EXPERIMENTAL STUDY OF EFFECT OF HEAT TREATMENT ON PROPERTY OF SPHEROIDAL GRAPHITE CAST IRON

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ABSTRACT

Ductile iron or popularly known as Spherodized graphite iron (SG iron) is a special variety of cast iron having carbon content more than 3% and has graphite present in compact, spherical shapes. These compact spheroids hamper the continuity of the matrix much less than graphite flakes which results in higher strength and toughness with a structure that resembles gray cast iron, thus imparting superior mechanical properties i.e. much higher than all other cast irons and which can be compared to steels. This unique property enables ductile irons to be used for numerous industrial applications.
Alloying element addition greatly affects the mechanical properties of SG iron with Si, Mn, Cu and Ni being more predominant. While copper helps increasing the tensile strength and hardness causing no embrittlement in the matrix, Ni helps enhancing the U.T.S without affecting the impact test values. Thus addition of Cu and Ni plays an important role in determining the end properties of SG iron after heat treatment.
The high ratio of performance to cost which they offer to the designer and end user makes them to be used extensively for industrial applications. However, to extend the consistency and range of properties of SG iron castings beyond its properties in as-cast condition, Heat treatment is a necessary operation. Tempering and Austempering are the two most widely used heat treatment operations in SG iron. For example a ferritic iron having 70-80% ferrite has a yield strength of 349Mpa while a similar material which is given a step quenching treatment shows a yield strength of 549-1251Mpa. Recently developed Austemperd Ductile iron (ADI) has good abrasion resistance combined with excellent ductility and toughness.

Keywords- Spherodized graphite iron (SG iron) Tempering and Austempering

1 INTRODUCTION

Spheroidal graphite (SG) cast iron was discovered in the 1948. However, if coke (which is high in sulfur) had not been used for melting iron and if high purity ores had been used, then ductile iron would have been accepted as the normal form of iron, with flake graphite iron only being discovered much later as an accident of adding S and O. This seems to have been close to the situation in China where spheroidal graphite irons were produced over 2000 years ago. The term Cast iron refers to an alloy of iron containing more than 2.0 percentage of carbon. The brittle behavior associated with the cast iron is an outdated and widely held misconception which implies all cast irons are brittle and none of them are ductile in nature. Ductile iron is one form of cast iron which is ductile and it offers the designer a unique combination of high strength, wear resistance, fatigue resistance, toughness and ductility in addition to good Castability, machinability and damping properties. Unfortunately these properties of SG iron are not widely well known because of the misconception about its brittle behavior.

Ductile iron or SG iron was discovered in 1948 at the American Foundry men Society Annual Conference. It was seen that by adding magnesium before pouring caused the graphite to form nodules rather than flakes.

This resulted in a new material, with excellent tensile strength and ductility. Adding these mechanical properties of this material to the advantages already offered by cast iron soon led to it finding its way into virtually every mainstream area of engineering, in many cases replacing existing steel castings or forgings due to achievable cost savings. It is shown that, recent process and developments open new avenues to this family of materials.

SG iron is an alloy of iron and carbon having nodules or spheroids of graphite embedded in a ferrite-pearlitic matrix. The nodules are compact spheres and are sharp and regular. The graphite occupies about 10-15% of the total material volume and because graphite has negligible tensile strength, the main effect of its presence is to reduce the effective cross-sectional area, which means that ductile iron has tensile strength, modulus of elasticity and impact strength proportionally lower than that of a carbon steel of otherwise similar matrix structure. The matrix may vary from a soft ductile ferritic structure through a hard and higher strength pearlitic structure to a hard higher and comparatively tough martensitic structure. General engineering grades of ductile iron commonly have the structures which are ferritic, ferritic/pearlitic or pearlitic. Controlled processing of the molten iron precipitates graphite as spheroids rather than flakes. The round shape of the graphite eliminates the material's tendency to crack and helps prevent cracks from spreading. The properties of SG iron are affected by elements like Si, Mn, Cu, Ni etc. Except carbon almost all the elements increase hardness and tensile strength. While except Si, all other elements promotes pearlite, except Si, Cu, Ni all other elements promote carbide formation.
Experiments have shown that heat treatment operations can improve the properties of SG iron to such an extent that it may overcome the properties shown by steels. Today austempered ductile iron is considered a bright prospect having a good combination of properties. Combining the tensile strength, ductility, fracture toughness and wear resistance of steel with production of economics of a conventional ductile iron, ADI offers the designer a great opportunity to create superior components at reduced cost.

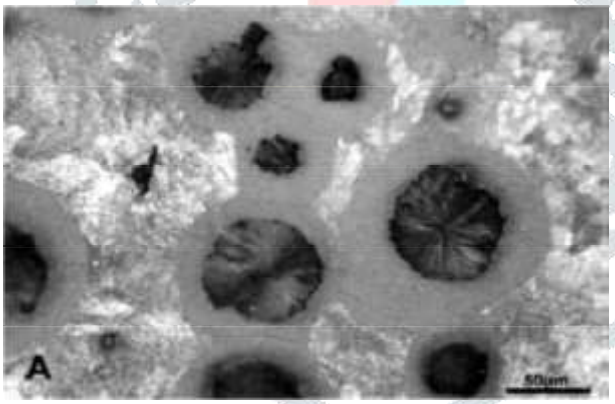


Figure 1: SG cast iron in which graphite is in spheroidal form.

1.1 Objective-

The objective of this work is to determine the mechanical properties of heat treated of spheroidal graphite cast iron. After that compare these properties with different treatment conditions, the treatment conditions are mainly Austenitising, Quenching and tempering, Austempering. Mechanical properties are:

1. Hardness,
2. Tensile strength,
3. % Elongation,

2 Literature Review

J.P. Monchoux, C. Verdu and R. Fougeres [1996], investigated the effect of ferritization heat treatment on the fracture toughness of ferritic S.G. Cast iron. Because of the high ductility of the material, $J_{0.2/BL}$ values were measured instead of K_{IC} values. The crack length was indirectly measured by compliance variations induced by the reduction of the loaded area due to the crack growth. It was found that $J_{0.2/BL}$ values increased

by ferritization heat treatment. This was explained by the disappearance of the pearlitic brittle phase. The weakening of the matrixgraphite interface after the heat treatment remains small and cannot compensate the former effect. The $J_{0.2/BL}$ values measured were found approximately constant with the Silicon content for the investigated materials.

