# A REVIEW ON EFFECT OF HEAT TREATMENT ON MECHANICAL PROPERTIES OF VARIOUS STEELS

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## ABSTRACT

*This review paper discusses the effect of various heat treatment processes like annealing, normalizing, tempering, carburizing & quenching performed by various people on medium carbon steel grade EN8 and low alloy steel. The mechanical properties of steel like toughness, hardness, ductility, yield strength, wear resistance etc. are greatly influenced by the type of heat treatment used and factors governing that process. The proper combination of heat treatment parameter can greatly affect the outcome. The grain structure formed after each heat treatment process is significantly responsible for the property the material will acquire. The literature survey of past work had thoroughly studied and examined and presented collectively.*

***Keywords*: EN8 Steel, Medium carbon steel, Heat treatment, Tempering, Hardness, Toughness**

## 1. INTRODUCTION

As we know EN8 steel is an important grade of steel for manufacturing of axles and shaft, bolts, gear etc. Heat treatment is an important step in achieving desired mechanical properties for different applications. The process of heat treatment is carried out first by heating the metal and cooling in water, oil and brine water. The purpose of heat treatment is to change grain size, to modify structure of material and relief the stress set in the material. Various heat treatment processes are annealing, normalizing, hardening, austempering, martempering, tempering and surface hardening. Previous investigations have depicted that quenching in water results in higher hardness then that in air. Also tempering at higher temperature results in smaller grain size will further result in smaller grain which in turn increases hardness.

In both cases, machinability decreases. To get perfect balance between machinability and hardness it is vital to optimize tempering parameters accordingly. In the present work we bring forth work of various authors who have worked on various heat treatment parameters i.e. temperature, quenching medium etc. and the results obtained will be discussed in brief.

## 2. MATERIALS AND PROCESSES

The application of any materials in any given industrial or scientific field is only determined by its mechanical properties. The below mentioned literature survey gives us the brief idea of the metals and alloys used in various sizes and forms and also process used by authors as they carried out their research.

Palash Biswas et.al. [1] investigated on the mechanical properties of EN8. The specimen were round bars with 11mm length and 25 mm diameter. Samples were annealed at 480$^0$C with 45 minutes of holding, Normalized at 850$^0$C with 2 hours of holding and tempered at 300$^0$C. Quenching was done in oil bath and till room temperature.

Mohamed H. Frihat[2] carried out his investigation on low alloy steel with 0.31, 0.24, 0.23 and 0.29 % Carbon respectively. Each specimen was divided into four group for different experiment. Pack carburizing was applied at 900$^0$C-1050$^0$C water was used as quenching medium. The testing of mechanical properties was carried out by performing the tensile test on UTM, Vickers hardness testing & impact testing on the specimens. A microscope was used to observe the microstructure of the specimens after every step.

Cullen M. Moleejane et.al. [3] conducted his research on EN-8 grade of steel. The specimen was divided into four groups. Group A was austenitized at 950$^0$C followed by furnace cooling , B was austenitized at 914$^0$C followed by furnace cooling, C was austenitized at 914$^0$C with furnace cooling with different holding time. D was austenitized at 914$^0$C and quenched in oil. To observe the micro structural features optical electronic microscope(OEM) & scanning electron microscope (SEM) were used. Micro structure analysis was done after each heat treatment process. The elongation and yield strength were studied for each specimen after tensile testing. Hardness value after each heat treatment were found using Brinell hardness tester.

S.D. Vetrivel et.al. [4] in his work used medium carbon steel. Surface treatment was done by using nitriding and induction hardening. Three specimen were heated at 500$^0$C,550$^0$C and 600$^0$C at different soaking time and different quenching medium followed by tempering. The aim was to change mechanical & tribological properties via heat treatment processes. Firstly, annealing was performed at 800$^0$C on the cylindrical specimen for removing stresses and after that vicker hardness test, sliding abrasive wear test and XRD analysis was performed.

