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Research Article

The effectivity of used-oil as quenching medium of 42CrMo4 steel for automotive materials

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ABSTRACT

The research aims to investigate the effect of the cooling medium on the hardness characteristic and microstructure of the 42CrMo4 steel due to hardening treatment at a temperature of 830°C and holding time of 30 minutes. Various oil such as SAE-10W40, SAE-20W50, SAE-40, and used oil was used in the cooling medium. The changes in product size, hardness, and microstructure have been carefully assessed. The results indicated that the viscosity of the coolant medium strongly influenced the cooling rate of the cooling medium, hardness, and microstructure. SAE-10W40 oil and SAE-20W50 oil only needed 2 hours to return within room temperatures before quenching, whereas SAE-40 oil and used oil took 3 hours. The sample size did not change after hardening-quenching. However, there was a residual carbon layer on the sample surfaces. Quenching caused the changes of microstructure from pearlite and ferrite to ultrafine double phase, consisting of martensite and austenite, which were unable to transform during rapid cooling. The highest hardness value was achieved by the treated product, which was quenched in SAE-10W40, which had 54.59 HRC. The high hardness was attributed to the content of 95% martensite. However, used-oil caused in similar hardness as SAE-20W50.

1. INTRODUCTION

Working conditions involved high temperatures, and heavy loads commonly need high quality of construction with a proper characteristic of materials. The mechanical properties such as the strength of the material, impact toughness, fracture toughness, fatigue resistance, material hardness, and wear resistance were needed to address its conditions. As an alternative, medium-carbon steel with a martensitic or tempered-martensitic structure has been developed since the early 1980s and was commonly used in automotive and mechanical construction, oil drilling, and gas industry, including other application of manufacturing industries [1].

Low alloy steel containing chromium and molybdenum was widely used for wear and corrosion-resistant parts due to its strong hardening properties [2]. Similar to 42CrMo4 steel, which was medium carbon steel with Cr-Mo alloy parts, was mostly used under conditions of quenching and tempering [3]. The type of 42CrMo4 steel was commonly used as a structural material for automotive parts that often have various types of static and cyclic loading [4][5].

The coefficient of friction and the rate of carbon steel wear decreased with increased surface hardness [6]. Moreover, wear resistance was not only related to material hardness, but it was also determined by microstructure. The mechanism of wear was dependent on the composition and the microstructure. The optimum combination of mechanical properties of steel could be obtained from the creation of the ultrafine dual-phase microstructure [7][8].

The dual-phase ultrafine was of high strength [9]–[11]; its structure consists of martensite/bainite and retained austenite [12]. This phase was achieved by heat treatments such as hardening, case hardening, normalizing, and tempering [13]. Traditional quenching and tempering of steel material were widely applied to have a healthy combination of both strength and toughness of martensite structures [14]–[17]. The phase of martensite had a beneficial interstitial carbon that produces high hardness, high strength, but brittle [18]. At high temperatures inhibited by chromium, the diffusion of carbon atoms to martensite produced cementite particles in globular forms [19]. However, a certain amount of austenite retained could theoretically increase the ductility and toughness of the steel [20].

Water as a cooling medium had several disadvantages. First, rapid cooling rates at lower temperatures, where distortion and cracking were more likely to occur, so water cooling was usually confined to simple cooling. Second, the use of water results in layers or steam blankets that create steam traps and, as a result, generate unequal hardness and stress. Therefore, unequal distribution of tension resulted in distortion or soft spots. Water cooling in steel products could also cause corrosion, ultimately requiring faster handling.

The use of oil as a cooling medium consisted of mineral oil and vegetable oil. Oil could be typically applied with additives. The use of mineral oil and plants as a coolant in the quenching process indicated that the two oils have fairly close effects. Oil had the advantage of being able to be used effectively at different temperatures. Generally, oil had a slower cooling rate relative to water or saltwater. This cooling medium could, therefore, provide less distortion and cracking to the quenching results. Oil had various flash points ranging from 130 - 290°C. To prevent the risk of oil burning, the temperature of the cooler was typically between 75°C and 110°C below the flashpoint [21].

