# Evaluation of Mechanical Properties of Medium Carbon Steel Quenched in Water and Oil

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## *Abstract*

*Samples of medium carbon steel were examined after heating between 900ºC-980ºC and soaked for 45 minutes in a muffle furnace before quenching in palm oil and water separately. The mechanical behavior of the samples was investigated using universal tensile testing machine for tensile test and Vickers pyramid method for hardness testing. The microstructure of the quenched samples was studied using optical microscope. The tensile strength and hardness values of the quenched samples were relatively higher than those of the as-cast samples, suggesting improved mechanical properties. However, samples quenched in palm oil displayed better properties compared with that of water-quenched samples. This behavior was traced to the fact that the carbon particles in palm oil quenched samples were more uniform and evenly distributed, indicating the formation of more pearlite structure, than those quenched in water and the as-received samples.*

***Keywords:*** *Muffle furnace, tensile strength, hardness value, Vickers pyramid method.*

## 1. Introduction

Plain carbon steels are widely used for many industrial applications and manufacturing on account of their low cost and easy fabrication (Smith and Hashemi 2006). They are classified on the basis of their carbon content as their major alloying element is carbon. According to Rajan *et al*. (1988), steels with carbon content varying from 0.25% to 0.65% are classified as medium carbon, while those with carbon content less than 0.25% are termed low carbon. The carbon content of high carbon steels usually ranges within 0.65-1.5%. Hardness and other mechanical properties of plain carbon steels increase with the rise in concentration of carbon dissolved in austenite prior to quenching during hardening heat treatment (Rajan *et al*. 1988; Thelning 1984), which may be due to transformation of austenite into martensite (Feng and Tahir 2008).

Therefore, the mechanical strength of medium carbon steels can be improved by quenching in appropriate medium. However, the major influencing factors in the choice of the quenching medium are the kind of heat treatment, composition of the steel, the sizes and shapes of the parts (Rassizadehghani *et al*. 2006).

Based on the parameter of “quenching severity” *H*, the cooling capacity of water is treated to be unity (Krauss 1990). The *H*-parameters of various quenching media, which reflects their capacity for removing heat in the quenching process, are thus compared with that of water. Mineral oils have been found to exhibit best cooling capacity for the majority of alloy steels (Grishin and Churyukin 1986), but they are relatively expensive, toxic and non-biodegradable. Therefore, there has been considerable work in the past on the possibility of replacing mineral oils with aqueous solutions of chemical substances and polymers

(Grishin and Huryukin 1986; Kulikov 1997; Tolstousov and Bannykh 1981). More recently, the use of locally available cooking oils, which are relatively cheap, non-toxic and environmental friendly, as quenching media, has begun to generate attention (Ndaliman 2006). In the present study, medium carbon steel samples are heat-treated at different temperature above the austenitic region and quenched in water and palm oil in order to investigate the effect of different heating and quenching regimes on the mechanical properties of the steel. The changes in mechanical behavior as compared with un-quenched samples are explained in terms of microstructural development within the surface and changes in tensile strength and hardness after quenching treatments.

## 2. Materials and Methods

The chemical composition of medium carbon steel samples used for this investigation is given in Table 1.

### 2.1 Test specimen preparation

A set of specimens was prepared for hardness tests and microstructural analyses. Tensile test specimens were also produced from the as-received medium carbon steel samples of the same composition. The specimens were prepared after series of machining operations following the International Test Standard, as shown in Fig. 1 (Senthilkumar and Ajiboye 2012). Another set of specimens was also prepared for hardness tests and microstructural analysis.

### 2.2 Heat Treatment and Quenching

The prepared tensile test samples and other samples were heated to 900ºC, 940ºC and 980ºC and soaked for 45 minutes using a muffle furnace. The test samples were quickly taken out of the furnace after each of the heat treatment temperatures and quenched in water and palm oil separately. Surface morphologies of the quenched samples were examined and hardness and tensile tests were also carried out on each of the samples.

### 2.3 Mechanical Test

***2.3.1 Tensile Testing:*** Tensile tests were carried out on both the water and palm oil quenched specimens using Instron Universal Tester. Each of the specimens was loaded till fractured, and the fracture load for each sample was recorded as well as the diameter at the point of fracture and the final gauge length. The initial diameter and initial gauge length for each sample were noted before the application of the uniaxial load. The elongation percentage and reduction of each sample were determined and the ultimate tensile strength and yield strength were obtained from the data generated.

