Global Scientific JOURNALS

GSJ: Volume 11, Issue 9, September 2023, Online: ISSN 2320-9186

www.globalscientificjournal.com

Influence of Quenching Media of Different Viscosities on the Tensile Properties of Mild Steel Rods

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Abstract

This study aims to investigate the effects of various quenching media on the tensile properties of steel, providing valuable insights for the selection of appropriate quenching methods in industrial applications. Tensile tests were conducted on steel specimens that were quenched in various media, including water, vegetable oil, engine oil, and pap. The obtained results were thoroughly analyzed to evaluate the impact of each quenching method on the elongation and ultimate tensile strength of the steel samples. The findings revealed that water quenching exhibited the highest percentage elongation and ultimate tensile strength, indicating improved ductility and strength compared to the other quenching media. Notably, vegetable oil quenching demonstrated significant elongation and strength but slightly lower values compared to water quenching. On the other hand, both engine oil and pap quenching resulted in lower elongation and tensile strength. These findings emphasize the importance of carefully selecting the appropriate quenching media to achieve desired mechanical properties in steel components.

Keywords: tensile properties, mild steel rods, quenching, liquid media, viscosities, ultimate tensile strength, elongation.

1.0 Introduction

Mild steel is a commonly used material in various engineering applications due to its favorable combination of strength, ductility, and cost-effectiveness. The mechanical properties of mild steel can be enhanced through appropriate heat treatment processes, such as quenching. Quenching is a critical step in heat treatment, where the material is rapidly cooled from a high temperature to achieve desired material characteristics. The choice of quenching media plays a vital role in determining the resulting microstructure and mechanical properties of the material (Yao *et al*., 2022). Also, different quenching media, including water, oil, glycerin, and pap, exhibit varying cooling rates and thermophysical properties (Ali et al., 2021). The quenching process is a rapid cooling technique used to cool high-temperature objects by immersing them in a significantly cooler liquid. Several parameters influence the behavior of the quenching process, including the surface properties of the substance, thermal-hydraulic properties of the coolant, and the temperatures of the substance and coolant (NirupamaPatra, et al., 2017).

For low-alloy and tool steels, quenching is performed to achieve controlled amounts of martensite in the microstructure (Abdulhakeem et al., 2022). Successful hardening involves obtaining the desired microstructure, hardness, strength, or toughness while minimizing residual stress, distortion, and the risk of cracking (Samuel et al., 2022; Tran et al., 2021).. The choice of quenchant medium depends on the hardenability of the specific alloy, the section thickness and shape of the object, and the required cooling rates to achieve the desired microstructure. Liquids and gases are the most commonly used quenchant media (Canbay, et al., 2019). Hardness, as a property, is not intrinsic to any material like density or melting point. It is a characteristic that arises from the composition, thermal and mechanical history, and most importantly, the microstructure of the specimen (Abdulhakeem et al., 2022). One widely used method for hardness testing is the Brinell hardness test, frequently applied to iron and steel castings. This method is advantageous for these materials as the results provide an average surface hardness value since their microscopic structure is not uniform (Elia, 2003).

Among the properties of the quenching media, viscosity is a key factor that can influence the heat transfer rate and the material's transformation kinetics during quenching (Kandi et al., 2019). The viscosity of a quenching medium affects its ability to extract heat from the material and control the formation of desired phases, such as martensite (Barrena-Rodríguez et al., 2021). According to Bhagyalaxmi et al., (2023) observed that higher viscosity generally leads to slower cooling rates, which can have significant implications for the resulting microstructure and mechanical behavior of the quenched material.

Extensive research has been conducted to explore a wide range of quenchant options for the production of various steels. Various quenching methods have been thoroughly investigated, including water treatment, different types of oil, salt solutions, liquid metal baths, and pre-heated bitumen (Amuda, et al., 2017; Sharma, 2017; Ramesh & Prabhu, 2014; Herring, 2010; Adeyemi & Adedayo, 2009; Rashid, 1981). Several studies, such as those conducted by Gao et al. (2010), Meng et al. (2009), and Liang et al. (2008), specifically focus on the effect of water quenching on cold-rolled DP steels. These studies reveal that water quenching leads to an increase in hardness and tensile properties of DP steels. Consequently, water as a quenchant is deemed suitable for steels with lower tensile strength and hardenability (Alaneme et al., 2010). Adebayo et al., (2018) investigated the effect of these media (groundnut oil, palm oil, shea butter and air) on the mechanical properties of mid steel, the results showed groundnut oil quenched specimen recorded the highest Vickers hardness number (209.2 VHN) compared to other medium-quenched samples while groundnut oil showed higher ultimate tensile strength which was attributed due to the cooling rate in the media. Also, the air cooled specimen recorded the highest elongation which was attributed to low cooling rate. Previous research by Adekunle et al. (2013) focused on the rate of heat extraction from bio-quenching oils, including melon oil, shea butter oil, palm kernel oil, and palm oil. Their findings indicated that the rate of heat extraction decreases in the following order: melon oil, shea butter oil, palm kernel oil, and palm oil.

