# ASSESSMENT OF VARIOUS HEAT TREATMENTS ON THE TENSILE STRENGTH OF AISI 1045 STEEL

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***Abstract :*** The AISI 1045 is a popular grade of medium carbon steel. It is widely used in automobile industry and marine industry due to its good mechanical properties such as good tensile strength and good hardness. Alloying and conventional heat treatment processes have been very effective in enhancing mechanical properties of the alloys. In recent studies a new quenching method has been found which has been proven very efficient in providing good mechanical properties to the alloys. In this method, the alloy is subjected to discontinuous quenching in a highly agitated brine solution and then continuous quenching in air. In this current study effects of " in-depth " quenching on the mechanical properties of AISI 1045 steel are being studied. The specimens were subjected to austenizing in muffle furnace and then subjected to " in-depth" quenching technique and conventional heat treatments. Tensile testingwas done on specimens to determine the differences in the mechanical properties of conventionally heat treated and non-conventionally specimens. Results indicated in-depth quenched specimen had better tensile strength compared to conventional heat-treated specimens.

***Index Terms*** **– Heat Treatment, Non-conventional quenching, AISI 1045, Mechanical Properties.**

## I. INTRODUCTION

Steels are one of the most important groups of engineering materials throughout the world. They are cost efficient, versatile and have wide range of applicability. The physical and mechanical properties of steels are often exploited with the help of alloying and heat treatments to attain superior properties. The AISI 1045 steel is used for all industrial application requiring good hardness and tensile strength. Alloying different elements in steels can provide superior mechanical and physical properties from high hardness to better corrosion resistance (Maalekian 2007). The main disadvantage with alloying is its expensiveness. Heat treatments also enhance mechanical properties of the steels. Conventional heat treatment processes include annealing, normalizing, quenching and tempering. Among these conventional heat treatment processes, annealing is associated with relieving stresses, softening; grain refining which ultimately leads to the increased ductility and toughness in the steel. Annealing of medium carbon steel produces coarse ferrite-pearlite structure. In normalizing, steels are air-cooled after austenization. Normalizing encourages the formation of finer grains in the steel which improves the strength and hardness of the steel without losing its toughness and ductility. Normalizing forms finer ferrite-pearlite microstructure in the medium carbon steels. Traditional water quenching is associated with obtaining high hardness values in the steel by transforming the austenitic phase into the martensitic phase through rapid cooling. In iron-carbon alloys martensite is the hardest phase, ferrite is the softest phase and pearlite is an intermediate phase. Pearlite is a mixture of two different phases' ferrite and cementite in lamellar form. Formation of martensite produces high surface stresses and hence provides high hardness values to the steel but at the expense of reduced ductility and toughness (Gopalkrishna, Gurumurthy, and Davanageri 2019; Katiyar et al. 2020). To improve the ductility in the quenched steel, tempering is performed. Tempering is performed by heating the steel below its lower critical temperature and held there for specific time. Tempering helps in relieving the internal stresses and improving the ductility and toughness of the quenched steel.

