The Role of ZnO Nano-fluids on Heat Treatments of Medium Carbon Steel

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Abstract. Conventional quenching versus ZnO-NP emulsion and heat treatments for medium carbon steel (CK45) has been carried out in laboratory environment condition. For comparison, the mechanical properties of CK45 and microstructure were examined. The main parameter focused in this work was the concentration of ZnO-NP in deionized water. Thus, emulsion represents a quenching medium for CK45 specimens. Optical microscope analysis for CK45 microstructure, hardness and tensile test for all specimens were done to evaluate the role of nano ZnO additives as quenching media at different concentration. Experimental results reveal that the addition of nanoparticles to the base fluid (water) astonishingly enhanced some mechanical properties as tensile strength and yield stress. 2wt.% of ZnO-NP raised the yield 14.8% and the UTS by 16.9%.

1. Introduction
Heat treatment is a combination of timed heating and cooling applied to particular metal or alloy in the solid-state in such a way as to produce certain microstructure and desired mechanical properties. Heat treatment is a procedure that includes a combination of heating, cooling and time-controlled operations of metal without changing the item shape and to get a desire mechanical properties of the metal or alloy [1]. The motivation behind heat-treating carbon steel is to modify the mechanical characteristics of steel, such as hardness, strength, ductility, impact resistance and yield tensile. The physical properties such as thermal conductivity also slightly changed during the heat-treatment process. The hardening mechanism by quenching is performed to avoid ferrite or pearlite formation and promotes bainite or martensite to be formed, The quenching medium choice relies upon the hardenability of a specific compound of alloy [2]. The segment thickness and shape included, and the cooling rate needed to accomplish the desired microstructure. Heat-treatment of numerous items utilized in our everyday life is done to get the necessary properties, for example, nuts, fasteners, joints, cams, dragger, furrow shave, rocket external shell packaging, and spout of rockets, spanner and numerous applications. The major requirement of medium carbon steel is high yield strength, high proportional limit and fatigue strength. These properties can be achieved by alloying elements or by heat treatment [3, 4]. Nanofluid is another sort of heat-transfer medium, containing nanoparticles (1–100 nm) which are consistently and steadily disseminated in a base liquid. These appropriated nanoparticles, for the most part, a metal or metal oxide incredibly improve the thermal conductivity of the nanofluid, builds conduction and convection coefficients, considering more heat transfer [5]. Nanofluids have been considered for applications as assortment and the multifaceted nature of the nanofluid frameworks, no understanding has been accomplished on the size of potential advantages of utilizing nanofluids for heat transfer applications [6]. It has been demonstrated that the nanoparticles will upgrade the heat conductivity and improve heat execution of heat-transfer of the base liquid [5].
Concentrates on the exhibition of nanofluids with different sorts of particles have been done by numerous scientists [7-9].

The present work is aimed to improve the mechanical properties of carbon steel type CK45. The quenching and tempering of carbon steel samples in traditional media water and nanofluid consist of water and ZnO-NP nanoparticles with different concentration. The consequence of nanofluid concentration was examined to demonstrate an optimal ratio of nanoparticle, which is used to attain the desired material properties.

2. Materials and Method
The analytical chemical composition of medium carbon steel bar type CK45 samples used for this work is given in Table 1. The medium steel bar machined in order to produce fourteen tensile samples according to ASTM E8M-04, as shown in Figure 1. In every concentration, it takes two tensile samples. The quenching temperature was 850°C and tempering temperature 300°C by using electrical muffle furnace. The microstructure analysis and hardness test employed to study the samples after quenching and tempering; consequently, the samples were taken from the tensile samples after the test was done. The samples used for metallographic examination mounted by hot mounting and grounded via silicon carbide emery paper with various grades (200-1200) and polished using alumina slurry (0.05 micron), after drying applied Nital etching solution (2Vol.% HNO₃) in ethanol solution.