However, the precise influence of quenching media viscosity on the tensile properties of mild steel rods remains to be thoroughly investigated using these quenchants namely; water, vegetable oil, engine oil, and pap water. Therefore, this study aims to examine the effects of quenching media viscosity on the tensile properties of mild steel rods. The tensile properties of interest include elongation, which reflects the material's ductility and ability to deform plastically before fracture, and ultimate tensile strength, which represents the maximum stress a material can withstand before fracture. By systematically quenching mild steel rods in different media and analyzing their tensile behavior, this study aims to provide insights into the relationship between quenching media viscosity and the resulting mechanical properties.

2.0 Materials and Specimen Preparation

Mild steel rods of the same batch were obtained for this study. The rods were brought into the workshop and cut into various size lengths to serve as the test specimens. For the tensile tests, specimens were machined on a lathe.

2.1.1 Tensile Test Specimen:

The tensile test specimens were prepared with a specific design. The length of each specimen was set to 70mm. A 10mm portion was machined at both ends of the specimen, leaving a 50mm gauge length in the center. A gap with a diameter of 6mm was machined in between the two 10mm sections. This design allows for accurate measurement of elongation during the tensile test. Five tensile test specimens were prepared in total, with four of them subjected to different heat treatment processes using different quenching media, and one left as received for comparison

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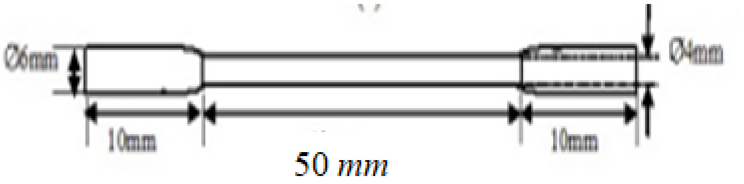

(a) (b)

Fig. 1: (a) Machined Mild Steel (b) Tensile Coupons Specification

2.2 Experimental Heat Treatment:

The prepared specimens were heat-treated to enhance their mechanical properties. The heat treatment process involved heating the specimens to a temperature of 800°C, known as the austenizing temperature. The specimens were soaked at this temperature for a period of 30 minutes to ensure complete transformation. Subsequently, the specimens were quenched in different liquid media with varying viscosities. The selected quenching media for this study included water, oil, glycerin, and pap. Each specimen was quenched in a separate container containing the respective quenching medium.

2.3 Experimental Tensile Test:

Tensile tests were conducted to evaluate the mechanical properties of the quenched specimens. The tests were performed using TBTHST-D50 tensile testing machine (FIG 2). Each specimen was clamped between two split-type chucks, ensuring a secure grip. The tensioning shaft of the machine applied a continuous tensile force to the specimen. During the test, the applied force and the corresponding elongation were recorded using a graph sheet wrapped around the drum of the machine. The elongation was measured using a style (pin), and the values were plotted on the graph sheet.

FIG 2: Tensile Test Machine

Table 1: Parameters of the Tensile Testing Machine

No.	Item	Specification
1	Tensile Impact Load	50kN
2	Grade/Class	Class 0.5
3	Measuring Range of Load	0.4% - 100% FS
4	Relative Error of Indication	±0.5%
5	Load Resolution	1/±300000 FS
6	Measuring Range of Deformation	0.2% - 100%
7	Tensile Impact Test Speed	15m/min
8	High-Speed Tensile Impact Starting Time	≤2.0s
9	High-Speed Tensile Impact Stop Time	≤2.0s
10	High-Speed Tensile Impact Speed Accuracy	≤±0.5%
11	Tensile Impact Position Resolution at High Speed	0.033μm
12	Accuracy of High-Speed Tensile and Impact Load	≤±0.5%
13	Control Method	Computer control
14	Working Voltage	1ph, 220V 50Hz
15	Weight	Approx. 400kg

2.4 Determination of Ultimate Tensile Strength (UTS):

The ultimate tensile strength (UTS) was calculated for each quenched specimen using the recorded data. The ultimate tensile load applied during the test was divided by the cross-sectional area of the specimen. The cross-sectional area (CSA) was determined using Equation 1

$$CSA = \frac{\pi D_o^2}{4} \qquad (1)$$

Where;
D_o is the original diameter of the specimen.