3 Heat Treatments:

The various heat-treatments employed for our study were:

1. Austenitizing, Quench & Tempering
2. Austempering

3.1. Austenitizing, Quench & Tempering

a) Three specimens of each type were heated to austenitize at 900 Deg. C for 2 hours.
b) These austenitized specimens were quenched in an oil bath maintained at room temperature
c) These specimens were now put inside the furnace maintained at 600 Deg. C and then were taken out of the furnace one by one for air-cooling after duration of 30min, 1hr 30min & 2hrs.

3.2. Austempering

a) Six specimen of each type were heated to austenitize at 900 Deg. C for 2 hours.
b) Three specimens of each type were then immediately transferred to the salt bath, which was prepared by taking 50% $NaNO_3$ and 50% KNO_3 salt mixture, maintained at 300 Deg. C.
c) The remaining three specimen of each type were transferred to the other salt bath of same composition maintained at 350 Deg. C.
d) One by one specimen of each type in pairs was taken out of the salt baths at 300 Deg. C & 350 Deg. C. after a duration 1hr 15min, 2hr, 2hr 30min.

3.3. Study of Mechanical Properties

3.3.1 Hardness Testing -The method utilized for hardness testing was Rockwell Hardness Testing. In this process

1. The specimen was put on the specimen holder
2. The minor load of 10kg was applied by rotating the axle
3. When the reading on the display became zero the rotating was stopped and final loading was applied by pressing the loading button.
4. The scale used was A-scale.

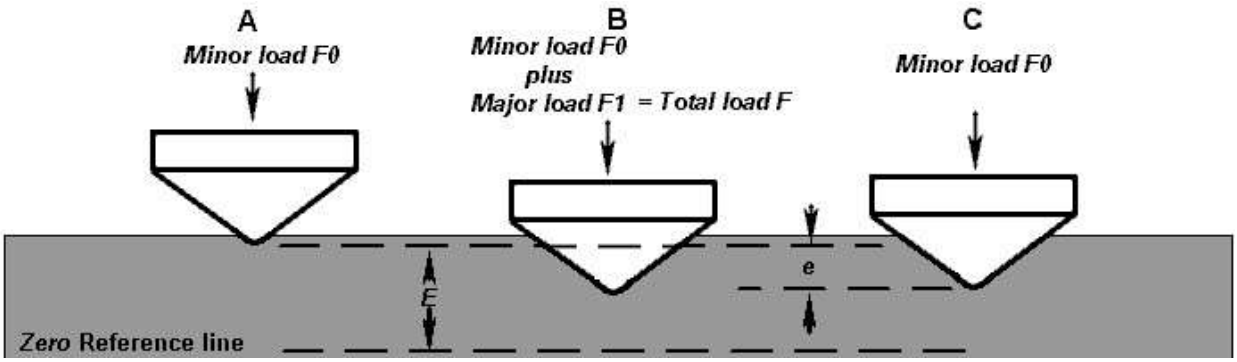


Figure 3.5: **Rockwell Principle**

3.3.2 Tensile Testing

ASTM A536 method (EN1563) was employed for tensile testing. The machine used was Instron Universal Testing Machine Model 1195. The specimen prepared in the specimen preparation stage was made according to ASTM A536 specification and hence was directly used.

1. The process is as followed:
2. The specimen's dimensions (thickness/gauge length/total length in mm etc) were measured accurately with an electronic slide calipers
3. The details were fed into the testing machine
4. The distance between the jaws was fixed according to the gauge length of the specimen
5. The specimen was inserted into the machine and gripped by the jaws.
6. Maximum load was set to 148KN and loading was done till the specimen failed.
7. The corresponding readings generated for Yield Strength, %elongation Ultimate.

4 RESULTS & DISCUSSIONS

4.1 HARDNESS TESTING RESULTS

Table 4.1: Rockwell Hardness (A-Scale) of various heat treated S.G. Cast Iron Specimens

Specimen Specification	Specimen	Time	Hardness (R_A)
As Received	A	--	43
	B	--	44
Quenched from 900 and tempered at 600 degree Celsius	A	30min	61
		1hr	58
		2hr	57
	B	30min	62
		1hr	59
		2hr	58
	A	1hr15min	66
		2hr	64

Austempered at 300 degree Celsius		2hr30min	63
	B	1hr15min	62
		2hr	67
		2hr30min	68
Austempered at 350 degree Celsius	A	1hr 15min	49
		2hr	52
		2hr 30min	53
	B	1hr 15min	48
		2hr	51
		2hr 30min	49

4.2 Tensile Testing

Table 4.2: Tensile Properties of various heat treated S.G. Cast Iron Specimens

Specimen Specification	Specimen	Time	UTS (in MPa)	Yield Strength (in MPa)	Elongation %
As Received	A	--	371	288	21
	B	--	566	214	7
Quenched from 900 deg C and tempered at 600 degree Celsius	A	30min	375	289	23
		1hr	371	294	25.8
		2hr	368	286	26.9
	B	30min	578	225	9.7
		1hr	569	222	10.9
		2hr	567	216	12
Austempered at 300 degree Celsius	A	1hr15min	512	304	22
		2hr	522	311	23.8
		2hr30min	522	323	22.6
	B	1hr15min	828	244	8
		2hr	843	255	8.9
		2hr30min	840	267	9.5
Austempered at 350 degree Celsius	A	1hr 15min	449	338	26
		2hr	453	342	27
		2hr 30min	464	363	25.2
	B	1hr 15min	692	274	11
		2hr	704	286	11.8
		2hr 30min	694	295	10.9

4.3 IMPACT TESTING:

Table 4.3: Impact Properties of various heat treated S.G. Cast Iron Specimens

Specimen Specification	Specimen	Time	Charpy Impact (J)
As Received	A	--	16.85
	B	--	7.43
Quenched from 900 and tempered at 600 degree Celsius	A	30min	15.59
		1hr	14.94
		2hr	13.87
	B	30min	6.42
		1hr	5.89
		2hr	4.57
Austempered at 300 degree Celsius	A	1hr 15min	12.88
		2hr	11.65
		2hr 30min	10.65
	B	1hr 15min	4.65
		2hr	3.65
		2hr 30min	3.65
Austempered at 350 degree Celsius	A	1hr 15min	9.65
		2hr	8.66
		2hr 30min	6.66
	B	1hr 15min	2.8
		2hr	2.66
		2hr 30min	2.66