Not all traditional metal industries are concerned with steel heat treatment processes, including the hardening-quenching process. The combination of both processes can improve the mechanical properties of steel, such as strength, hardness, and wear resistance. The steel is heated to a hardening temperature and then rapidly cooled using a quenching medium to improve the mechanical properties. Water and oil are the most accessible means of quenching to find and are most commonly used. This work focuses on the use of oil as a cooling medium. Besides, special oil as a quenching medium is not freely sold on the market, which means that alternative oil is needed that is readily available on the market. The purpose of this study is to determine the relationship between the physical properties of the oil. Used oil is used as an alternative way of squeezing to reduce production costs.

2. MATERIAL AND METHODS

The material selected in this study was 42CrMo4 steel with an initial hardness value of 27.11 HRC. Based on the composition test, the initial material has chemical ingredients, as presented in Table 1. The microstructure of 42CrMo4 steel before quenching is given in Figure 1. It was found that the microstructure is made up of fine pearlite (P) and ferrite (α). The ferrite phase is greyish-white, and the dark pearlite phase is shaped like fingerprints.

Table 1. Chemical composition of 42CrMo4 steel before hardening.

Contents	%
C	0.456
Si	0.25
Mn	0.667
P	0.02
S	0.02
Cr	0.954
Mo	0.147
Ni	0.028

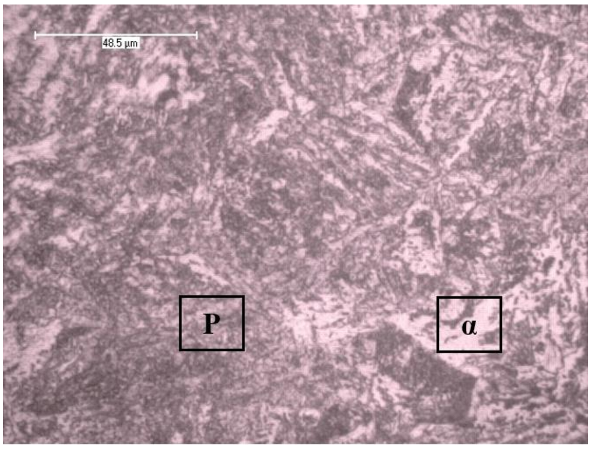

Figure 1. The 42CrMo4 steel microstructure before quenching (p is pearlite, α is ferrite).

The samples in the form of 20 mm diameter steel cylinders and 20 mm height are shown in Figure 2, whereas Figure 3 illustrates sample sizing before hardening. The cooling media used are oil, SAE-10W40 oil, SAE-20W50 oil, and SAE-40 oil. The used oil was obtained from motorcycle repair shops with customers who, on average, use multi-grade oil such as SAE10W40, and SAE-20W50. The test findings using the Zahn cup indicated that the oil used has a viscosity of 208.38 cSt, following the SAE-20 oil criterion. Each type of oil was supplied with 3 litres of 3 test samples.

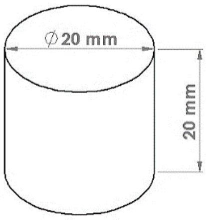

Figure 2. The size of the sample used for the hardness test and microstructure observation.

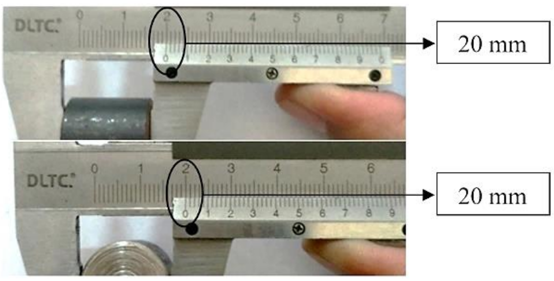

Figure 3. Sample sizing before hardening.

The process of hardening is shown in Figure 4, where the steel was heated to 830^{0}C and held for 30 minutes, accompanied by rapid oil cooling. The heating process used a heat treatment furnace with 3 phase AC electricity, a potential difference of 400 V, a frequency of 50/60 Hz, a current of 28.8 A, and 20 kW, which results in maximum furnace temperature of 1280^{0}C.

