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Effect of Addition CuO Nanoparticle to Quenching Media on Properties of Medium Carbon Steel

Abstract*- In current work the effect of addition CuO nanoparticles to the polyalkylene glycol (PAG) water solution quenching media on some properties of medium carbon steel was examined. Five cooling media was used to quenching the steel: water, 5 and 10 % water solution of polyalkylene glycol, and 5 and 10 % water solution of polyalkylene glycol with addition of 1% of CuO nanoparticles. In addition, in this study, the cooling curves for these media and the properties of tensile and affect for quenched and unquenched medium carbon steel were studied and evaluated. The results showed that the addition of CuO nanoparticles strongly improve the quenching media features and contribute to reduce water quenched sample defects (such as distortion and cracking), while at the same time still maintaining the desired mechanical property improvements. The experimental observations indicate that samples quenched 5% polyalkylene glycol water solution of with 1% CuO nanoparticles brought the best combination of mechanical properties.*

Keywords*- Impact test, Quenching medium, Polymer quenching medium, Tensile strength.*

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1. Introduction

Quenching treatments refer to the processes of rapidly cooling of the austenitized steel for the purpose of transformation of the austenite to martensite and avoid forming other softer constituents (ferrite, pearlite, and retain austenite) [1]. It is essential to choose a proper quenchant to achieve this goal. Many parameters affected the quenching media, which can be selected, including the type, and thermal features of the quenchant, the conditions of using quenchant (like speed, temperature, and concentration of polymer, etc.), thickness of component, and the transformation features of the alloy to be quenched [2,3]. Successful quenching treatment always means obtaining the required as quenching properties such as hardness, strength, or toughness while at the same time reducing internal and residual stresses which forming within the component during quenching process in order to avoid distortion, and the possibility of cracking [4]. Oil and water were used, for many years, as quenching media for hardening steel. Water is an effective quenching medium; however, its ability to quickly extract heat often leads to cracking the components during quenching treatment. Oil is also an effective quenching medium for several alloys, but smoke can be generated during quenching process due to high vapor pressure of oils and frequently produces fires in quench equipment [5,6]. Nowadays, with the continues in engineering advancements and increasing concern over the environment, climate, and safety issues an increased attention was devoted to the improvement, and evaluation of a new quenching media as substitutes to quenching water and oils [7,8]. The nano particles addition to quenching media provide a chance to employ a new process and to produce medium sized grains materials. Nano fluids are the fluids, which contain colloidal suspensions of nanoparticles [9]. Nano fluids can offer a new possibility through the heat transfer improvement in comparison to conventional media which can be have better features than the pure fluid. In current work, different quenching media (water, 5% polymer water solution, 10% polymer water solution, 5% polymer water solution+1% nano CuO, and 10% polymer water solution+1% nano CuO) was used to hardening the medium carbon steel samples. The main objective of this work is to study effects of addition of CuO nanoparticles to quenching baths on properties of quenched samples. The tensile and impact properties of samples were investigated. In addition to the cooling curves of the different quenching media were determined and evaluated.

2. Materials and Methods

I. Materials and Equipment

In order to determine the response of steel to various quenching operation, an alloy of medium carbon steel with chemical composition of 0.42%C, 0.22%Si, 0.5%Mn, ≤0.04%P, ≤0.05%S, ≤0.05%V, ≤0.05%Pb and the reminder Fe was procured. polyalkylene glycol (PAG) and CuO nanoparticle powder were also used to serve as the quenching media. The equipment used to perform the practical part of research includes: electrical furnace, thermocouple, digital timer, tensile testing machine, and impact testing machine.