Table 1. Chemical composition of the mild steel sample (wt.%).

| Element | Average content |
|---|---|
| C | 0.3302 |
| Si | 0.1894 |
| S | 0.0453 |
| P | 0.0527 |
| Mn | 0.7580 |
| Ni | 0.1090 |
| Cr | 0.1170 |
| Mo | 0.1169 |
| V | 0.0018 |
| Cu | 0.0033 |
| W | 0.0878 |
| As | 0.0028 |
| Sn | 0.0204 |
| Co | 0.0124 |
| Al | 0.0006 |
| Pb | 0 |
| Ca | 0 |
| Zn | 0.0034 |
| Fe | 98.0413 |

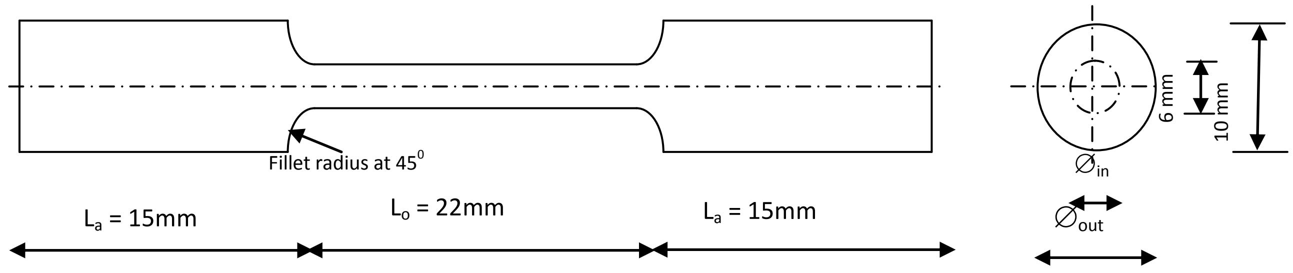


Fig. 1. Tensile test specimen from medium carbon steel (Senthilkumar and Ajiboye 2012).

***2.3.2 Hardness Test:*** Vickers pyramid method was used for the determination of the hardness of the quenched samples. Each of the test specimens was flatten after the different heating and quenching regimes and then mounted on the anvil. The specimens were brought in contact with the pyramid indenter and allowed to rest for a dwell time. The hardness of a specimen is indicated by the penetration of the indenter on the said specimen and displayed by the machine. Average values were recorded after repeating the test for each one of the test specimens.

## 3. Results and Discussion

Tables 2-5 show the mechanical properties of the quenched steel samples compared with the un-quenched samples at different heat treatment temperatures. The effects of the heat treatment temperatures on the tensile strength, Young's modulus of elasticity, elongation percentage and hardness (Vickers hardness number, VHN) of both the water quenched and oil quenched test samples are shown in Figs. 2-5, respectively.

Table 2. Effect of cooling rates on the tensile strength of medium carbon steel.

| Sample quenching medium | Temperature (°C) | Tensile strength (N/mm$^2$) |
|---|---|---|
| As-received | - | 649.4 |
| Water | 900 | 852.2 |
| Water | 940 | 905.6 |
| Water | 980 | 1063.9 |
| Oil | 900 | 834.1 |
| Oil | 940 | 889.2 |
| Oil | 980 | 996.7 |

Table 3. Effect of cooling rates on the elongation percentage of medium carbon steel.

| Sample quenching medium | Temperature (°C) | Elongation Percentage |
|---|---|---|
| As-received | - | 32 |
| Water | 900 | 24.8 |
| Water | 940 | 30.6 |
| Water | 980 | 31.2 |
| Oil | 900 | 32.1 |
| Oil | 940 | 34.6 |
| Oil | 980 | 35.2 |

Table 4. Effect of cooling rates on the Young's modulus of elasticity of medium carbon steel.

| Sample quenching medium | Temperature (°C) | Young's modulus of elasticity ($N/mm^2$) |
|---|---|---|
| As-received | - | 2020.0 |
| Water | 900 | 3436.6 |
| Water | 940 | 2959.5 |
| Water | 980 | 3409.9 |
| Oil | 900 | 2598.4 |
| Oil | 940 | 2569.9 |
| Oil | 980 | 2831.5 |

Table 5. Effect of cooling rates on the hardness of medium carbon steel.

| Sample quenching medium | Temperature (°C) | Hardness (Vickers hardness number) |
|---|---|---|
| As-received | - | 286 |
| Water | 900 | 376 |
| Water | 940 | 418 |
| Water | 980 | 464 |
| Oil | 900 | 336 |
| Oil | 940 | 394 |
| Oil | 980 | 438 |

As shown in Fig. 2, the tensile strength of both the water quenched and oil quenched samples increases with the increase in the heat treatment temperature. The increase in the tensile strength of the quenched samples as compared with that of un-quenched (as-received) sample showed that the heat treatment and quenching operations influenced the strength of the steel samples. However, the tensile strength of the water quenched samples was higher than those quenched in oil, which may be due to the formation of fine pearlite as a result of fast cooling. Ndaliman (2006) investigated the mechanical properties of a medium carbon steel heat-treated at 850°C and quenched in both water and oil. He found that the tensile strengths of the heat-treated samples were higher than that of the standard AISI C1035 steel sample, with the water quenched sample showing a higher strength.