Prof. S.R. Thakare et.al. [5] in his study used EN8 steel. The specimen were preheated at 880$^0$C-910$^0$C. After that various heat treatment process were applied like hardening, quenching in different mediums and finally tempering at 200-300$^0$C. He used the Rockwell hardness tester for testing the hardness and he used the Taguchi method to optimize all parameters.

Sakthivel Munisamy et.al. [6] investigated the properties of EN8 after quenching in different mediums. Specimen were heated in two different furnaces namely Gas carburizing furnace and seal quenching furnace where quenching is done outside and inside furnace respectively. Heating was done at 930$^0$C and quenched in different medium like closed oil, open oil, water and air.

Ali Emamian [7] studied the mechanical and tribological properties of Fe-based powdered metallurgy parts.He prepared the test samples, 64 round discs with 7 mm diameter and 10 mm thickness that are made of low carbon alloy and produced by powder metallurgy method. The specimen were firstly pack carburized at nearly 850$^0$C-950$^0$C. Wear testing was done by the means of a pin on disk tribometer. He applied Charpy test on standard impact specimen with notch, at room temperature. Lastly the macro and micro hardness tests were applied on metallography samples.

K. Miernik et.al. [8] investigated on mechanical properties of low carbon structural steel when incomplete quenching was done. Normalizing was done at 870$^0$C and quenching from various phase range temperature was done followed by high temperature tempering after each process.

Jaykant Gupta [9] had investigated on properties of mild steel. Different range of carburizing temperature i.e. 850$^0$C,900$^0$C and 950$^0$C were taken and heated in muffle furnace with 2 hours of holding time and quenched in water. Tempering was done at 250$^0$C after each process with 30 minutes of holding time. Mechanical properties like hardness, tensile test and wear resistance was tested after the heat treatment of specimen.

T. Senthikumar et.al. [11] performed his work on medium carbon steel. The specimen tensile test where made as per standard specifications. After this heat treatment process has carries on. Hardening process was done at 850$^0$C with holding on 2 hours and water quenched. Tempering was then followed up at 350$^0$C. Annealing at 870$^0$C and normalizing at 850$^0$C were conduct respectively. After the process tensile test was done using UTM and further analyzed.

D.A. Fadare et.al. [12] investigated on NST-37-2 steel containing 0.2% carbon samples where prepared for impact and tensile test. Various heat treatment process namely annealing, normalizing, hardening and tempering here conducted.

TehareemKanwal et.al. [13] had conducted his study on mild steel specimen containing 0.2%v carbon. His aim was to find how quenching and tempering affects the mechanical properties of mild steel. Samples were heated for one hours at 960$^0$C in muffle furnace followed by quenching in water and oil tempering was done at about 150-550$^0$C. After his hardness and tensile properties how were tested.

Muhammad IshqueAbro et.al.[14] had conducted his research on low alloy steel SUP9 to study effects on heat treatment on leaf springs where this material is used frequently. Cryogenic tests were also done by soaking in liquid nitrogen to study ductile to brittle transition. As for hardening samples were heated at 900$^0$C soaked for 20 min and quenched in oil. Tempering was done at 480$^0$C and 600$^0$.

NurudeenA.Raji et.al. [15] had investigated on tempering properties of low carbon cold drawn steel with 0.12%C. to improve annealing process different temperature range with 500-650$^0$C was taken and with varying holding time of 10-60 min study how it affects toughness and tensile strength of low carbon steel.

Ibharimsevim et.al.[16]He studied about empirical relation between hardness, wear resistance & abrasive particle size on carbon steel. He used wear test on different heat treated material, non heat treated material & relation between in both. He heated the material at different temperature and hold at various time then quenched into water. After heat treated he again tempered the specimen and study on that specimen. After his study he concluded that the relation between wear resistance $W^{-1}$ and hardness $H$. depending on abrasive particle size $d$ for non heat treated steel is.

## EQUATION

$$W^{-1}=\frac{1}{9.2\sqrt{d}}\frac{H}{P}$$

Where $P$ is applied pressure on surface.