4.4 PLOTS & DISCUSSIONS:

a) Hardness Testing:

According to the results obtained the following tabulation and graphs have been plotted for various heat-treatments conducted:

Table 4.4: Hardness Testing Tabulation for as-Cast & Heat-treated Specimens for type A

Specimen A	Hardness (R_A)
As Cast Sample	47
Austenitizing, Quenchigng & Tempering at 600 Deg. C for 2hrs	58
Austempering at 300 Deg. C. for 2hr	67

Austempering at 350 Deg. C for 2hr	52

Table 4.5: Hardness Testing Tabulation for as-Cast & Heat-treated Specimen for type B

Specimen B	Hardness (R_A)
As Cast Sample	46
Austenitizing, Quenchigng & Tempering at 600 Deg. C for 2hrs	57
Austempering at 300 Deg. C. for 2hr	65
Austempering at 350 Deg. C for 2hr	53

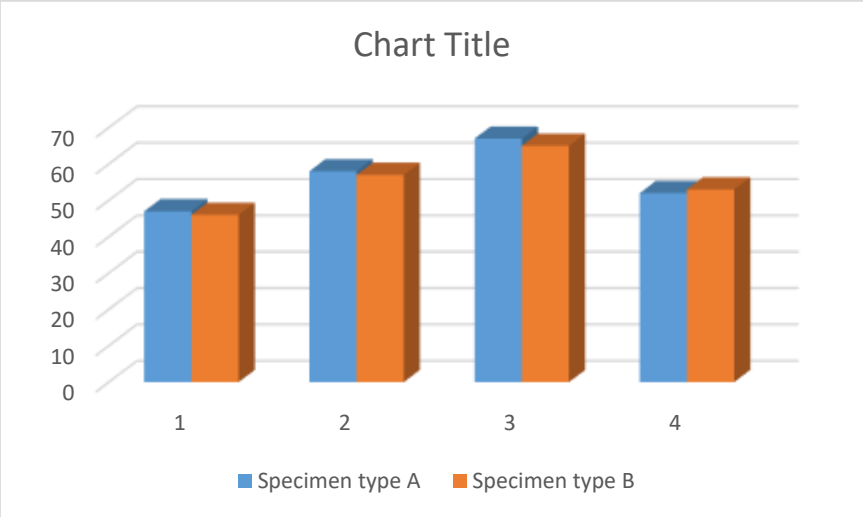


Figure 4.1: Hardness variation with heat treatment for different specimen types

OBSERVATION 1:

It can be observed from the hardness data obtained that when tempering time was increased from 30 minutes to 2 hours hardness values decreased. This was same for both samples having Copper and Nickel respectively.

INFERENCE 1:

As tempering time increases hardness decreases and softness is induced in the quenched specimen.

OBSERVATION 2:

It has been observed that as the Austempering temperature increases hardness value decreases. As the Austempering temperature increases from 300^0C to 350^0C the hardness values decreases for the time intervals of 1 hour, 2 hour and 2.30 hours. However, the hardness values increases as the Austempering time is increased from 1hour 15 minutes to 2hours 30 minutes.

INFERENCE 2:

It is quite clear from the hardness data that as the Austempering time increased, hardness value increases due the presence of ferrite and high carbon austenite. As temperature increases this high carbon austenite

decomposes to ferrite and cementite thus decreasing the hardness. Hence with increase in Austempering temperature, hardness decreases. We can clearly see that in case of Austempering hardness is maximum at 2hour and 30minutes. Hardness value is lowest at 1hour 30minutes time.

Note: Among all the heat treatment operations we have the highest hardness in case of

Austempering at 300^0C followed by tempering at 600^0C and then Austempering at 350^0C

4.5 Tensile Testing:

4.5.1 Tempering:

Table 4.6 Tensile Testing Tabulation for Specimens tempered at 600 Deg. C

Specimen	Time	UTS (in MPa)	Yield Strength (in MPa)	Ductility (%)
A	30min	375	289	23
	1hr	371	294	25.8
	2hr	368	286	26.9
B	30min	578	225	9.7
	1hr	569	222	10.9
	2hr	567	216	12