II. Methods

Samples preparation and heat treatment procedure

The as-received bulk rod of 14 mm diameter machined by using a lathe and milling machine to tensile sample configuration (Figure 1) with gauge length of 62.5 (mm) and diameter of 12 (mm) in according with ASTM-E8; and Charpy impact sample configurations (Figure 2) with dimensions of 55 x 10 x 10 (mm) with 2 (mm) notch in according with ASTM-E23. Six sample sets were machined each for the predetermined five different quenching media and one for the control. The samples were primarily annealed by heating to austenitic region and allowed to cool in furnace to remove the stresses and mechanical history of the machined specimen [8]. Subsequently, all samples were heat treated at 810 °C in an electrical furnace and soaked for 30 min prior to rapid cooling in prepared various quenching media mixtures of (water, 5% polymer water solution, 10% polymer water solution, 5% polymer water solution+1% nano CuO, and 10% polymer water solution+1% nano CuO) placed in a vertical tube. The quenched samples were cleaned and designated to avoid mix-up in the course of inspections as illustrated in Table 1.

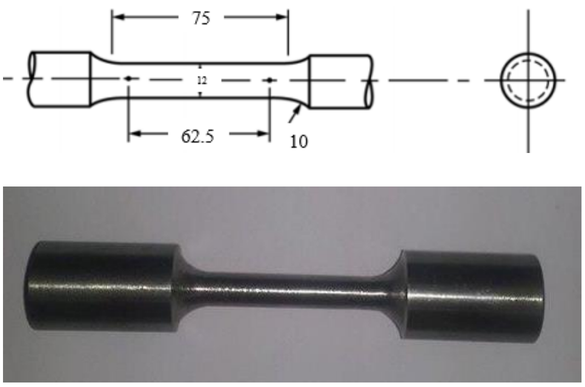

Figure 1: Tensile test specimen (all dimensions in mm)

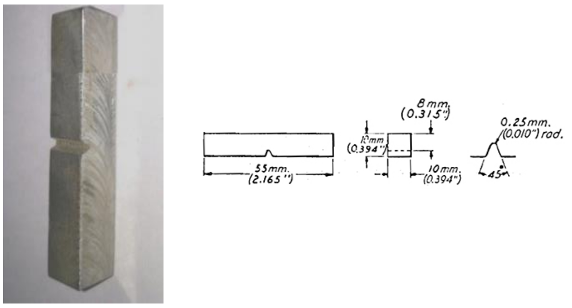

Figure 2: Charpy Impact Test Specimen (all dimensions in mm)

Table 1: Test samples classification

No.	Symbol	Heat Treatment	Quenchant
1	A	As received	……….
2	B	Quenching	water
3	C	Quenching	5% polymer (PAG)+95% water
4	D	Quenching	10% polymer (PAG)+90% water
5	E	Quenching	5% polymer (PAG)+94% water+1% Nano CuO
6	F	Quenching	10% polymer(PAG)+94% water+1% Nano CuO

Cooling curve determination

A thermocouple inserted in each sample and when heated sample quickly moved from the furnace to quenching medium the temperature and time were determined by using thermocouple reading and digital timer. The readings were recorded and cooling curves were plotted directly.

3. Results and Discussion

I. Cooling curve

The resultant cooling curves indicate that the addition of polyalkylene glycol (PAG) to water based quenching medium leads to reducing the velocity of heat transfer from the heated elements. In addition, introducing CuO nanoparticles into the quenching bath boosts the effect (reducing the cooling rate). Figure 3 presents the change of temperature with time. It can be observed that there is a considerable reducing in cooling speed in the region below the temperature of 800°C and the cooling rate becomes stabile below the temperature of 100°C for baths with addition nanoparticles. In addition, Figure 3 indicates that the 5 and 10% polyalkylene glycol water solution of with 1% CuO nanoparticles has the lowest cooling speed. The highest cooling speed for this quenchant in the range of the lowest austenite occurrence area on CTP diagrams for this steel grade and slower cooling in the range of initial martensitic transformation temperature, that ensures reduce stress values, reduce dimension changes, and less deformation of the quenched components. which led to a conclusion that the most beneficial system was obtained for the 5 and10% polyalkylene glycol water solution of with 1% CuO nanoparticles.