The relation between wear resistance and hardness for heat treated steel is given below [9].

$$W^{-1}=\frac{1}{P}\left(\frac{1.4}{d}+2.6H\right)$$

AshishBhateja et.al. [17] in his work investigated on EN31, EN8 and D3 which are used in tool steel. The samples were cut and heat treated for hardness testing. Annealing was done at800$^0$C with 2 hours of soaking time for normalizing temperature range of 880-900$^0$C was taken with soaking of 30 minute and tempering was done at 850-960$^0$C with one hour soaking time. Hardness reading were taken after each process.

Yashwant Mehta et.al.[18] had done his research on Fe-P alloy to study its corrosion resistant behaviour and how microstructure arranged themselves after different cooling rate during heat treatment. This carbon alloy has 0.3% Fe, 0.14% P. Samples were heated at 850$^0$C temperature till 30 minute and quenched in water and another sample in air. Micro hardness test was done using Vickers tester. Micro structure was analysed using SEM.

A. DI .Schino et.al.[19] select 0.2% carbon steel with Cr and Mo as alloying agent for his study. Heat treatment was done at 980$^0$C and 1050$^0$C. Tempering temperature was 540-680$^0$C. After the heat treatment of samples they were analysed by impact testing and tensile testing for various mechanical properties.

## 3. EFFECT OF HEAT TREATMENT ON MECHANICAL PROPERTIES

### 3.1 EFFECT ON HARDNESS

Palash Biswas et.al. [1] Had worked on to find the optimum value of hardness of EN8 steel so that it balances machinability as well. He showed annealing gives lower hardness than normalizing and also quenching gives highest hardness. He also concluded that combination of normalizing and tempering balances hardness with machinability. He showed his findings in the form of a graph as below:

