OPTIMIZATION OF HEAT TREATMENT PROCESS FOR 16MnCr5

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***Abstract*: -** The requirement of mechanical properties of the material depends on the application of the material. As the alloying elements have tendency to change the mechanical properties of the material, but an alternative can also be used to change the mechanical properties by heat treatment process after keeping a fixed alloying element and this will serve great reduction of cost paying for alloying element. By experiment it is found that heat treatment process on the alloy steel can change the mechanical properties of the material without the variation of alloying element in iron. As heat treatment is the variation of temperature and time, this variation can set optimum values of mechanical properties, so it becomes necessary to select a suitable heat treatment out of available number of processes so that desired mechanical properties can be maintained for required application. In this paper a comparative statement has been made for obtaining maximum yield strength and hardness for a highly stressed environment parts and optimum value has been selected for 16MnCr5 material with number of heat treatment processes. Consequently it is found that austempering; a heat treatment process gives the maximum value of hardness, UTS and yield strength with other excellent mechanical properties.

Keywords: Heat treatment, Micro hardness, Austempering Phase transformation.

1. INTODUCTION

Heat treatment is process of heating and cooling of material. It is possible to obtain the desirable mechanical properties for steel or alloys by heat treatment. In heat treatment temperature variation with time is basic parameter to alter mechanical property of the component. If this variation is proper so that phase transformation is according to part application requirement, because the basic requirement of mechanical properties is different for different environment. In this paper a grade of alloy steel 16MnCr5 has been taken for experiment purpose in highly stressed application and number of heat treatment processes has been carried out to carry out a right heat treatment process, which impart the optimum value of mechanical properties. In these heat treatment processes a variation is made over temperature and time and optimum value has been selected by Taguchi technique. General description of heat treatment processes is given below to understand their function.

The most important heat treatments and their purposes are:

Stress relieving - a low-temperature treatment, to reduce or relieve Internal stresses remaining after casting.
Annealing - to improve ductility and toughness, to reduce hardness and to remove carbides.

Normalizing - to improve strength with some ductility.

Hardening and tempering - to increase hardness or to give improved Strength and higher proof stress ratio.

Austempering - to yield bainitic structures of high strength, with significant ductility and good wear resistance.

Surface hardening - by induction, flame, or laser to produce a local wear resistant hard surface.

2. LITERATURE REVIEW

In heat treatment area number of researcher contributed lot for attaining the desired mechanical properties for particular application of the product, since here few of researchers view toward heat treatment is given as:

Kuma and Gupta (1990) studied the abrasive wear behaviour of mild, medium carbon, leaf and high carbon, low Cr. Steel by means of a dry stand rubber wheel abrasion apparatus. They found that the heat treated high carbon low Cr. Steel and mild steel carburized by their own technique to be the best abrasion resistance materials. The abrasive wear resistance values of the two materials wear found to be very much comparable with each other.

Lancaster (1989) has suggested that graphite crystallite are embedded into the surface valley aspirates and acts as nuclei as a for lubrication film building and thus reduced the effectiveness of abrasive wear of aspirates physically.

Stevenson and hutchengs (1994) have reported that sinter particles wear cause to ease gross fracture of the carbide and so those materials with a high volume fraction of carbide shared the greatest resistance to erosive wear.

After this literature review there is still need of selecting a proper heat treatment process for a particular application.

3. EXPERIMENTAL SETUP

The samples of 300 mm × 20 mm × 20 mm was prepared and subjected to solid solution heat treatment processes with chemical composition and its physical properties are given as

Elements	**Min. (WT %)**	**Max. (WT %)**
C	0.14	0.40
Si	-	0.19
Mn	1	1.30
P	-	0.035
S	0.020	0.035
Cr	0.80	1.10

Table 1: Chemical Composition for 16MnCr5

16MnCr5		
Chemical Composition: C = 0.40%, Mn = 0.8%, Cr = 0.8%		
Property	Value in metric unit	
Density	7.872×10^3	kg/m³
Modulus of elasticity	205	GPa
Thermal expansion (20 ºC)	12.6×10^{-6}	ºC⁻¹
Specific heat capacity	452	J/(kg-K)
Thermal conductivity	44.7	W/(m-K)
Electric resistivity	2.28×10^{-7}	Ohm-m

Table 2: Properties of 16MnCr5

3.1. ANNEALING

a) The specimen was heated up to a temperature of 950 ^{o}C.

b) At temperature 950 ^{o}C the specimen was held for 2 hour.

c) Then the furnace was switched off so that the specimen temperature will decrease with the same rate as that of the furnace the objective of keeping the specimen at 950 ^{o}C for 2 hrs is to homogenize the specimen. The temperature 950 ^{o}C lies above Ac1 temperature. So that the specimen at that temperature gets sufficient time to get properly homogenized .The specimen was taken out of the furnace after 1 day when the furnace temperature had already reached the room temperature.