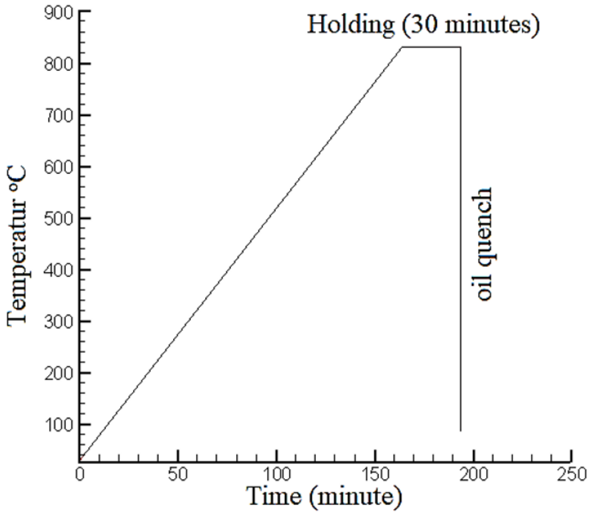

Figure 4. Hardening process.

The temperature of the tested samples was observed using an infrared thermocouple. The thickness of the sample was measured by a ruler with an accuracy of 0.02 mm. The chemical composition of the material has been tested with an emission spectrometer (brand Hilger, serial number E-9-OA701, 20 element/2 capacity cast iron and steel system, type E2000-Fe). The microstructure was examined using a metallographic microscope machine (Nikon brand, series no. 661103, 500x size, model X1005TTEPL). Steel hardness testing was carried out using the Rockwell C or HRC scale process. The indicator used a 120° angle diamond tip, a load of 150 kgf/1471.5 N in compliance with the Rockwell ASTM E18 hardness requirements.

3. RESULTS AND DISCUSSION

3.1. Cooling rate

A comparison of cooling rates after quenching treatment is shown in Figure 5. SAE-10W40 and SAE-20W50 oil cooling speeds are higher than that of the SAE-40 and the oil used. The oils SAE-10W40 and SAE-20W50 require just 2 hours to return to the initial oil temperature before the oil is extinguished, whereas the SAE-40 oil and used oil take 3 hours. It means that multi-grade oil cools quicker than a single grade or monograde oil. The monograde lubricants are only capable of operating at such viscosities, while multigrid lubricants are capable of working under a range of viscosity.

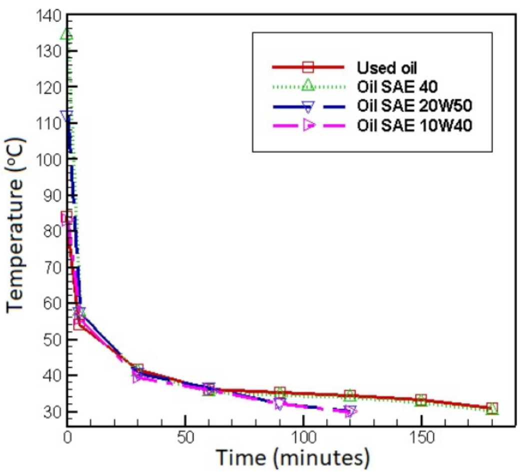

Figure 5. Comparison of the cooling rate of the cooling medium.

3.2. Product size

The analysis of the samples is shown in Figure 6. The size of the sample does not change before and after hardening. However, a thin layer of carbon on the surface of the sample does not have a chance to bind austenite to martensite. It is due to the presence of residual carbon. Following what has been stated by Totten [21], the oil cooling media can provide less distortion and crack to the quenching results.

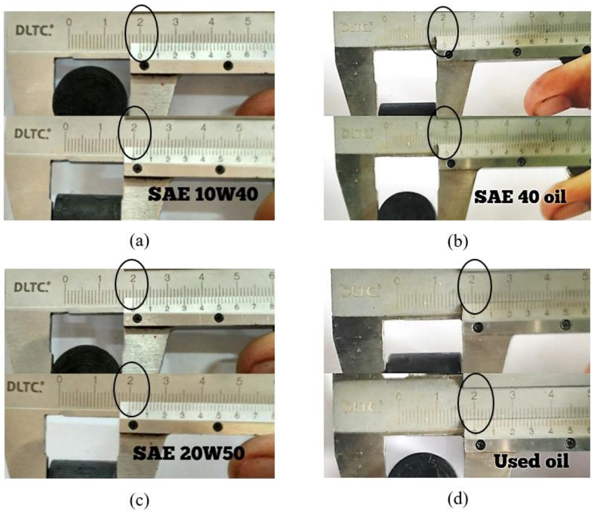

Figure 6. Sample size after quenching, (a) SAE 10W40 oil (b) SAE 40 oil (c) SAE 20W50 oil (d) used oil.