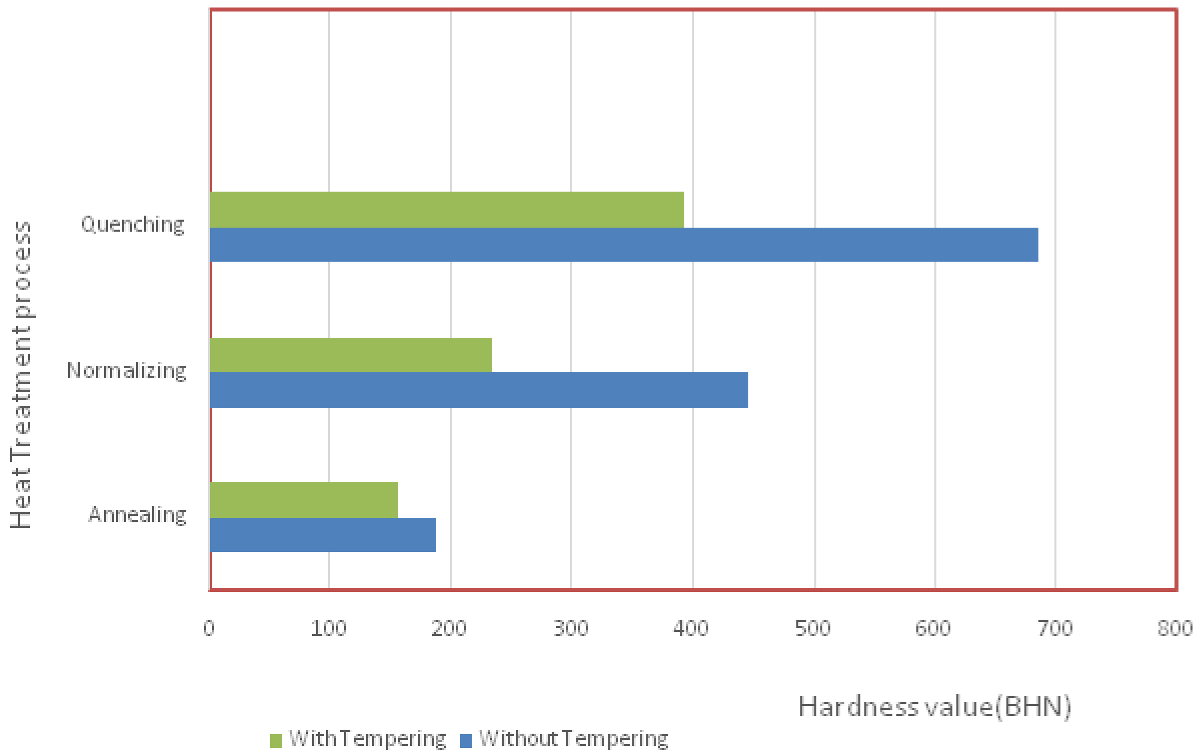


**Figure 1:Variation of hardness with temperature at heat treatment process**

Cullen M. Moleejane et.al. [3] austenitized EN8 at 914$^0$C and quenched in oil to get the formation of fine grains. He also concluded that the smaller the grain size the greater is the hardness value.

S.D. Vetrivel et.al. [4] evaluated microhardness of medium carbon steel specimen using Vicker micro hardness testing machine. He carried out nitriding and induction hardening for surface hardening. He concluded that better hardness is achieved by induction hardening also reduced defects and is advisable for automotive applications too.

Prof. S.R. Thakare et.al. [5] performed case hardening of EN8 through gas carburizing and induction hardening. There were a number of factors responsible for surface integrity like preheating, carbon % etc. furnace temperature and quenching time influenced Gas carburizing while power played significant role in induction hardening. Taguchi technique was used to find optimum process parameters.

After his research, he found optimum gas carburizing process condition to obtain a better and increased surface hardness which is given in the following table as:

**Table 1:** Optimum parameters for gas carburizing process

| Sr. no. | Process Variables | Values with unit |
|---|---|---|
| 1. | Furnace temperature (Celsius) | $910^0$C |
| 2. | Quenching time (minute) | 15 minute |
| 3. | Tempering temperature(Celsius) | $300^0$C |
| 4. | Tempering time(minute) | 15 minute |

Sakthivel Munisamy et.al.[6] used different quenching medium only to find that hardness was more in water quenched material and increasing over raw material. The Rockwell hardness values of his work is depicted in the chart below.