Water Quenching with higher cooling rate often leads to distortion and generation of cracks in the material. To avoid distortion and cracking in steels, quenching in oils and polymers is suggested but hardness values achieved through these quenchants is compromised. In recent times, a non-conventional heat treatment technique "in-depth" quenching has been developed (Przyłcka et al. 2003). This technique is an alternative method for obtaining superior hardness in steels without compromising its toughness but also reducing distortion in the steel parts. In in-depth quenching the steel parts are subjected to quenching at extremely high cooling rates in a highly agitated brine then in air. The quenching is interrupted when the surface compressive stresses reach their maximum value. The steel parts are cooled rapidly within martensitic transformation region. High cooling rates during the in-depth quenching are achieved by providing a vigorous, uniform agitation of brine in the in-depth quenching setup (Aronov et al. 2015). The high flow rates of brine through the set-up eliminates the film boiling and nucleate boiling process, starting the convection mode of heat transfer instantly after the quench begins(Aronov et al. 2015).Installing the hydrodynamic emitters in the quench set-up improve the quenching for batch processing (Nikolai I Kobasko 2016b).The in-depth quenched parts have superior mechanical properties and less probability of distortion due to the generation of high residual compressive stresses at the surface of the steel. When the steel is subjected to extremely high cooling rates during in-depth quenching, the martensite starts to form in the part surface layer while the core temperature remains close to austenitizing temperature. The surface compressive stresses develop at both case and core due to the volumetric expansion of the steel parts when transforming from austenite to martensite. The compressive stresses are further increased by the thermal shrinkage of the core which pulls the martensitic surface layer inward producing its compression. The quenching is then interrupted when the residual compressive stresses are maximum at the surface and continuing cooling the steel in the air (Aronov et al. 2014). Slowing down the cooling rate of the steel stops the formation of the martensitic structure in the core resulting in mixed microstructure at the core with either of these intermediate phases such as, pearlite, bainite, ferrite and martensitic microstructure at case depending upon the cooling rate. Since this mixed core structure has less volume than a pure martensite core, higher level of residual stresses is obtained compared to the traditional quenched version. Different microstructure of case and core provides higher hardness in the steel without compromising the toughness. The formation of bainitic part core through IQ is discussed in (N. Kobasko 2016a). In-depth quenching favors to the creation of high residual compressive stresses at the surface of parts. During in-depth quenching, in martensitic range of transformation there is creation of large dislocation density in the material which results in the strength improvement of the material. The formation of high dislocation density and high compressive stresses at the surface layers of in-depth quenched parts enhances their service life (Aronov 2003). Optimal quenched layer should be generated after in-depth quenching in order to enhance the service life and strength of the material. This is done by interrupting it at accurate time and then normalising in air resulting martensite in case and pearlite in Core(Aronov, Kobasko, Powell, and Ghorpade 2005; Aronov 2003).The distortion behavior of the components without phase transformation can furthered be described with the help of Biot number. Higher biot number is associated with higher number of residual stresses.The generation of residual stresses is also influenced by martensite transformation in in-depth quenching (Rath et al. 2010). The in-depth quenching is also an environment friendly process as it uses brine and water as quenchants instead of hazardous oils and polymers, which further increases the service life of steels (N. I. Kobasko et al. 2009). The in-depth quenching eliminates the expensive carburizing process, saves energy and also decreases the emission of excess carbon dioxide in the atmosphere (N. I. Kobasko et al. 2009; N. Kobasko 2007).Parts processed through in-depth have relatively less distortion as compared to conventional quenched parts. This process increases the surface and the core hardness of the steel part, resulting in finer grains and super strengthened martensite, improved fatigue strength properties of steel parts (Aronov, Kobasko, and Powell 2001).The current investigation is aimed at studying the effect of conventional heat treatments and in-depth quenching on the mechanical properties of the AISI 1045 steel in detail and compare the properties with each other to determine which type of treatment is suitable for providing better tensile strength in the AISI 1045 steel which are needed for its various applications.

## 2. Experimental

The procedure started with the selection of hot rolled AISI 1045 steel of diameter 19mm.The AISI 1045 steel was then subjected to mechanical and compositional analysis for getting reference values .After evaluation of sample, it was then subjected to machining treatment for dumbbell shaped specimen, as it is required for tensile testing. Total length of dumbbell was 8inch with holding diameter of 19mm& length of 2.5inch each side. Gauge length was of 3inch with an internal diameter of 16 mm. After obtaining tensile values for the steel specimens for hot rolled steel. Different specimens of same size were subjected to conventional and non-conventional heat treatments .For conventional heat treatment process, the selected specimens were austenized in muffle furnace at 850℃ for 50 minutes .The furnace was heated at the rate of 5-6 ℃. The specimens were then subjected to furnace cooling (annealing), air cooling (normalizing) and water cooling (quenching) separately. The water quenched specimen was further subjected to tempering at 600℃ for 2 hours.

For in-depth quenching of the specimens, in-depth quenching set-up was prepared first. For agitating the quenchant, two125W A.C. motors were used as the agitator. For quenchant, 6 kg of NaCl with 10 gm of KOH was mixed in 60 liters of water in quenchant tank to form 10% brine at temperature of 20℃. Small amount of KOH was also added to the solution to keep pH within 8 -12 for corrosion prevention.The selected specimens after austenizing were removed and were put into the quenching tank having agitated brine as quenching at temperature of 20 ℃, for in-depth quenching. The quenching of the specimens were interrupted at time intervasls of 1 to 6 sec then the specimens were further cooled in air.

Tensile testing of conventionally heat treated and non-conventionally quenched specimens were performed with the help of universal testing machine to determine their ultimate tensile strength.

