To study effect of annealing, normalizing and quenching on mechanical properties of shaft like steel specimen

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Abstract: In this work we have analyzed the effect heat treatment on properties of shaft shape steel specimens under various heat treatment processes. Specimen was subjected to heat treatment in electric muffle furnace. Heat treatment temperature, soaking time and cooling rate were selected as per phase diagram of specimen material. Specimens were tested for mechanical properties before and after heat treatment. Different heat treatment processes compared with respect to their effect on properties of shaft shape specimens.

Keyword: Steel, Heat Treatment, Hardness

1. Introduction:

Heat treatment is a industrial process which is used to alter the properties of a material. The main application is metal processing. Heat treatments can also be used in the manufacture of other materials e.g. glass. Heat treatment is an process which involving heating at a specific rate and then soaking at a temperature for pre-determined period of time and then cooling specified rate. Aim to select suitable metal or alloy is key requirement in manufacturing industry. Shaft like structures are often observed in production area. Selection of suitable material for these structures requires study of various parameters during manufacturing operations. Keeping all in view the present work was planned with following objectives:

- To study mechanical properties of shaft like steel specimen before heat treatment.
- To analyze effect of heat treatment on mechanical properties of sample specimen under three different heat treatment processes.
- To compare mechanical behavior under different heat treatment parameters before and after heat treatment.
- To compare effect of three different heat treatment operation on mechanical properties.

2. Materials and Methods:

Material: Low alloy steel rod was used as specimen (Purchased from local market) for present work. Dimensions of shaft shape specimen were Dia. x length = 16 mm x 140 mm, with ultimate tensile strength 900 MPa and yield tensile strength 670 MPa , elongation 15 % (Max.), yield stress (0.2%) = 672 MPa, Hardness (Rockwell)= 30 HRC.

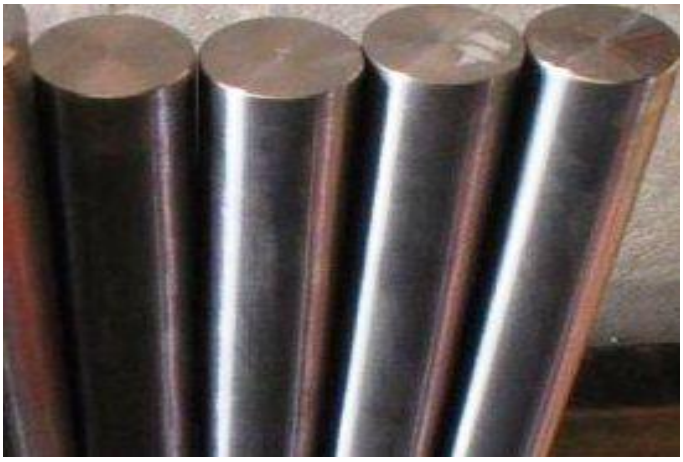

Figure 1: Low alloy steel specimens before heat treatment.

3. Heat Treatment Process: In present wok specimens are analyzed before and after heat treatment (HT), to observe changes in mechanical properties after heat treatment. Here three HT operations namely annealing, normalizing and quenching are performed and data obtain is compared to conclude effect of heat treatment on mechanical properties. Heat treatment was performed in Electrical Muffle furnace at the predetermined temperature range as per sample material phase diagram & process parameters.

Figure 2: Samples after heat treatment.

4. Results & discussions:

Hardness Test-: Samples were prepared for hardness testing. Hardness test was performed before and after heat treatment. Rockwell hardness Tester in HRC mode is used for hardness measurement with a load of 150 Kg.

Indenter Used = Diamond Cone
Load Applied = 150 Kg

Above data obtained can be co-related to following facts:

a. Increase in hardness in normalizing can also be attributed to formation of martensite (it contributes to hardness of material). Percentage of carbon in steel is key factor which also contributes in change in hardness after heat treatment. The plot below shows formation of phase with percentage of carbon & variation in Hardness of material. Our results are well in order with theoretical facts.

b. In case of annealing there is decease in hardness, which can be because, annealing is implemented in materials which undergone cold working, casting or quenching during fabrication, further metal/alloy becomes softer after annealing, which can be attributed to phase change due to slow heating and cooling rate that offers enough time for formation of phase with reduced hardness which is favorable for machining of material. [30-33]

c. Quenching bring out sudden product phase formation due to time lag between heating and cooling cycle or in other words we can say that it prevents phase transformations to takes place. It is often used to harden steel to high value, with increase in brittleness with formation of martensite phase.

SPECIMEN/HT OPERATION	LOAD APPLIED (Kg)	TOUCH POINT HARDNESS (HRC)	HARDNESS (HRC)	
			Before HT	After HT
Specimen 1(Annealing)	150	240	Experiment 1 = 30	Experiment 1 = 28
			Experiment 2 = 31	Experiment 2 = 28
			Experiment 3 = 31	Experiment 3 = 27
			Average ~= 31	Average ~= 28
Specimen 2(Normalizing)	150	240	Experiment 1 = 31	Experiment 1 = 34
			Experiment 2 = 31	Experiment 2 = 33
			Experiment 3 = 31	Experiment 3 = 34
			Average ~= 31	Average~= 34
Specimen 3 (Quenching)	150	240	Experiment 1 = 32	Experiment 1 = 37
			Experiment 2 = 31	Experiment 2 = 37
			Experiment 3 = 31	Experiment 3 = 38
			Average ~= 31	Average~= 37

Touch point hardness-: It refers to hardness when indenter just touches the surface of specimen, before actually pressing it.

