350˚ C for various times and the executed hardness is measured. In all the cases higher S/N ratio shows the better results, from the experimental outcome, the following conclusions are found:

1) The hardness of ADI decreases with the increase in austenitization and austempering temperature.

2) The hardness of ADI decreases with the increase in austenitization and austempering time.

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It is concluded that the optimum range of austempered ductile iron is T_y=850 ^oC, t_y=60 min, T_A = 280 ^oC and t_A = 30 min.

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