## 3. Results and discussion

The AISI 1045 steel with chemical composition C 0.486%, Mn 0.780%, S 0.033%, P 0.040%, Si 0.225% was used.The variation in U.T.S of conventionally heat-treated specimens and the as-rolled specimen is shown in Fig. 1. The as-rolled specimen (923.8 MPa) shows higher value of U.T.S than the conventional heat-treated specimens. It is due the generation of more residual stresses in as-rolled specimen than the other specimens. Among the heat-treated specimens normalized specimen (648 MPa) shows highest U.T.S value and annealed specimen shows lowest U.T.S(509 MPa) value. The increase in U.T.S of normalized specimen is due to presence of more surface residual stresses than the annealed specimen. The tempering of quenched specimen caused decrease in the surface compressive stresses therefore the quenched and tempered specimen has lesser ultimate tensile strength than the normalized specimen(Fadare, Fadara, and Akanbi 2011).

The variation in the ultimate tensile strength at different quench interruption time is shown in Fig. 2**Error! Reference source not found.**. The tensile strength of in-depth quenched specimens increases to a maximum value of 1057.3 MPa for interruption time of 2 sec after that it starts to decrease yet it remains greater than 923.80 MPa. The increase in ultimate tensile strength of the specimens is due to the formation of compressive stresses because of martensitic shell formation at the case surface and mixed structuremar tensite and pearlite at the core of the specimen. The residual compressive stresses are maximum and the martensitic shell is fully developed at the interruption time of 2 sec which giveshighest ultimate tensile strength value. The decrease in the ultimate tensile strengthof the specimen at 1 sec observed, is due to the formation of incomplete martensitic shell (Aronov et al. 2002) and the decrease in the ultimate tensile strength after 2 sec is due to the mixed core structure Martensite and Pearlite and the decrease in compressive residual stresses in the specimens.