3.5 Determination of Elongation:

The elongation values for each specimen were calculated using Equation 2, while the percentage elongation (P.E), was calculated using Equation 3.

$$E = L_f - L_o \qquad (2)$$

$$P.E = \frac{E}{L_o} \times 100 \qquad (3)$$

Where;

L_f is the final length (mm), L_o is the initial length (mm), E is the elongation, and P.E is the percentage elongation.

3.6 Determination of Viscosities:

The viscosities of the quenching media (water, oil, glycerin, and pap) were determined using a viscometer. The viscometer was equipped with a rotor that rotated inside the liquid, and the corresponding viscosity value was obtained by reading the scale on the instrument. Mild steel rods of the same batch were obtained and brought into the workshop and cut into various size to serve as the test specimens. For the tensile tests, specimens were machined on the lathe.

3.0 RESULTS AND DISCUSSION

The results of the fatigue tests, as well as the tensile, impact, and elongation tests, are presented and discussed below.

3.1 Tensile Test Results

The obtained results from the tensile tests are shown in Table 2, which includes sample identification, original diameter (D_o), final length (L_f), final diameter (D_f), and elongation at fracture in percentage (%).

Table 2: Variation of percentage elongation of specimens quenched in different media

Sample Identification	Lo (mm)	Do (mm)	L_f (mm)	D_f (mm)	Elongation at Fracture	(%) Elongation at Fracture
As received	27.6	4.9	28.8	4.6	0.043	4.3

Water quenched	28.2	5.4	29.3	4.9	0.039	3.9
Vegetable Oil quenched	30.6	4.9	34.4	4.5	0.124	12.4
Engine Oil quenched	26.2	5.0	32.5	2.6	0.240	24.0
Pap quenched	26.7	5.2	35.1	3.4	0.315	31.5

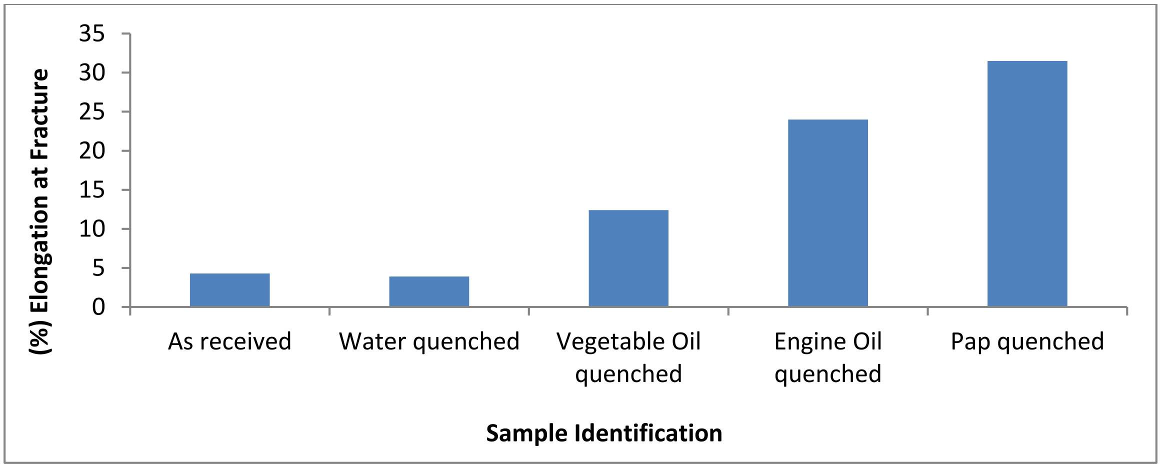

FIG 3: Percentage elongation at fracture versus sample identification, while

Based on the results presented, Table 2 and FIG 3 present the elongation and percentage elongation of the mild steel in the quenching media under review. It can be observed that the pap water-quenched sample exhibited the highest percentage elongation (31.5%) at fracture compared to other media, this can be attributed to high cooling rate also indicating improved ductility, this findings is in agreement with the work of Bhagyalaxmi et al., (2023). This shows pap water has low viscosity which fastens the cooling rate from the mild steel sample into the media. Samples quenched in engine oil quenched and vegetable oil-quenched experienced elongation at 24.0% and 12.4% respectively. Also, As received and water quenched samples showed slight elongation. The low elongation shows that the mild steel quenched in water and As received media tend to have higher stiffness and maintain its shape, also, it is less prone to permanent deformation thus minimal risk of material failure. This is in agreement with the findings of Yue, et al., (2018) & Omoniyi et al., (2022).