In order to study the effect of ZnO-NP as quenching media, water base emulsion containing Zn-NP temperature was kept the constant (82 ± 2 °C) during the quenching process by immersing the container (Figure2) in a water bath. The microstructure, hardness (HRC) and tensile strength studied as significant outcome values. The nanofluid of ZnO of 20nm average particles size (APS) purchase from Shanghai Xinglu Chemical Technology. Co., Ltd. Supported details are listed in Table.2.

Table 1. Chemical composition of CK45.

| Element                      | C   | Mn   | Si   | Cr   | Ni   | Mo   | Cu   | P     | S     |
|------------------------------|-----|------|------|------|------|------|------|-------|-------|
| Actual                       | 0.430 | 0.574 | 0.256 | 0.0241 | 0.0396 | 0.004 | 0.0934 | –     | –     |
| CK45 (ASTM A681)             | 0.42-0.50 | 0.50-0.80 | 0.40 | 0.40 | 0.40 | 0.10 | 0.25 | 0.035 | 0.02-0.04 |

Figure 1. Photograph of tensile samples after fracture machined according to ASTM E8M-04.
Table 2. Physical properties of Nano Zinc Oxide powder (ZnO).

| Physical properties of ZnO |
|---------------------------|
| APS (nm) | Purity (%) | SSA (m²/g) | Volume density (g/cm³) | Density (g/cm³) | Crystal form | Color |
|----------|------------|------------|-------------------------|-----------------|--------------|-------|
| 20       | >99.0      | 100        | 0.3 -0.45               | 5.6             | Cubic        | White |

The amount of ZnO dissolved in water were suggested by using Design of Experiment (DOE) model. The input data was range from 0 to 3.8wt.% of ZnO and the other factor was the specific heat data of ZnO were taken from Vajjha [10] at 82°C. The outcome results data was analyzed by ANOVA cubic model. The suggested model for DOE of the amount of ZnO nanopowder (0, 0.25, 0.5, 1, 2, 3.2, 3.5, 3.8) wt.% and the specific heat are listed in Table 3. To describe the procedure of preparing nanofluid of ZnO-NP, by dissolving an exact amount of ZnO-NP measured by 4-digit balance in 500ml of deionized water and sonicate the solution for 1hr, followed further stirring the solution by magnetic stirrer (250rpm) at room temperature. This process repeated in each concentration of ZnO-NP.

![Figure 2. The quenching container made of aluminium Al6061.](image)

Table 3. Parametric of quenching media containing ZnO-Np in deionized water solution and the significant out-coming mechanical properties.

| No. | Sample name | ZnO-NP (wt.%) | Specific Heat (J/kg. °C) | Hardness (HRC) | UTS (MPa) | Yield Stress (MPa) |
|-----|-------------|---------------|--------------------------|----------------|-----------|-------------------|
| 1   | b           | 0             | 3342.04                  | 77             | 1120      | 1080              |
| 2   | b           | 0             | 3342.04                  | 77             | 1120      | 1080              |
| 3   | b           | 0             | 3216.48                  | 77             | 1120      | 1080              |
| 4   | b           | 0             | 3090.91                  | 77             | 1120      | 1080              |
| 5   | c           | 0.25          | 3216.83                  | 65             | 1240      | 1180              |
| 6   | c           | 0.25          | 3216.83                  | 65             | 1240      | 1180              |
| 7   | d           | 0.5           | 3321.36                  | 50             | 1260      | 1190              |
| 8   | e           | 1             | 3216.83                  | 50             | 992       | --                |
| 9   | e           | 1             | 3090.91                  | 50             | 992       | --                |
| 10  | f           | 2             | 3386.36                  | 63             | 1320      | 1240              |
| 14  | g           | 3.8           | 3386.36                  | 62             | 1310      | 1260              |
| 15  | g           | 3.8           | 3279.06                  | 62             | 1310      | 1260              |
| 16  | g           | 3.8           | 3279.06                  | 62             | 1310      | 1260              |
3. Results and Discussion
The model of surface response as represented in Figure 3 for the hardness model, which is the most effective factor affected the properties as listed in Table 3 of the CK45 medium carbon steel. In Figure 3a, the desirability of surface response was a range between 2-3.5 wt%. However, the hardness predicted at that range is 79 HRC as shown in Figure 3 b,c. The ultimate tensile strength (UTS) model graph as shown in Figure 4 a,b represent a linear fit factor graph, at the upright quarter in the graph of the relation between specific heat and weight percent, the UTS is around 1300 MPa when the specific heat in the maximum. The variation and inclined line in Figure 4a, provide the most significant factor effected on the model. Moreover, the yield stress model graph with a cubic fit summarized of 1260 MPa yield in range 1-2 wt%. with a less effective response in 3.8 wt.%.