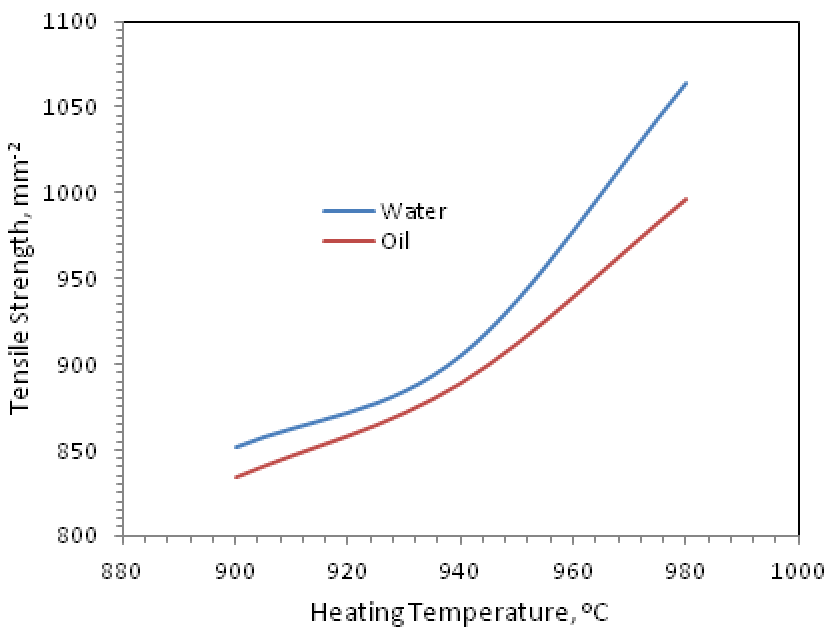


Fig. 2. Change in tensile strength of the medium carbon steel on quenching in water and oil after heating to different temperatures (soaking for 45 minutes).

Figure 3 shows that the elongation percentage of the steel samples increased with increasing the heating temperature for both quenching media. However, the elongation tends to improve for oil quenching compared with water quenching as the faster cooling rate has been reported to have a negative effect on elongation (Gündüz and Çapar 2006).

The transformation temperature is lowered by the increased cooling rate and finer pearlite grains are formed at lower temperatures (Askeland 1996). Martensitic structure, which has a detrimental effect on toughness, is also produced during continuous water quenching (Madariaga *et al*. 1999).

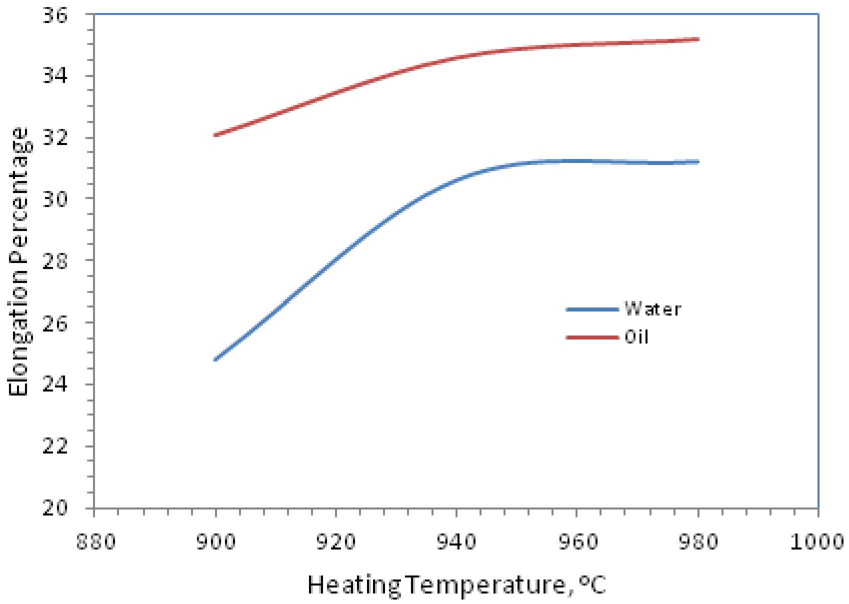


Fig. 3. Change in elongation percentage of a medium carbon steel on quenching in water and oil after heating to different temperatures (soaking for 45 minutes).

The values of the Young's modulus of elasticity were calculated from the tensile strength and strain values and the graph is presented in Fig. 4. As it can be observed in Fig. 4, the value of the Young's modulus of elasticity decreased by increasing the temperature from 900°C to 940°C for both the water quenched and oil quenched samples. Above 940°C, the value of the Young's modulus of elasticity further decreased for the water quenched sample, while it slightly increased for the oil cooled sample, indicating a possible improvement.