The ultimate tensile strength represents the maximum stress a material can withstand before breaking. From the data, it can be observed that the water-quenched sample exhibited the highest ultimate tensile strength (848.20 MN/m^2), this collaborates with the elongation findings. Followed by the vegetable oil-quenched sample (765.43 MN/m^2), the as-received sample (768.19 MN/m^2), the engine oil-quenched sample (640.55 MN/m^2), and the pap-quenched sample (550.85 MN/m^2). These results suggest that the water-quenched sample had the highest strength among the tested samples, indicating that water quenching might have resulted in improved hardening and strengthening of the material. On the other hand, the pap-quenched sample showed the lowest ultimate tensile strength, suggesting that the quenching process using pap had a lesser effect on enhancing the material's strength.

Table 3: Ultimate Tensile Strength (UTS) of specimens quenched in different media

Sample Identification	Diameter (mm)	Ultimate Tensile Load (N)	Cross-sectional Area (mm^2)	Ultimate Tensile Strength (MN/m^2)
As received	4.9	14518.8	0.0000189	768.19
Water quenched	5.4	19423.8	0.0000220	848.20
Vegetable oil quenched	4.9	14466.6	0.0000189	765.43
Engine oil quenched	5.0	12554.8	0.0000196	640.55
Pap quenched	5.2	11678.0	0.0000212	550.85

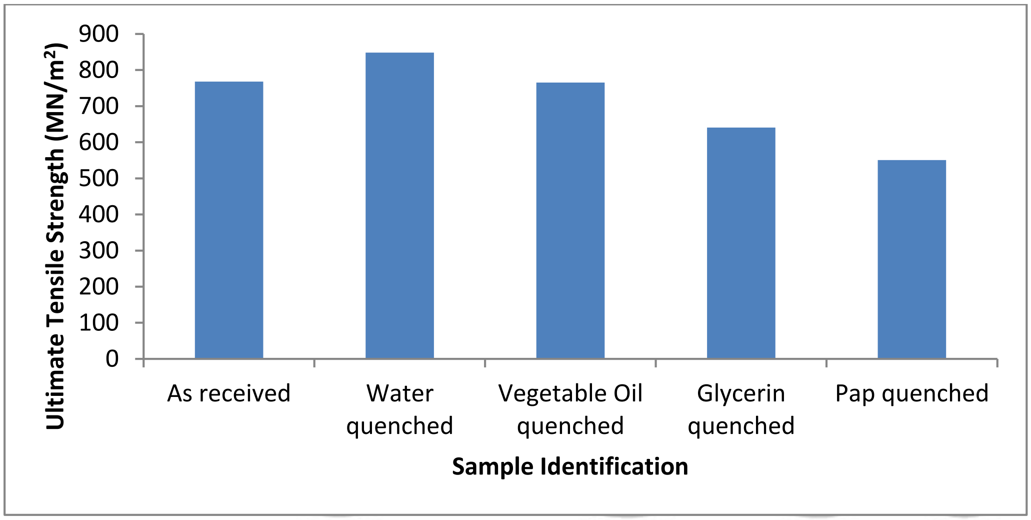

FIG 4: Ultimate Tensile Strength vs Sample Specimens

4.0 CONCLUSION

In this research, the tensile properties of mild steel rods quenched in liquid media of different viscosities were studied. The results of the study indicate that water quenching resulted in the highest ultimate tensile strength among the tested samples, demonstrating effective hardening and strengthening properties. The vegetable oil-quenched sample showed the second-highest tensile strength, while the engine oil and pap-quenched samples exhibited lower strengths. The as-received sample, without specific quenching treatment, still displayed inherent strength. These findings emphasize the significance of selecting suitable quenching methods to achieve desired mechanical properties in materials, with water quenching proving to be the most advantageous in this study.

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