Table 1: Hardness test data before and after HT.

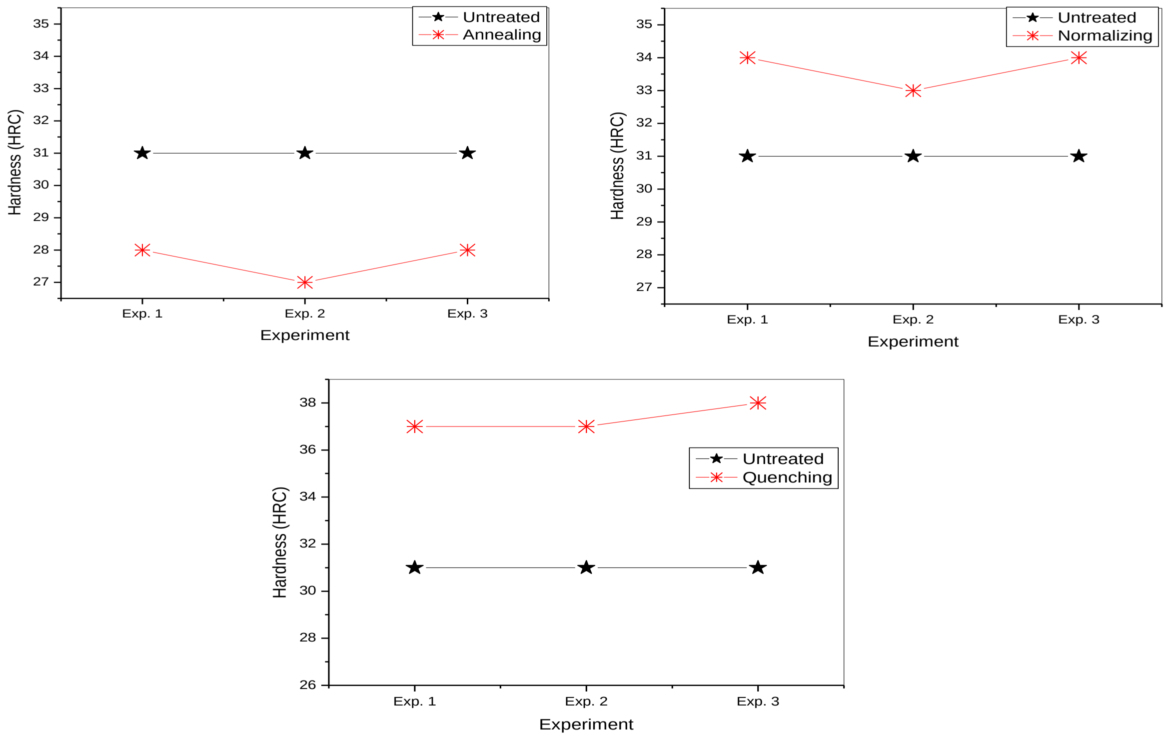

Figure 3: Plots of variation in hardness with type of HT.

Tensile Strength Testing: Data obtained shows a variation in tensile strength for all three heat treatment operations. From observed that, one can draw conclusion that, their exist a relation between tensile strength and hardness of samples before and after HT. Here tensile strength shows approximately a linear relationship with hardness. [36]

Stress Type = Tensile Stress
Peak Load = 187.12 KN
Maximum Cross Head Travel = 20.7mm
Tensile Strength (Before HT) = 900 N/mm^2
Load at Break = 167.32 KN

Specimen	Maximum Load (KN)		Load at break (KN)		Percentage Elongation (%) & Reduction in Area (mm)		Tensile Strength (N/mm^2)	
	Before HT	After HT	Before HT	After HT	Before HT	After HT	Before HT	After HT
Specimen 1(Annealing)	170.32	175.4	165	168	Negligible		900	855
Specimen 2 (Normalizing)	171.72	174.6	167.3	172	Negligible		900	958
Specimen 3 (Quenching)	172	176	169	172	Negligible		900	988

Table 2: Tensile strength test data before and after HT.

Impact strength/Toughness Test: Toughness of specimens was determined with Charpy test. Here annealing results in increase in toughness, normalizing and quenching results in decrease in hardness. Our results are in order with theory, such as annealing results in decrease in hardness, which in turn increases ductility and thus increases ability to absorb energy or to resist shock, hence there is increase in toughness. [37]

Toughness (Joule)			
Before Heat Treatment	After Annealing	After Normalizing	After Quenching
56	58	53	50

Table 3: Toughness test data.

5. Conclusions:

All observation from study of different mechanical properties before and after three different heat treatment operations, following conclusions has been drawn:

- Heat treatment of low alloy shaft specimen results in significant changes in mechanical properties.
- Annealing reduces hardness with destruction of cementites /pearlite networks during phase transformation by heat treatment. Normalizing results in formation of martensite, cementites and hence improves hardness, in similar way increase in hardness after quenching is more, which can be due to time lag for any phase transformation to takes place.
- Annealing results in decrease in tensile strength, where as normalizing and quenching results in increase in tensile strength. Results are as expected from theory.
- Increase in toughness observed for annealed sample, where as toughness decreases in case of normalized and quenched sample.

Thus difference in heating rate, soaking time & cooling rate, give rise to different effect on properties of metals/alloys, which may be due to difference in overall phase transformation mechanism in case of all above HT operations. Here one can not mention which HT operation brings improvement in properties, All have their unique important according to application in production of various metal/alloy structures.

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