II. Tensile strength

Figure 4 shows the ultimate tensile strength (UTS) result of steel samples quenching in different media. The as received sample as expected, exhibited the lowest the ultimate tensile strength, and this result for the as received sample was agreement with observation of many previous researcher [10,11]. While the quenched sample showed a significant improvement in tensile strength values, which confirm that the tensile stress of steel strongly depends on individual phases formed in the metal. Sample B quenched in water showed the highest value, which indicate the capability of this sample to withstand highest load prior to failure as compare with others. However, as result of extreme brittleness and high residual stresses, which formed in sample B during quenching process, almost these samples are inapplicable practically unless followed by tempering treatment. Tempering treatment means additional process leading to increase the time and cost of hardening process. In the other hand, sample E quenched in 5% polymer + 1% CuO displayed a tensile strength value which is very close to that for sample B with advantage of keeping the desired mechanical property improvements (toughness strength). Adding the CuO nanoparticles will help to provide homogeneous heat transfer rate by increasing actual contact surfaces points. [12] states that the increasing in the actual surface contact point of the nanoparticle in relative to traditional media improves the extract heat from hot objects, and raise the suspension stability. The UTS of sample C was reduced to 779 (MPa) while the obtained tensile strength values of the samples D and F were comparable values in the range of 694-701 (MPa). These results indicate that formation of hard phases (martensite and bainite) was limited while in the same time the volume fraction of soft phases (ferrite and pearlite) become more predominate.

IV. Toughness

The resultant toughness values showed in Figure 5 varied strongly depending on the kind of quenching media. Highest toughness strength value was obtained for the sample E quenched in 5% polyalkylene glycol water solution of with 1% CuO nanoparticles. It is the result of lower stresses forming in the sample that was cooled at a lower speed in quenching media with polymer agent. This larger toughness for the samples E attributed to the changes of cooling speed in such quenching medium. The addition of nanoparticles to cooling medium will ensure fast cooling rate in the range of the smallest area of forming of austenite (500–600ºC) on TTT diagram for medium carbon steel. This leads to prevent the formation soft phases (ferrite and pearlite) in quenched microstructures. Slower cooling temperature at the starting of martensite transformation confirms create the lowest residual stresses. Moreover, this will reduce dimension changes and reduce deformation of quenched parts. This is associated with lower tetragonality of martensite create in microstructure of medium carbon steel. Similarly, Sample F exhibits relatively high value of toughness strength quenched in 10% polyalkylene glycol water solution of with 1% CuO nanoparticles while the toughness strength for samples C and D were reduced to 93 and 46 (J) respectively as a result of microstructure modifications and increase the brittle nature of formed phases.

4. Conclusion

Based on experimental results, it can be concluded:

1. The addition of CuO nanoparticles strongly improves the quenching media features and contribute to reduce water quenched sample defects (such as distortion and cracking), while at the same time still maintaining the desired mechanical property improvements.
2. The mechanical properties are mainly dependent on cooling rate behavior within transformation temperatures range of quenching bath.
3. The quenching bath of 5% PAG water solution with addition of 1%CuO nanoparticles produced excellent combination of mechanical properties (tensile and impact energy) relative to other quenchants.
4. Modification of the quenching media by addition of CuO nanoparticles leads to the best cooling capabilities in relative to the conventionally quenching media.
5. Higher toughness strength was obtained on samples quenching in the media with Nano CuO as compare to those for samples quenched in the media without added nanoparticles.