3.2. NORMALIZING

a) At the very beginning the specimen was heated to the temperature of 950 ^{o}C.

b) There the specimen was again kept for 2 hour.

c) Then the furnace was switched off and the specimen was taken out.

d) Now the specimen is allowed to cool in the ordinary environment i.e. the specimen is air cooled to room temperature. The process of air cooling of specimen heated above Ac1 is called normalizing.

3.3. QUENCHING

This experiment was performed to harden the 16MnCr5. The process involved putting the red hot specimen directly in to a liquid medium.

a) The specimen was heated to the temp of around 950 ^{o}C and was allowed to homogenize at that temp for 2 hour.

b) An oil bath was maintained at a constant temperature in which the specimen had to be put.

c) After 2 hour the specimen was taken out of the furnace and directly quenched in the oil bath.

d) After around half an hour the specimen was taken out of the bath and cleaned properly.

c) Now the specimen attains the liquid bath temp within few minutes. But the rate of cooling is very fast because the liquid doesn’t release heat readily.

3.4. TEMPERING

Tempering is the one of the important experiment carried out with the objective of the experiment being to induce some amount of softness in the material by heating to a moderate temperature range.

a) Firstly four specimens were heated to 950 ^{o}C for 2 hour and one of them is quenched in the oil bath maintained at room temp.

b) Secondly remaining three specimens were heated to 250 ^{o}C. But for different time period of 1 hour, 1and half hour and 2 hour respectively.

c) Now again three specimens were heated to 950 ^{o}C and after quenching in the oil bath then again heating to 450 ^{o}C and for the time period of 1 hour, 1and a half hour and 2 hour respectively.

d) Now again three specimens were heated to 950 ^{o}C and after quenching in the oil bath then again to 650 ^{o}C for same time interval of 1 hour. 1 and half and 2 hours respectively.

After the specimens got heated to a particular temperature for a particular time period, they were air cooled. The heat treatment of tempering at different temp for different time periods develops variety of properties within them.

3.5. AUSTEMPERING

This is the most important experiment carried out for this work. The objective was to develop all round property in the material.

a) The specimen was heated to the temperature of 950 ^{o}C. and sufficient time was allowed at that temperature, so that the specimen got properly homogenized.
b) A salt bath was prepared by taking 50% NaNO3 and 50 % KNO_3 salt mixture. The objective behind using NaNO3 and KNO_3 is though the individual melting points are high the mixture of them in the bath with 1:1 properties from an eutectic mixture this eutectic reaction brings down the melting point of the mixture to

290 ^{o}C. The salt remains in the liquid state in the temp range of 290-550 ^{o}C whereas the salt bath needed for the experiment should be at molten state at 350 ^{o}C.

c) After the specimen getting properly homogenized it was taken out of the furnace and put in another furnace where the container with the salt mixture was kept at 350 ^{o}C.

d) At that temp of 350 ^{o}C the specimen was held for 2 hrs in this time the austenite gets converted to bainite. The objective behind choosing the temperature of 350 ^{o}C is that at this temperature will give upper bainite which has fine grains so that the properties developed in the materials are excellent.

e) An oil bath also maintained so that the specimen can be quenched.

f) So after sufficient time of 2 hr the salt bath was taken out of the furnace and the specimen were quenched in the oil bath.

g) An oil bath is also maintained so that specimen can be quenched. Now the specimens of each heat treatment are ready at room temperature. But during quenching in a salt bath, or oil bath or cooling due to slight oxidation of the surface of cast iron, there are every possibility of scale formation on this surface if the specimens are sent for testing with the scales in the surface then the hardness value will vary and the specimen will also not be gripped properly in the UTS. To avoid these difficulties the specimens were ground with the help of belt grinder to remove the scales from the surface. After the scale removal the Specimens are ready for the further experimentations.

4. STUDY OF MECHANICAL PROPERTIES

As the objective of the project is to compare the mechanical properties of various heat treated cast iron specimens, now the specimens were sent to hardness testing and tensile testing.

4.1. HARDNESS TESTING

The heat treated specimens hardness was measured by means of Rockwell hardness tester. The procedure adopted can be listed as follows:

1. First the brale indenter was inserted in the machine; the load is adjusted to100kg.

2. The minor load of a 10 kg was first applied to seat of the specimen.

3. Now the major load applied and the depth of indentation is automatically recorded on a dial gage in terms of arbitrary hardness numbers. The dial contains 100 divisions. Each division corresponds to a penetration of .002 mm. The dial is reversed so that a high hardness, which results in small penetration, results in a high hardness number. The hardness value thus obtained was converted into C scale by using the standard converter chart.