Figure 3. The hardness model graph of the quadratic fit factor for the surface response, (a) the desirability factor in the maximum specific heat near the satisfactory in the region around 3wt% of ZnO-NP, (b) the predicted hardness 79 HRC, (c) 3D surface for the three factors.
Figure 4. The UTS model graph of the linear fit factor for the surface response, (a) the effective factor of UTS suggested is 1300 MPa, (b) 3D surface of the three parameters.

Figure 5. The Yield stress model graph with a cubic fit factor for the surface response, (a) the effective factor of Yield suggested is 1300 MPa, (b) 3D the surface of the three parameters.

The experimental results of the stress-strain curve of as received (annealed) CK45 tensile test as shown in Figure 6, the curve has obvious yield stress which is 311 MPa and ultimate tensile strength of 600 MPa. On the other hand, the stress-strain curves of CK45 after hardening and tempering is much higher. It is notable from Figure 6, the best UTS of the quenching media contains 2wt.% ZnO-NP and then followed by 3.8wt.%.
Figure 6. The stress-strain curves of CK45, the annealed (as received) CK45 after machining and the stress-strain curves after quenching and tempering in various wt.% of ZnO-NP.

From previous, it’s clear of increasing the amount of ZnO-NP will reduce the specific heat, and that proved by Vajjha [10]. The yield stress of quenching solution containing 2wt.% of ZnO-NP, slightly decreases from 1240 MPa to 1240 MPa, followed by 0.5wt.% and 0.25wt.% of ZnO-NP. In contrast, 1wt.% of ZnO has an adverse effect and reviles excessive over quenching with no clear yield stress point. Meanwhile, the 0wt.% of ZnO-NP has medium strength and yield as usual. The optical microstructure of CK45 after quenching at fully austenitic temperature 850°C followed by tempering at 300°C reveals the fully and partially martensitic microstructure is represented in Figures 7. In Figure 7a, or as received (annealed) sample has ferritic and pearlitic microstructure (light and dark respectively), the fully martensitic as shown in Figures 7 (b, c and d) with slightly existing of bainite structure, this approved with Ramesh [11]. In Figure 7e, the excessive of bainite structure during high cooling rate in 1wt.% of ZnO-NP this leads to conclusion of this amount has high dissipation cooling rate than distilled water, in Figures 7f, e, the microstructure have more homogeneous fine martensite with perlite and bainite, that diversity in composition leads to versatility in mechanical properties of medium carbon steel.
Figure 7. Optical microstructure of CK45, (a) annealed (as received), (b) 0wt.% ZnO-NP, (c) 0.25wt.% ZnO-NP, (d) 0.5wt.% ZnO-NP, (e) 1wt.% ZnO-NP, (f) 2wt.% ZnO-NP, (g) 3.8wt.% ZnO-NP.
4. Conclusion
In this study concentrate on new additive for water quenching media for medium carbon steel (CK45). In an industry where the emission of fumes during quenching which is consist of vaporizing oil and chemicals which is used during the process and has a hazard effect on the employers. The ZnO-NP has significant effects on cooling rate, which promotes the cooling rate at 1wt.% and that effect decreased with increasing ZnO-NP. At 2wt.% of ZnO-NP, the emulsion promotes some of the mechanical properties. The yield and the ultimate tensile strength kept high enough as compared with using water itself. The microstructure for 2wt.% ZnO-NP has found a fine microstructure of martensite with residuals of pearlite and bainite. The faster cooling rate reviles excessive of bainite with carbides when using 1wt.% of the zinc oxide nanoparticles.

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