3.3. Hardness

Three specimens were tested for each hardening-quenching treatment to have hardness characteristics. Five different positions were carefully evaluated. The comparison chart of the hardness value of 42CrMo4 steel after hardening-quenching is shown in Figure 7. The highest hardness is achieved in the SAE-10W40 oil cooling medium by 54.59 HRC, and the lowest hardness is achieved in the cooling medium of the used oil by 51.07 HRC (on average). The findings of this study are similar to those of previous research carried out by Rhaiem, et al. [2]. Steel hardness obtained after water-quenching is 55 ± 1 HRC, and oil-quenching is 53 ± 1 HRC.

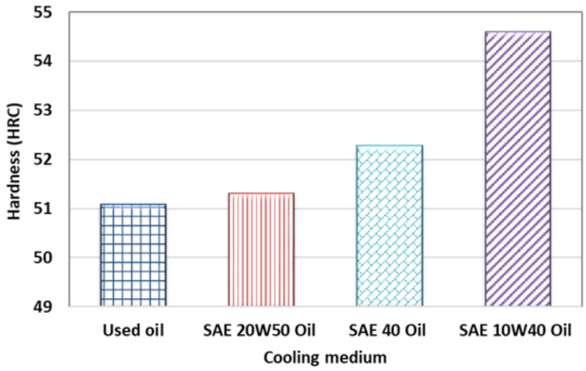

Figure 7. Comparison of 42CrMo4 steel hardness.

A summary of the change percentage in the hardness is shown in Table 2. The lower viscosity value of the cooling medium results in a quick and stable cooling so that the heat can be absorbed to the full in the quenching sample. The rapid cooling may result in a high percentage of martensitic microstructures. The hardness value gets higher when the martensitic presentation increases.

Table 2. The comparison of hardness before-and-after quenching.

Cooling Medium	Hardness (HRC)		% increase in hardness
	before	after	
used oil	27.11	51.07	88.37
oil SAE 20W50	27.11	51.3	89.23
oil SAE 40	27.11	52.27	92.81
oil SAE 10W40	27.11	54.59	101.36

If the microstructure is not fully martensitic, its hardness is lower. Another study noted that the various microstructures produced from certain alloy steels, martensite is the hardest and most durable but brittle [22]. The martensite phase has highly effective interstitial carbon, which results in the hardest, most reliable, and most brittle phase. The SAE-10W40 oil cooling medium achieves the highest increase in the hardness. It means that oil, which has a low viscosity and is capable of operating within the range of viscosity between two viscosity values (multi-grade) can cool quickly. The hardness resulted from the SAE-10W40 oil cooling media is 54.59 HRC. This finding is similar to hardness yielded by the quenching using water medium. It is consistent with the previous studies performed by Rhaiem et al., which is 55 ± 1 HRC [2]. SAE 20W50 oil has a higher viscosity with a viscosity value of 20 in cold conditions. Viscosity value increases up to 50 when the temperature is 100ºC. It results in reduced speed of heat release from quenching products.

The lowest hardness is produced by used oil. This value is almost the same as the hardness produced by SAE-20W50 oil. It is related to contamination from impurities produced in undesirable oxidation processes such as sediment, water, metal particles, and degraded additives [23]. It is decreasing the effectiveness of the lubricant results in less rapid cooling. It causes the percentage of martensite formation to decrease, followed by a decrease in the value of hardness. On the other hand, Totten [21] found that the use of mineral oil or plant oil as a cooling fluid in the quenching process showed relatively similar results.