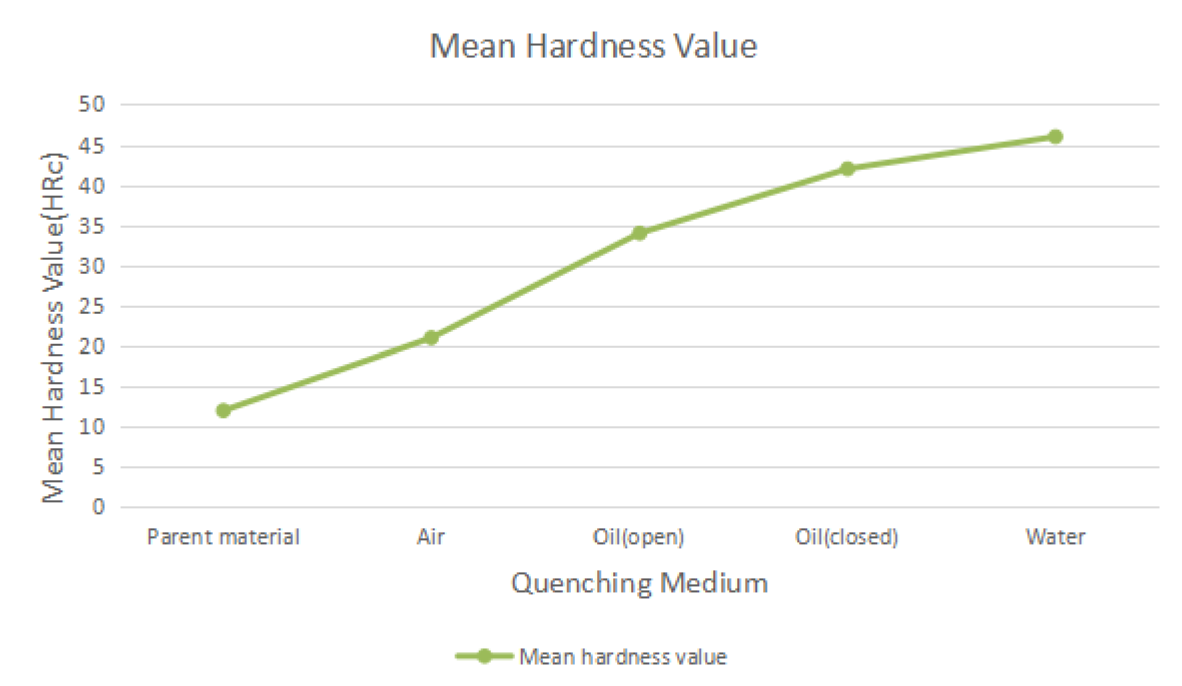


**Figure 2: Variation of hardness with different quenching medium**

K. Miernik et.al. [8] in his investigation on low carbon steel has found that tempering at higher temperature results in lower hardness. High temperature $900^0$C heating and sudden cooling gave increased hardness value.

Jaykant Gupta[9] took mild steel carburizing at various temperature and tempered at $200^0$C. He found better hardness properties are obtained by carburizing at $950^0$C.He found relation between hardness and many other quantities, we can see one of his findings as how hardness value varies with respect to carburizing temperature in the following chart.

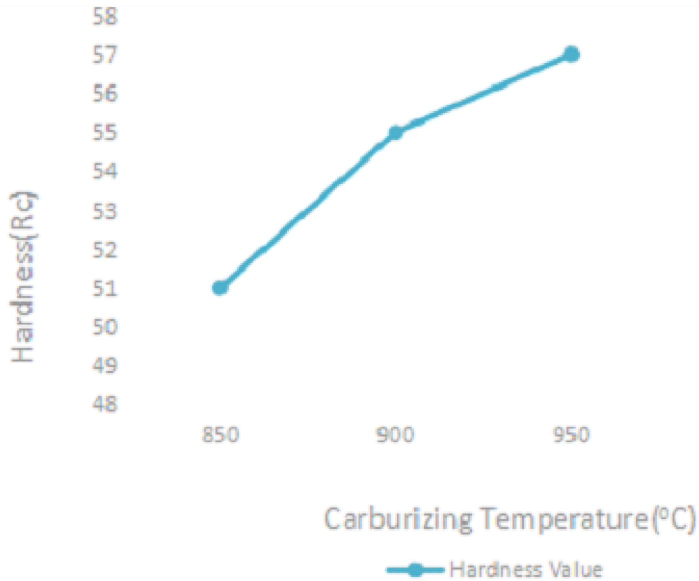


**Figure 3: Variation of hardness with carburizing temperature**

From the work of TehreemKanwal et.al.[13] it was clear that for mild steel hardness and strength increases in both oil and water quenching but much more in water quenched relatively. Tempering reduces hardness considerably.

EN-31 becomes more soft after annealing and after normalizing, hardness was more as compare to parent specimen . Same was true for EN8 but D3 sample become harder after annealing as compared to parent material. Heat treatment also improves corrosion resistance as per the study of Ashish Bhatija et.al.[17]

Based on work on Yashwant Mehta et.al.[18] it can be inferred that water quenching fetches for more hardness than air quenching due to the formation of pearlite and ferrite grains.

## 3.2 EFFECT ON WEAR RESISTANCE

The work of S.D. Vetrivel et.al. [4] Gives us some insight on the tribological properties of medium carbon steel.

He used pin-on-disc apparatus to examine wear resistance. To improve wear performance he used nitriding and induction hardening and saw that induction hardening was better than other heat treatment process in providing wear resistance.

Sakthivel Munisamy et.al. [6] in his investigation said that to obtain better wear resistance on EN8 steel, quenching medium should be water and wear resistance is increased over the raw material.

Ali Emamian [7] concluded wear resistance of PM parts are improved by carburizing.

A better wear resistance was obtained by Jaykant Gupta [6] by carburizing at $950^0$C.

## 3.3 EFFECT ON OTHER PROPERTIES

The work of Palash Biswas et.at. [1] had stated that better machinability of EN8 will be obtained on Annealing followed by tempering at $300^0$C. Also to obtain balance between machinability and hardness specimen should be first normalized then tempered.