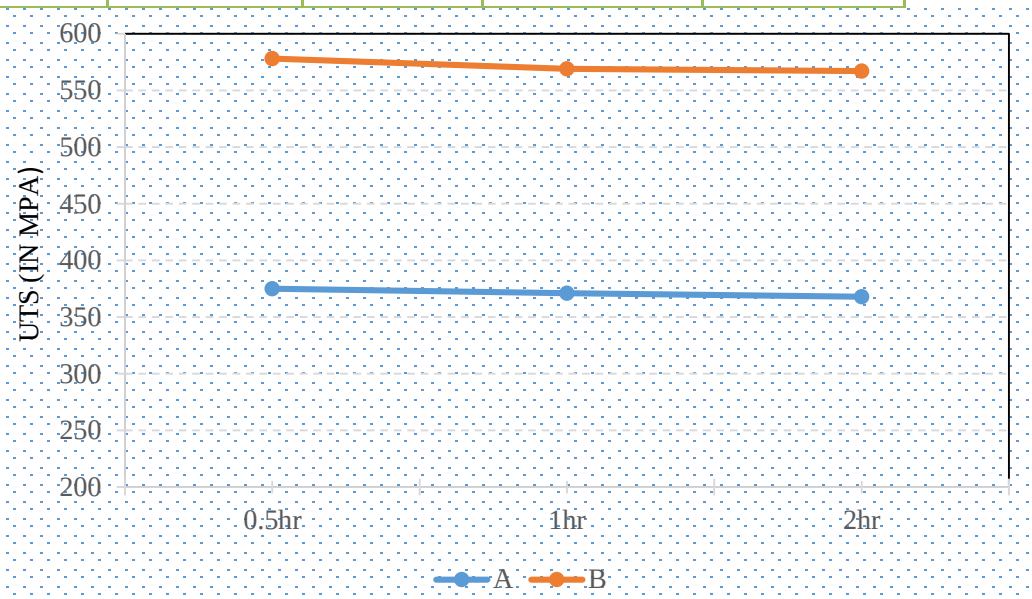


Figure 4.2: UTS vs Time plot for Tempering

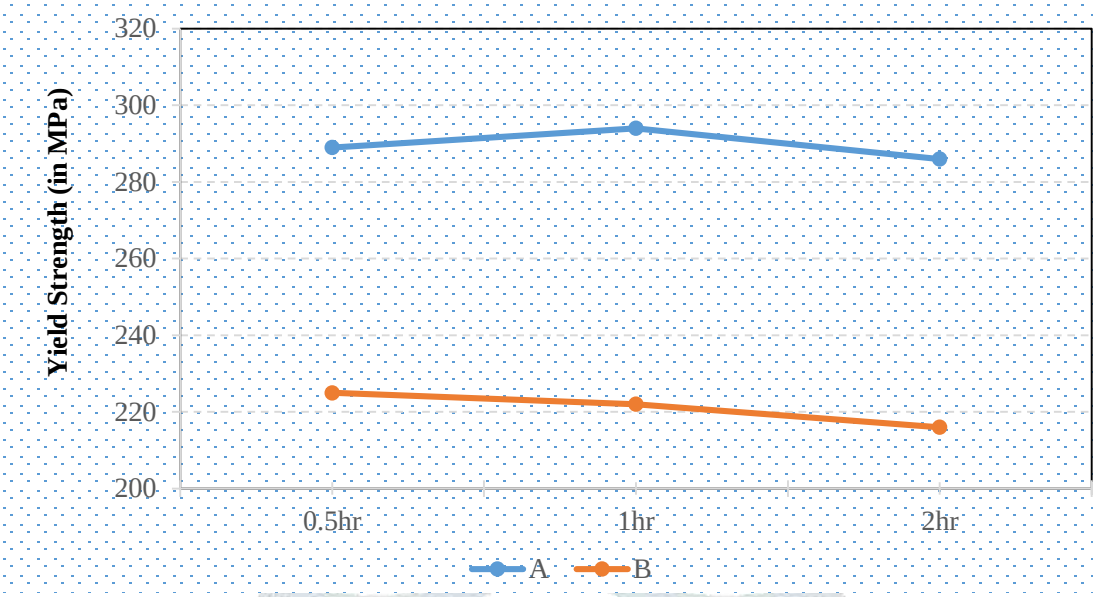
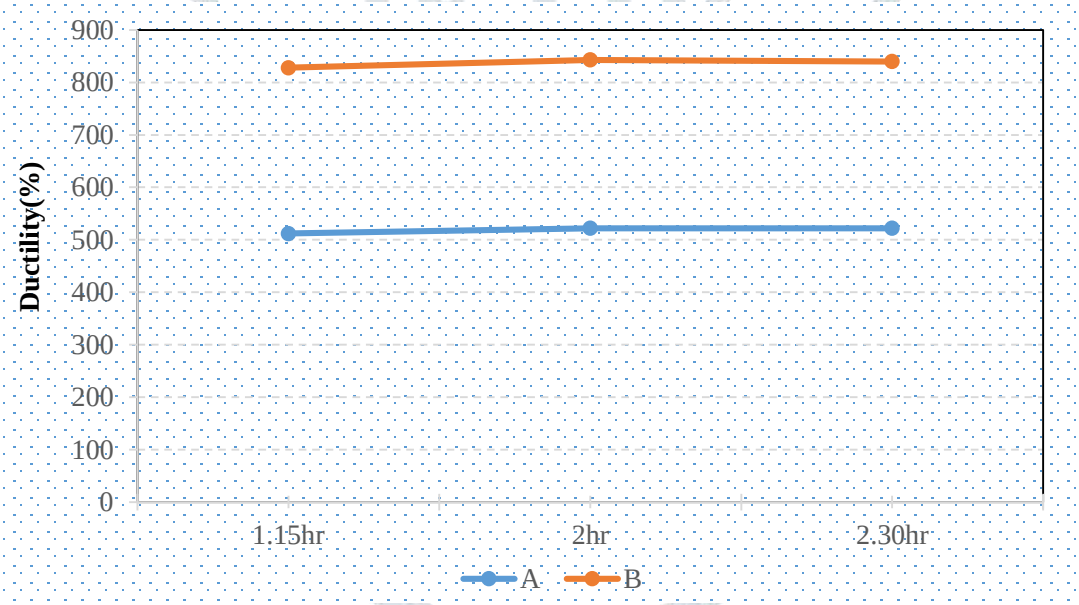


Figure 4.3: Yield strength vs Time plot for Tempering



OBSERVATION 3:

It has been observed from the graphs that with tempering temperature remaining constant, as we increase the tempering time both UTS decreases gradually while yield strength first increases, then decreases. It was observed that with increase in tempering time ductility increases clearly showing tempering effect.

INFERENCE 3:

As the tempering time is increased UTS decreases gradually while yield strength shows an abnormal behavior. Yield strength first increases, then decreases as time is increased further. This may be due the formation of lower and upper banite. As time increases the high carbon austenite decomposes into carbide and ferrite. Carbide is detrimental to mechanical properties of the material. Thus UTS and yield strength decreases.

4.5.2 Austempering at 300 Deg. C.

Table 4.7: Tensile Testing Tabulation for Specimens austempered at 300 Deg. C

Specimen	Time	UTS (in MPa)	Yield Strength (in MPa)	Ductility (%)
A	1hr15min	512	304	22
	2hr	522	311	23.8
	2hr30min	522	323	22.6
B	1hr15min	828	244	8
	2hr	843	255	8.9
	2hr30min	840	267	9.5