The findings of the microstructure observation after hardening-quenching are shown in Figure 8. The microstructure that formed during the hardening-quenching process is found to be needle-shaped martensite and residual austenite, which is not enough time to convert to martensite. The resulting microstructure is consistent with Smith's microstructure [24]. The 4140-alloy steel creates a martensitic structure after being austenitized at 843°C and cooled by gasoline. Alloy steel hardenability improves with the introduction of chromium, and there is a longer delay in the transformation of austenite to perlite in chromium molybdenum alloy steel so that rapid oil cooling can create a martensitic structure.

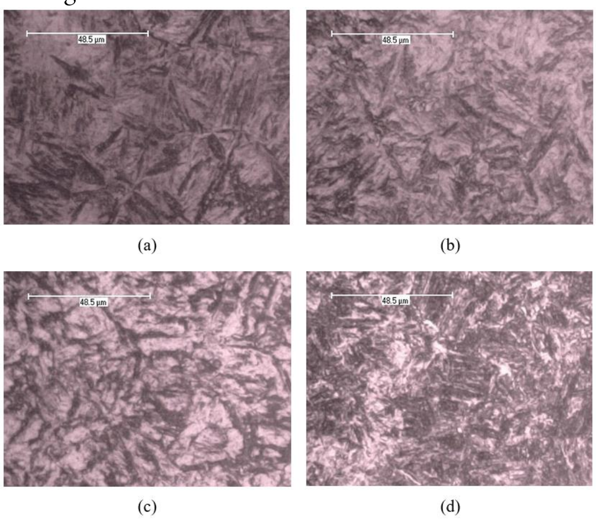

Figure 8. Microstructure of 42CrMo4 steel after hardening (a) SAE 10W40 oil (b) SAE 40 oil (c) SAE 20W50 oil (d) used oil.

The difference in the percentage of 42CrMo4 steel phases following the hardening-quenching cycle is shown in Table 3 and Figure 9.

Table 3. Percentage of microstructure after hardening.

Cooling medium	% Martensite	% Austenite
Used oil	80	20
Oil SAE 20W50	85	15
Oil SAE 40	90	10
Oil SAE 10W40	95	5

From Figure 9, the higher the hardness value, the higher the percentage of martensitic structure. It refers to the existence of the martensitic system, which is the hardest and most robust, but the most fragile [22].

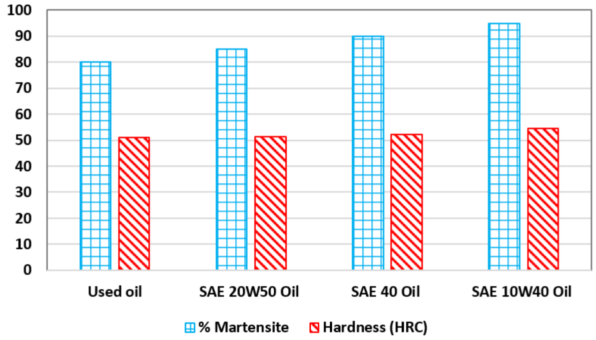

Figure 9. The relationship between hardness and martensite.

4. CONCLUSION

The hardening process has been carried out at 830ºC and holding time for 30 minutes, then continued by a quenching process with used oil, SAE-20W50 oil, SAE-40 oil, and SAE-10W40 oil on 42CrMo4 steel. It can be concluded that

- The cooling rate of SAE-10W40 and 20W50 oil cooling media is faster than that of SAE-40 and used oil.
- The sample size does not change significantly before and after hardening-quenching. However, a thin carbon layer occurs on the surface of the sample due to the presence of residual carbon, which cannot be bound to martensite by austenite.
- The rise in the hardness of the treated samples following subsequent quenching is as follows: SAE-10W40 oil increased 101.36%; SAE-40 increased 92.81%; SAE-20W50 oil increased 89.23%, and used oil increased 88.37%. The hardness value of the used oil and the SAE-20W50 oil is almost the same, meaning that the used oil can be used as an extinguishing medium.
- The microstructures that develop during the hardening-quenching process are martensite and residual austenite, which cannot be transformed into martensite. The proportion of martensite after continuous quenching is as follows: SAE-10W40 oil is made up of 95% martensite; SAE-40 oil is made up

of 90% martensite; SAE-20W50 oil is made up of 85% martensite, and used oil is made up of 80% martensite.

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