Mohamed H. Frihat [2] gave the result that Mechanical strength of low alloy steel increases with heat treatment temperature. The results of stress-strain curve showed after rapid cooling, brittleness increasing and elongation decreased.

As for as toughness goes K. Miernik et.al. [8] in his work found that heat treated material shows reduced toughness but tempering at high temperature toughened the material. Also high yield quenched in range of 800-820$^0$C high tempering also increases tensile and yield strength.

Jaykant Gupta[9] as per his study toughness decreases with rise in carburizing tempering but other properties increase like tensile strength, hardness, wear etc.

The results of the investigation of T.Senthikumar et.al. [11] shows material properties for different engineering purpose greatly depend on type of heat treatment and quenching medium used. Annealing gives better toughness together with ductility. While hardened steel gives more strength at the expense of toughness.

From the work of D.A fadare et.al. [12] it is clear that tensile strength and ductility increase with plastic deformation but on the other hand impact strength decreases due to hardening.

Muhammad Ishaque Abro et.al. [14] in his study found that tempering at 600$^0$C gives maximum toughness for his low alloy SUP9 steel but at the cost of hardness ductile to brittle transition in austempered and tempered was noted same where near -10$^0$C through not very clear. He stated that tempering at 600$^0$C which provide good balance in properties than at 450$^0$C, for application in leaf spring.

NurudeenA.Raji et.al. [15] found that the toughness and yield strength of cold drawn steel increases as we increases soaking time in the specified temperature range. But as a results tensile strength decreases.

Work of A.DI. Schino et.al. [19] revealed that for steel with Cr and Mo. Proper quenching and tempering can make steel tough enough to be used at very low temperatures. Proper microstructure play a very keen role for importing suitable strength.

### 3.4 MICROSTRUCTURE ANALYSIS

The microstructure can strongly influence the properties of any material as evident form the work of Mohamed H. Frihat [2], Microstructure of low alloy steel tend towards recrystallized ferrite grains as the heat treatment temperature increases.

Callen M. Moleejane et.al. [3] has founded that various grains size in material have variational influence. If a material consist of different phases of various grain size, weaker gain will be bottle neck. Annealing temperature and soaking time increased, promotes coarse grains. He also concluded that yield strength increases with decreasing grain size and elongation at failure decreases with decreasing grain size.

As per the microstructure analysis on the NST 37-2 steel by D.A Fadare et.al. [12] the untreated samples had ferrite and pearlite grain while normalized samples showed pearlite matrix. Having shorter flakes than annealed samples. Hardened samples formed martensite structure. When gives better hardness and tensile strength but low ductility.

## 4. OPTIMIZING METHOD

### 4.1 TAGUCHI METHOD:

Taguchi's techniques have been used widely in engineering design (Ross 1996 &Phadke 1989). The Taguchi method contains system design, parameter design, and tolerance design procedures to achieve a robust process and result for the best product quality (Taguchi 1987 & 1993). The main trust of Taguchi's techniques is the use of parameter design (Ealey Lance A.1994), which is an engineering method for product or process design that focuses on determining the parameter (factor) settings producing the best levels of a quality characteristic (performance measure) with minimum variation. Taguchi designs provide a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions. To determine the best design, it requires the use of a strategically designed experiment, which exposes the process to various levels of design parameters.[10]

## 5. CONCLUSIONS

After studying the past work in literature survey we conclude that:-

1) The mechanical properties of steel is enhanced with heat treatment and hardness is improved with carburizing and sudden quenching. The type of heat treatment done with different temperatures, quenching medium, tempering temperature etc. decide which property material will exhibit.

2) Micro-structure analysis is done to reveal the type of grain structure after subsequent heat treatment.

3) Most of them failed to generate the critical relation of hardness and toughness property.

4) As hardness increase brittleness also increases and toughness drops significantly.

5) Annealing is done to improve ductility, tensile strength and toughness of steel. Low temperature tempering can improve toughness without appreciable loss in hardness but high temperature tempering can significantly reduce hardness and increase toughness.

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