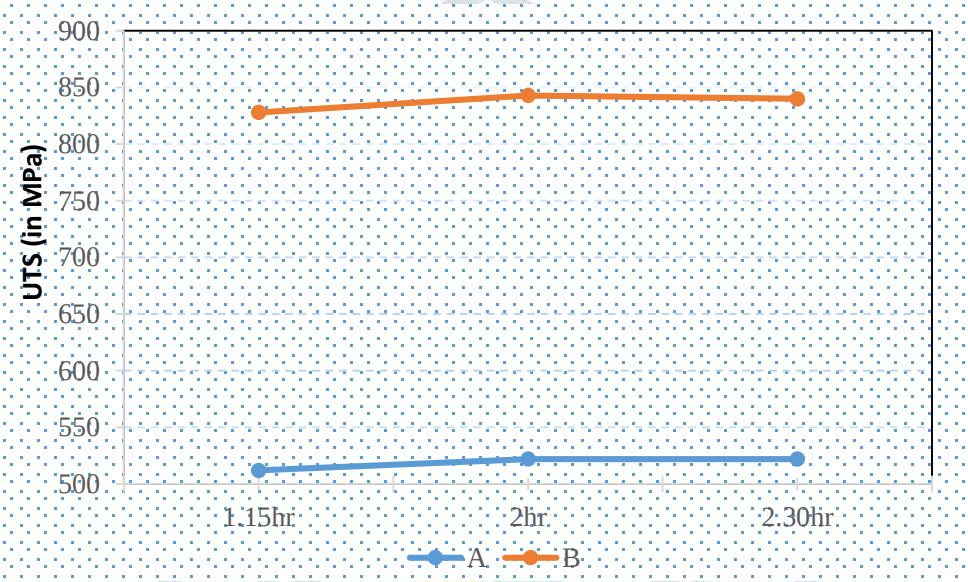


Figure 6.5: UTS vs Time plot for Austempering at 300deg C

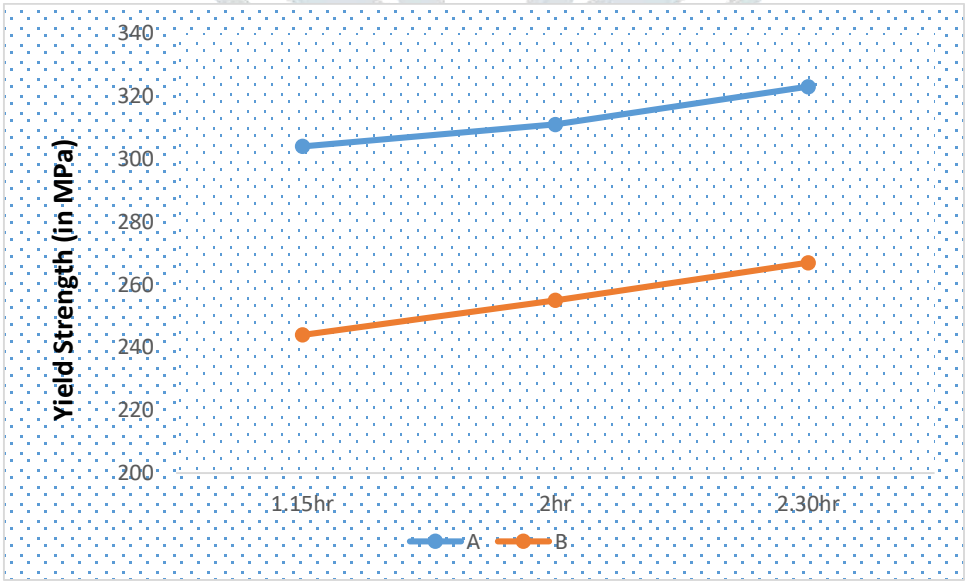


Figure 4.6: Yield strength vs Time plot for Austempering at 300deg C

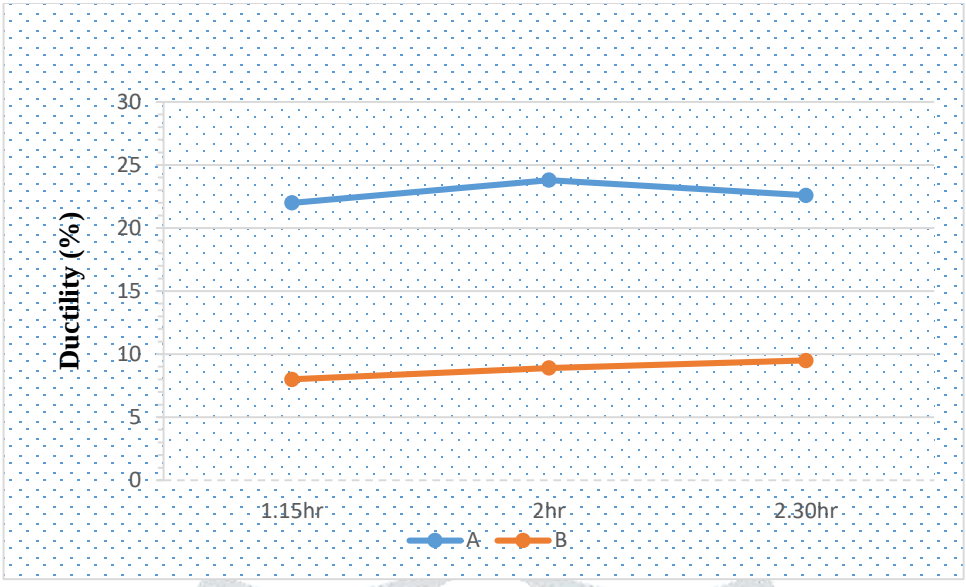


Figure 4.7: Ductility vs Time plot for Austempering at 300 deg C

4.5.3 Austempering at 350 Deg. C.

Table 4.8: Tensile Testing Tabulation for Specimens austempered at 350 Deg. C

Specimen	Time	UTS (in MPa)	Yield Strength (in MPa)	Ductility (%)
A	1hr 15min	449	338	26
	2hr	453	342	27
	2hr 30min	464	363	25.2
B	1hr 15min	692	274	11
	2hr	704	286	11.8
	2hr 30min	694	295	10.9