The hardness measurements presented in Fig. 5 show that water quenched samples had higher Vickers hardness number compared to oil quenched samples. This may be due to the faster cooling rate of water resulting in highest free carbon in martensite (Gündüz and Çapar 2006). Furthermore, the presence of fine dispersion of small particles in the pro-eutectoid ferrite and pearlitic ferrite, which will hinder the dislocation movement, may have also contributed to the higher Vickers hardness number of the water quenched sample.

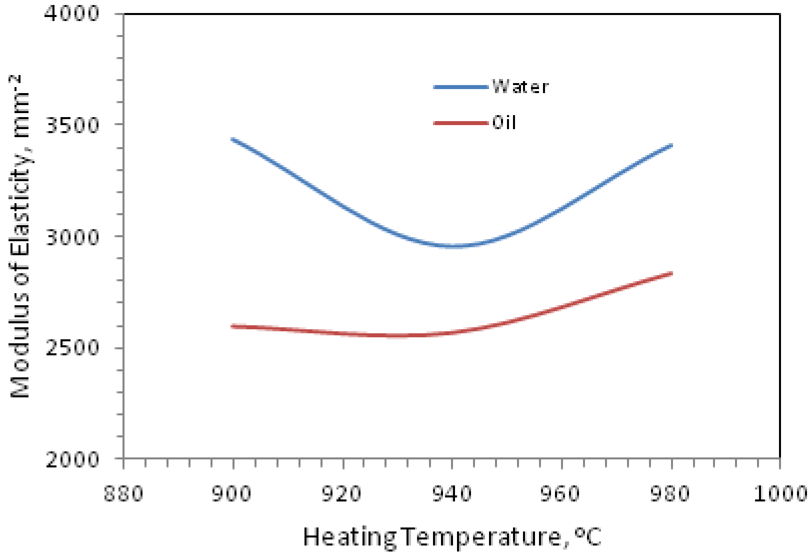


Fig. 4. Variation of Young's modulus of elasticity of a medium carbon steel on quenching in water and oil after heating to different temperatures (soaking for 45 minutes).

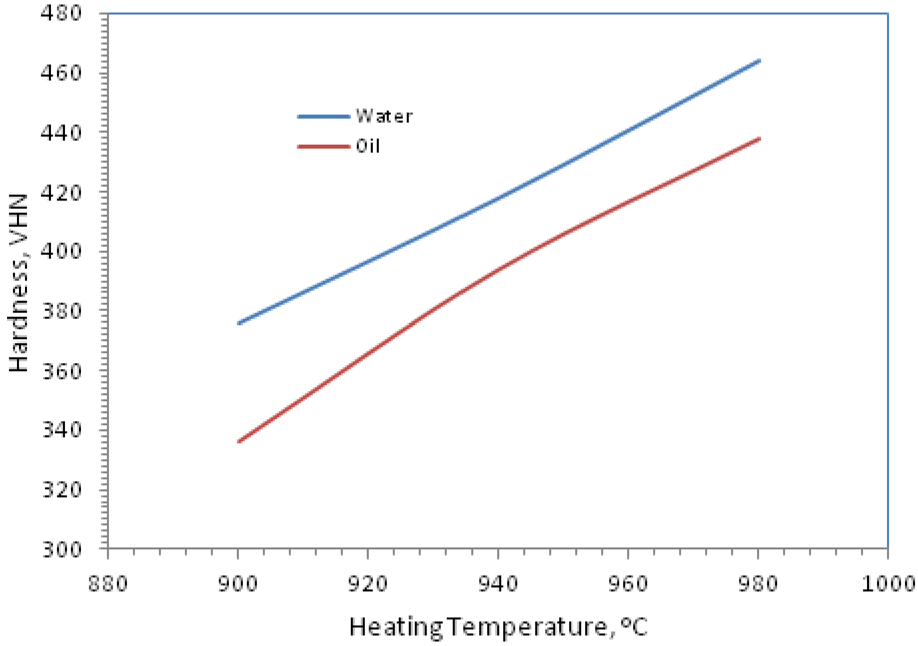


Fig. 5. Change in hardness values of a medium carbon steel on quenching in water and oil after heating to different temperatures (soaking for 45 minutes).

## 4. Conclusion

1. It has been established that palm oil can also be used as a quenching medium for medium carbon steel since the mechanical strength of some of the samples quenched with palm oil improved when compared with those of the as-received sample.

2. Quenching in water resulted in higher tensile strength and hardness possibly due to the formation of martensitic structure after quenching.

3. Palm oil cooling improves the ductility of the steel because of its lower cooling rate compared with water. Therefore, palm oil will be a viable quenching medium in such cases for which the improved elongation of the samples is critical.

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