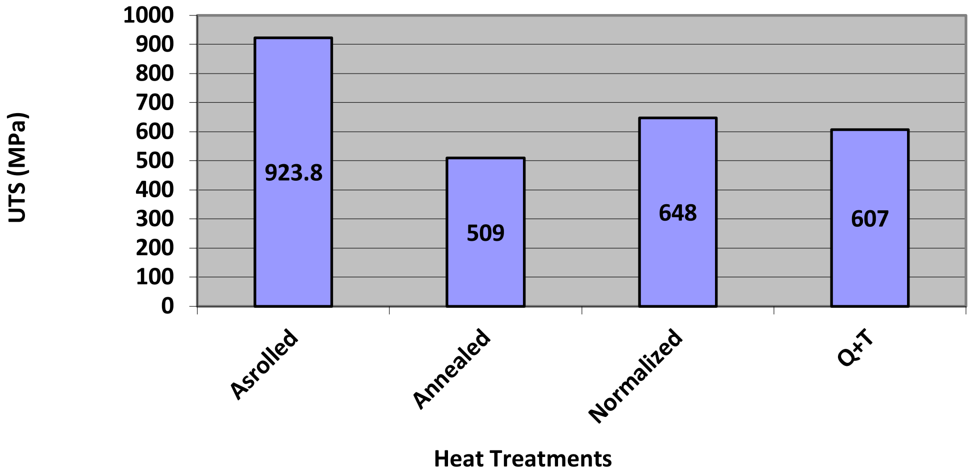


*Fig. 1. Comparison between UTS of conventionl heat treatment process*

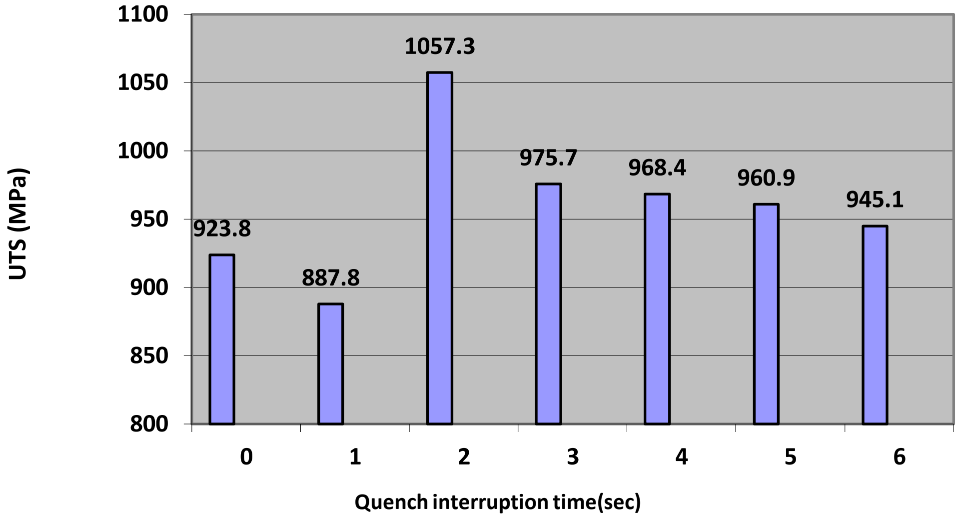


*Fig. 2. Variation in UTS w.r.t quench interruption time*

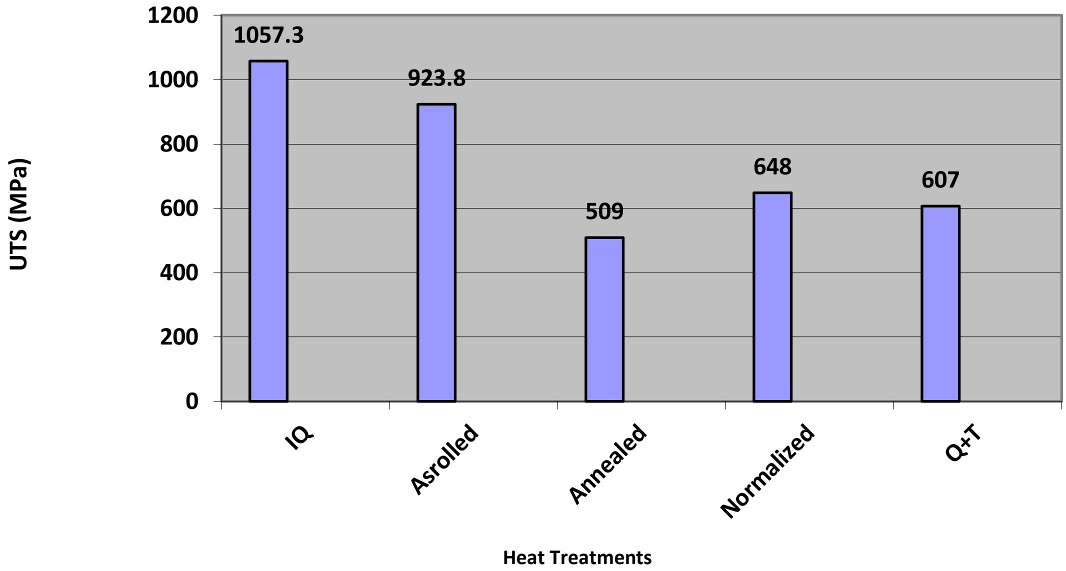


*Fig. 3. Variation in UTS of different heat treatments*

The comparison among different UTS of different heat treatment is shown in Fig. 3. For conventional heat treatments annealing, normalizing and quenching, decrease in ultimate tensile strength compared to as-rolled & in-depth specimen is observed Among these heat treatments the in-depth quenched specimen shows the highest U.T.S (1057.3 MPa). The IQ specimen has U.T.S value equal to 207.72% of annealed, 174.18% of quenched and tempered, 163.16% of normalized specimens. This increase in the ultimate tensile strength value of in-depth quenched specimen is due to the generation of higher residual stresses, compared to non-treated and conventionally heat-treated specimens.

## 4. Summary and conclusion

In this research, effect of different heat treatment processes on the mechanical properties of AISI 1045 steel was studied to select a heat treatment process which would allow the steel to obtained superior combination of mechanical properties. Among conventional and non-conventional heat treatments, the non-conventional heat treatment "in-depth" quenching provided the highest ultimate tensile to the AISI 1045 steel. It is attributed to the mixed core microstructure of the in-depth quenched specimen. The in-depth quenching uses water based quenchant with optimum concentration of salts instead of harmful oils and polymers for quenching therefore it is more environment friendly process and more economical. Therefore, in-depth quenching can be an effective replacement of conventional heat treatment Processes. For future aspects, effect of in-depth quenching on different metals and alloys can be studied and a new setup can also be established to make in-depth quenching a geometric independent process which can be applied in mass production of consumer steel or any other metal or alloy.

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