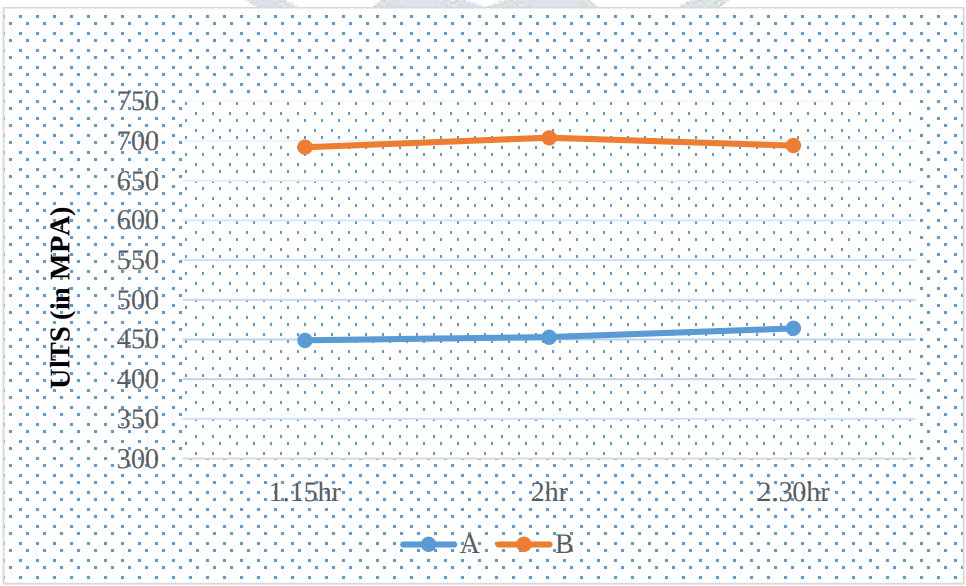


Figure 6.8: UTS vs Time plot for Austempering at 300 deg C

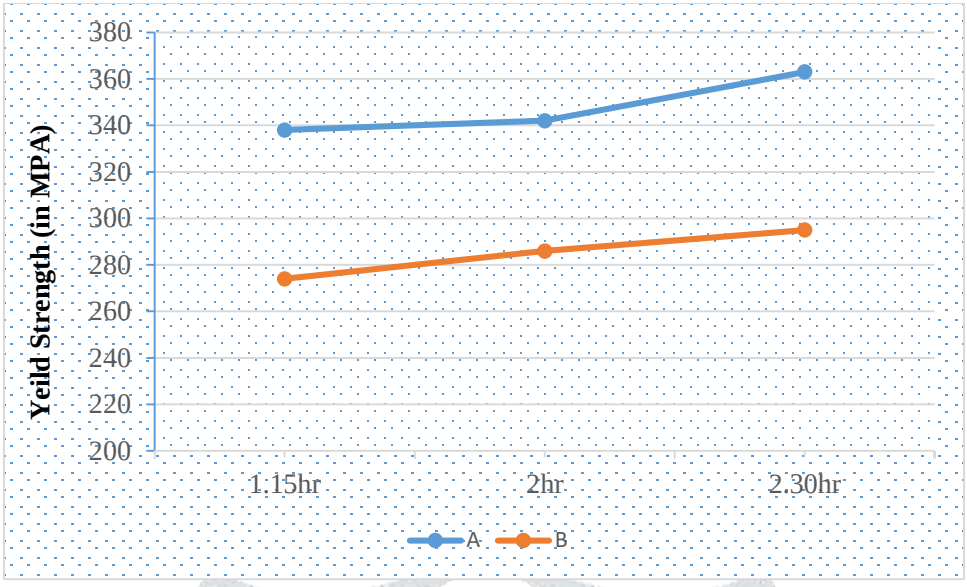


Figure 4.9: Yield strength vs Time plot for Austempering at 350deg C

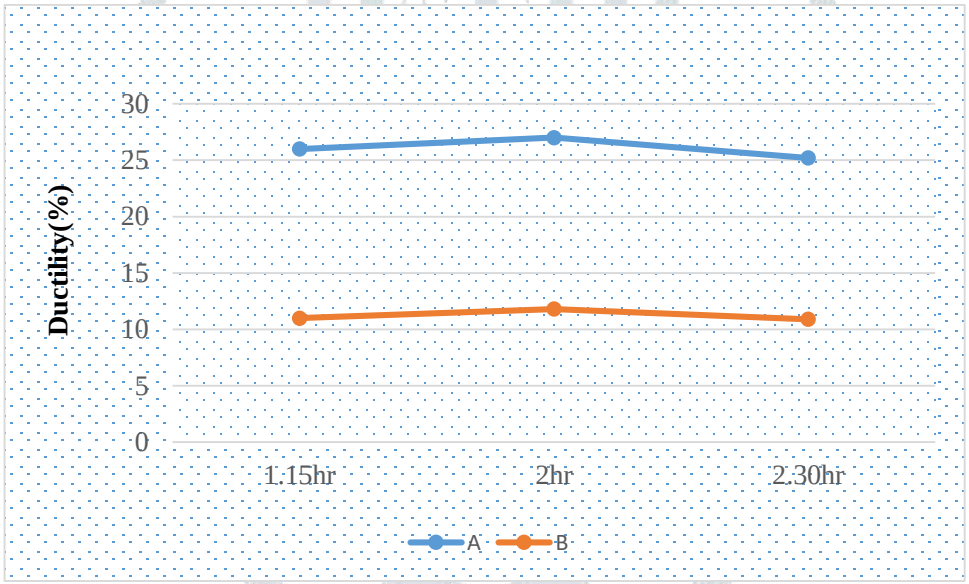


Figure 4.10: Ductility vs Time plot for Austempering at 350deg C

4.6 Mechanical Properties for Specimen A(C: 3.62%, Si: 2.14%, Mn: 0.18%, S: 0.009%, P: 0.026%, Cr: 0.029%, Ni: 0.72%, Cu: 0.02%):

Table 4.9: Tensile Testing Tabulation for as-Cast & Heat-treated Specimens for type A

Specimen A	Time	UTS (in MPa)	Yield Strength (in MPa)	Ductility (%)
As-Cast Sample	---	371	288	21
Austenitizing, Quenchigng & Tempering at 600 Deg. C	2hr	368	286	26.9

Austempering 300 Deg. C	2hr	522	311	23.8
Austempering at 350 Deg. C	2hr	453	342	27