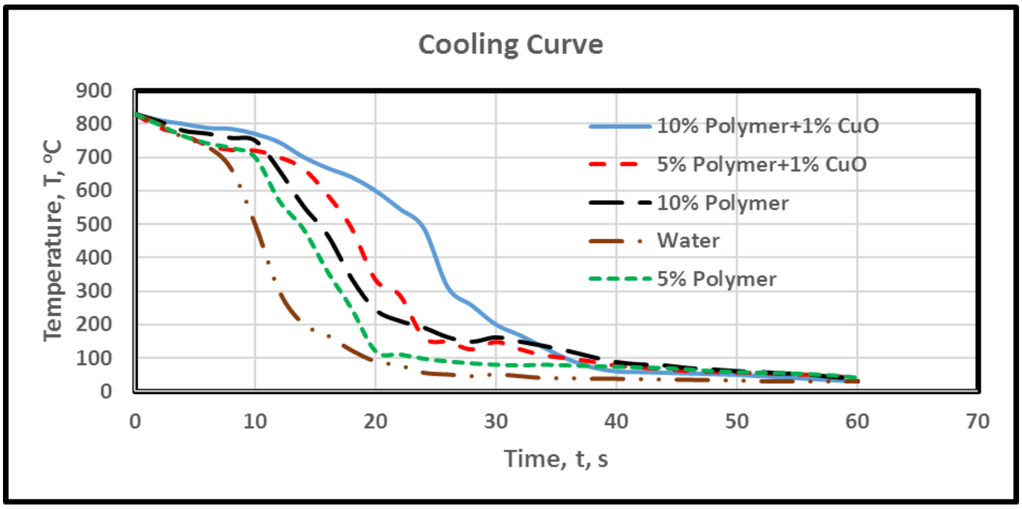

Figure 3: Cooling curves for samples hardened at various quenching media

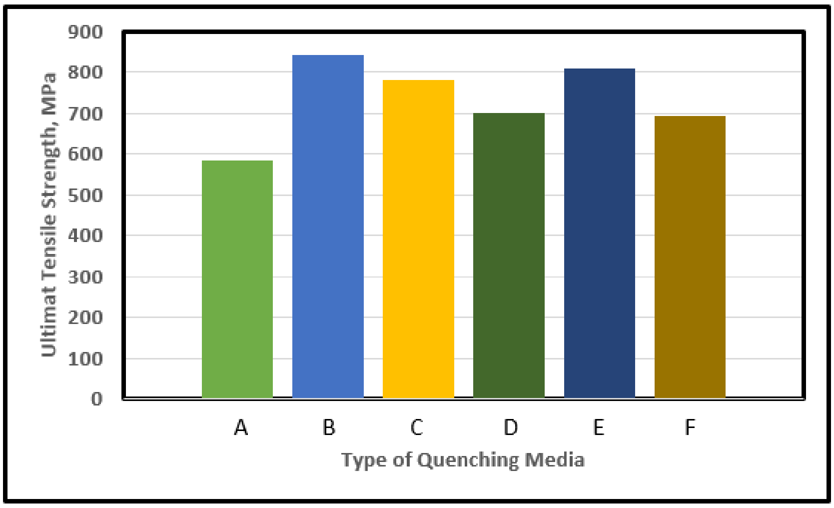

Figure 4: The effect of varying quenching media on ultimate tensile strength

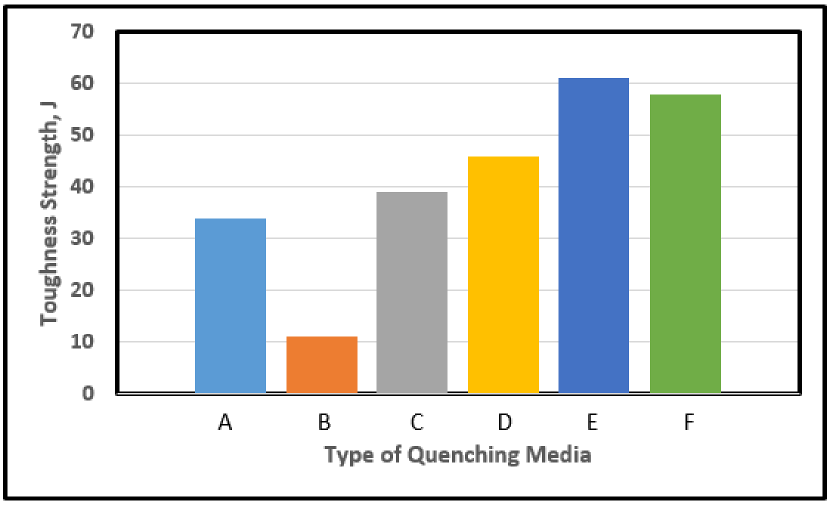

Figure 5: The effect of varying quenching media on toughness

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