4.2. ULTIMATE TENSILE STRENGTH TESTING

The heat treated specimens were treated in UTS Machine for obtaining the % elongation, Ultimate Tensile Strength, yield Strength. The procedures for obtaining these values can be listed as follows:

a) At first the cross section area of the specimen was measured by means of an electronic slide calliper and then the gauge length was calculated.

b) Now the distance between the jaws of the UTS was fixed to the gauge length of the specimen.

c) The specimen was gripped by the jaws of the holder.

d) The maximum load was set at 150 KN.

e) The specimen was loaded till it fails.

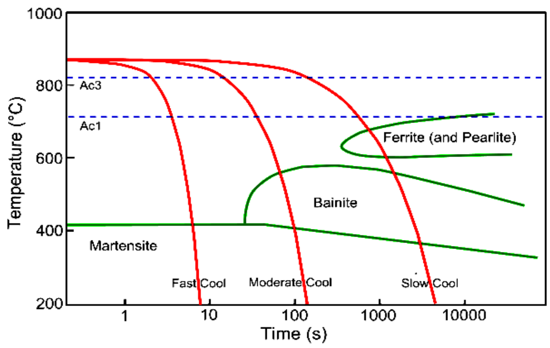
f) The corresponding Load vs. Displacement diagrams were plotted by using the software. From the data obtained the % elongation, yield strength and ultimate tensile strength were calculated by using the following formulae:-

% elongation = (change in gauge length of specimen/initial gauge length of the specimen.) ×100

Yield strength = load at 0.2% offset yield/ initial cross section area
Ultimate tensile strength = maximum load/ initial cross section area

5. PHASE TRANSFORMATION

In austempering the heat treat load is quenched to a temperature which is typically above the Martensite start of the austenite and held. In some patented processes the parts are quenched just below the Martensite start so that the resulting microstructure is a controlled mixture of Martensite and Bainite.



Fig, 1 Phase transformation in Austempering Process

The Martensite and Bainite microstructure of the specimen is given below which has been observed by microscope.

Fig. 2 Martensite Microstructure

Fig.3 Bainite Microstructure

6. RESULTS

From experimental setup following results are obtained from hardness testing and ultimate tensile strength testing is given as:

6.1. HARDNESS TESTING

Table 3 below shows the values of hardness for the specimen at different tempering temperature i.e. 250°C, 450°C and 650°and found that specimen has highest hardness at tempering temperature 250°C for the time period of 1hrs.

Specimen Specification	Time	Hardness
Quenched From 900 And Tempered At 250 Degree Celsius	1 Hour	46
	1 ½ Hour	42
	2 Hour	35
Quenched From 900 And Tempered At 450 Degree Celsius	1 Hour	38
	1 ½ Hour	34
	2 Hour	28
Quenched From 900 And Tempered At 650 Degree Celsius	1 Hour	32
	1 ½ Hour	27
	2 Hour	25

Table 3: Hardness of 16MnCr5 for different tempering temperature

Table 4 below shows the values of ultimate tensile strength (UTS) and values of yield strength for the specimen at different tempering temperature i.e. 250°C, 450°C and 650°C and found that specimen exhibit highest ultimate tensile strength at 250°C for the time period of 1 hrs and maximum value of yield strength at 250°C for the time period of 2 hrs.

Specimen Specification	Time (hrs)	UTS (MPa)	Yield Strength (MPa)	Elongation (%)
Quenched from 900 and tempered at 250 degree centigrade	1	550	337	9.453
	1 ½	542	334	12.167
	2	413	268	21.722
Quenched from 900 and tempered at 450 degree centigrade	1	498	298	14.675
	1 ½	316	286	18.446
	2	384	252	27.64
Quenched from 900 and tempered at 650 degree centigrade	1	322	234	21.456
	1 ½	486	240	24.747
	2	256	201	26.842

Table 4: UTS & Yield strength of 16MnCr5 for different tempering temperature

Treatment	U.T.S (MPa)	0.2% Y.S (MPa)	% Elongation	Hardness (RA)
Annealed at 900°C	242.7	205.3	18.1	45
Normalized at 900°C	464	219	8.85	48
Oil quench at 900°C	350	240	5.02	49
Quenched at 250°C	550	337	9.453	46
Quenched at 450°C	498	298	14.675	34
Quenched at 650°C	486	240	24.747	32

Table 5: Final values of UTS and Hardness from all heat treatment processes

7. CONCLUSION

Thus in this paper a comparative statement has been made for different heat treatment processes and results obtained during the experiments concluded that there is tremendous variation of mechanical properties depending upon the various heat treatment processes. Hence depending upon the properties and applications of the work material we should select a suitable heat treatment processes. When there is only ductility is criteria tempering at high temperature for 2 hours gives the optimum result among all tempering experiments. Whenever we require hardness of the alloy steel of grade 16MnCr5 we should select low temperature tempering for 1 hour. From the results and observation it is found that annealing causes a tremendous increase in ductility (% elongation). Consequently it is clear by comparing all the heat treatment processes, only austempering give optimum values for UTS, Yield Strength, and hardness for the required application of the alloy steel of grade 16MnCr5.

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