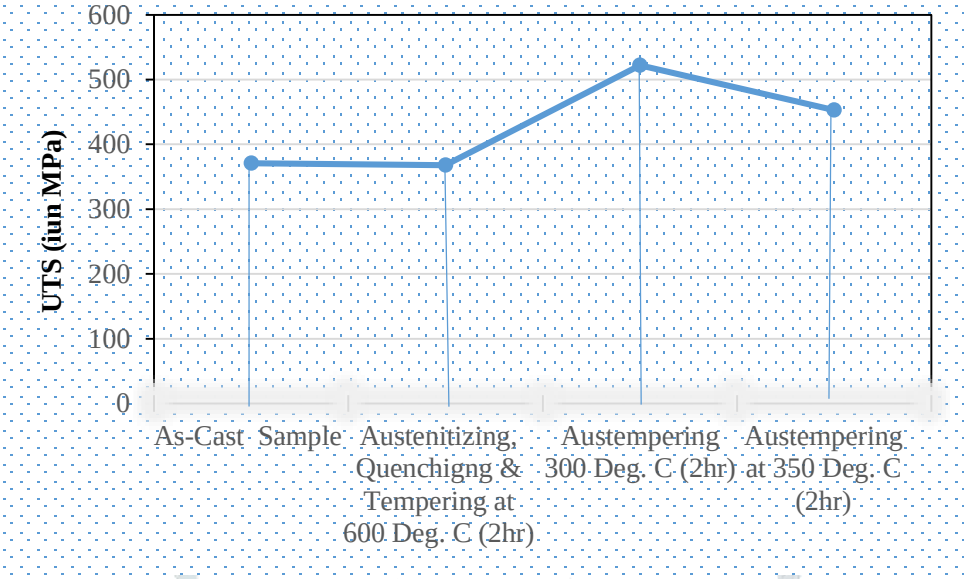


Figure 4.11: UTS vs Heat treatment plot for specimen A

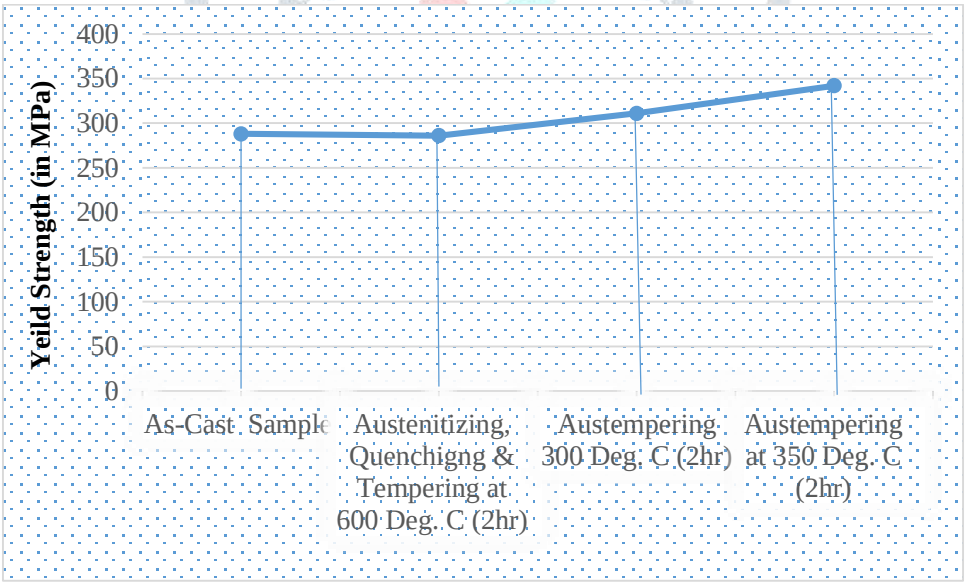


Figure 4.12: Yield Strength vs Heat treatment plot for specimen A

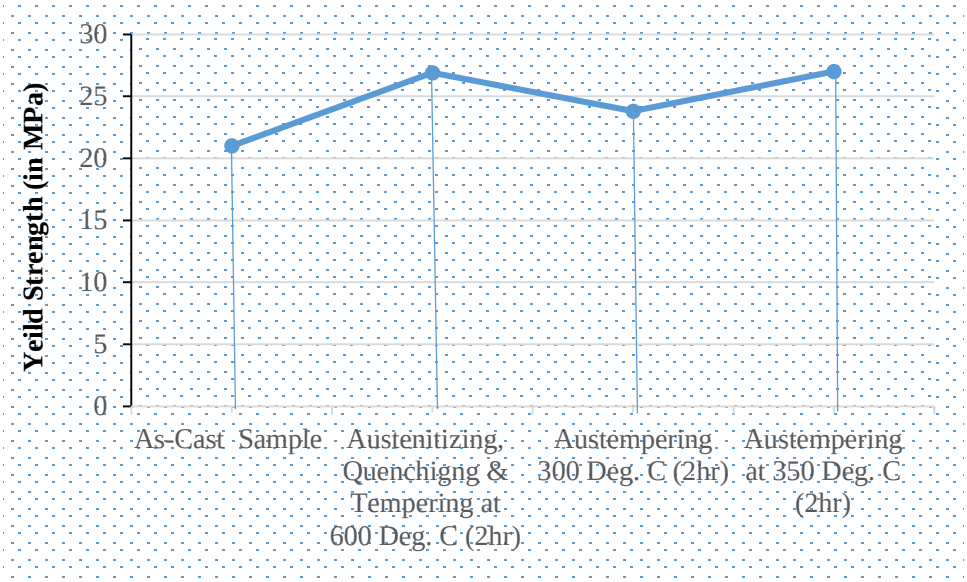


Figure 4.13: Ductility vs Heat treatment plot for specimen A

4.7 Mechanical Properties for Specimen B(C: 3.58%, Si: 2.08%, Mn: 0.2%, S: 0.042%, P: 0.024%, Cr: 0.03%, Ni: 0.1%, Cu: 0.43%):

Table 4.10: Tensile Testing Tabulation for as-Cast & Heat-treated Specimens for type B

Specimen B	Time	UTS (in MPa)	Yield Strength (in MPa)	Ductility (%)
As Cast Sample	--	566	214	7
Austenitizing, Quenchigng & Tempering at 600 Deg. C	2hr	567	216	12
Austempering at 300 Deg. C.	2hr	843	255	8.9
Austempering at 350 Deg. C	2hr	704	286	10.9

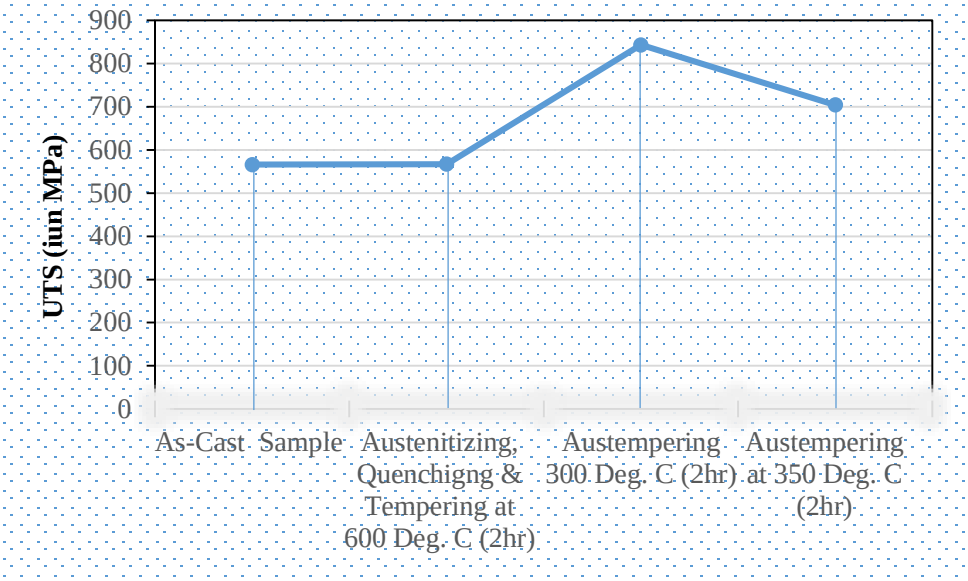


Figure 4.14: UTS vs Heat treatment plot for specimen B

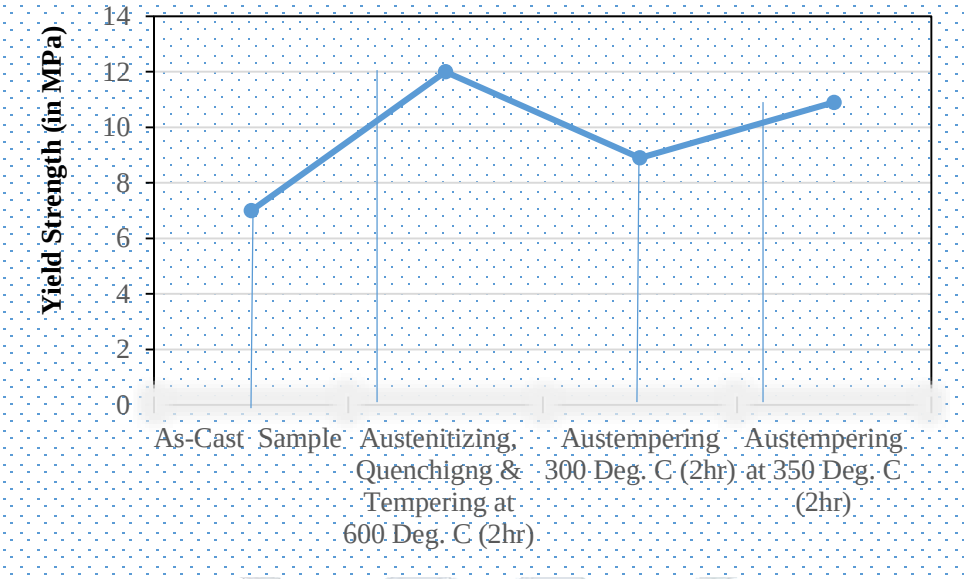


Figure 4.15: Yield Strength vs Heat treatment plot for specimen B

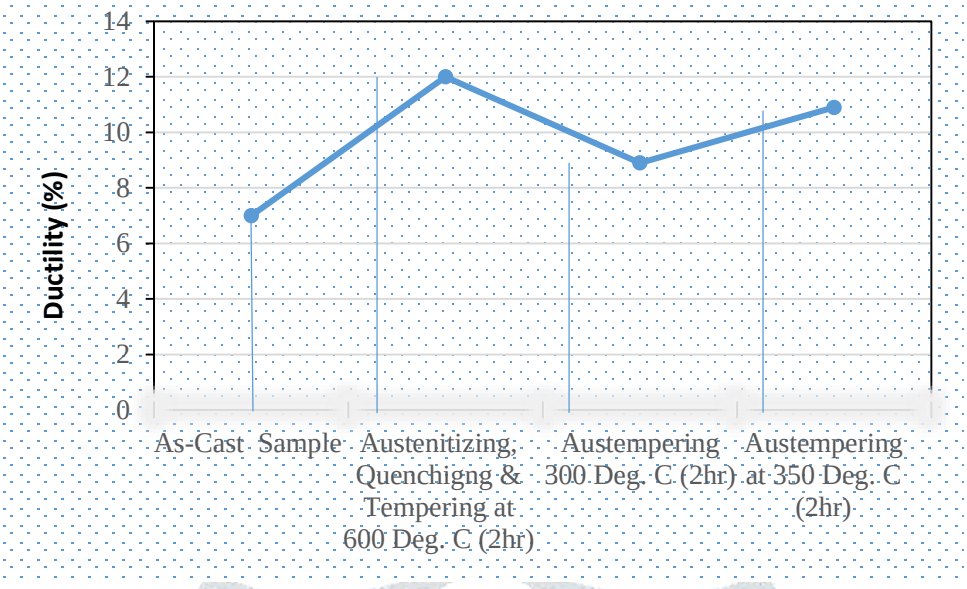


Figure 4.16: Ductility vs Heat treatment plot for specimen B

OBSERVATION 4:

From the tabulations we can clearly see that, as we increase the Austempering temperature from 300 to 350^{0}C there is a gradual decrease in UTS values. The yield strength though increases with temperature. Ductility first increases then decreases when Austempering time is increased. It increases when Austempering temperature is increased.

INFERENCE 4:

UTS decreases as Austempering temperature increases while it first increases then decreases when time is increased. Yield strength first increases and then decreases with increase in time while it increases as the Austempering temperature is increased. Ductility increases with increase in Austempering temperature and shows an abnormal behavior with increase in Austempering time.

4.8 IMPACT TESTING:

OBSERVATION 5:

From the tabulations it is clear that the impact values decrease slightly with increase in tempering time from 30minutes to 2hours. In case of austempering impact values also decrease slightly when the temperature is changed from 300^{0}C to 350^0.

INFERENCE 5:

Hence it can be inferred that as the time is increased from 30minutes to 2 hours for tempering (at 600^{0}C) & from 1hour 15minutes to 2hour 30minutes for austempering (at 300^{0}C and 350^{0}C) process the impact values decreases slightly. Hence Heat treatment processes like austempering & tempering though enhance mechanical properties but lead to decrease in impact values.

5 CONCLUSION

From the results obtained it can be concluded that the properties of Spheroidal Graphite Cast Iron can be enhanced & altered according to service condition & application requirement. Earlier limitations on the usage

of ductile iron due to limited knowledge of property enhancement processes can now be overcome by various heat treatment operations. It has been found that by heat-operations like tempering & austempering, their brittle behavior can be transformed to ductile behavior applicable in various applications. These heat-treatment processes produce properties comparable to steels at a very low cost. Tempering significantly increases ductility, also applications where higher hardness is desired low temperature tempering operation can be applied but that will hamper the strength requirements. But comparing all the heat treatment processes austempering gives the best combination of yield strength, UTS & % elongation as well as hardness. Hence it can be considered to be the best possible heat treatment operation that can be applied to ductile iron.

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