The Effect of Graphite and Activated Carbon as Dispersed Particle in Base Fluid as Quench Medium on the Hardness of S45C Carbon Steel

Wahyuaji Narottama Putra[1, a)], Danika Aprilia Somadinata[1], Ghiska Ramahdita[2]

[1]*Department of Metallurgy and Materials Engineering, Faculty of Engineering, Universitas Indonesia, Depok, 16424, Indonesia*
[2]*Mechanical Engineering & Materials Science, Washington University in St. Louis. One Brooking Drive, St. Louis, MO. 63130*

Corresponding author: *a) wahyuaji@ui.ac.id*

Abstract. Adding a solid particle dispersion into a base fluid could increase its thermal conductivity, increasing heat transfer characteristics. One example of this thermally enhanced fluid is in the heat treatment industry as a quench medium. By controlling the amount of the dispersed particle, the cooling rate of the quench medium can be altered and affect steel hardness after heat treatment. In this research, the dispersed particle used was commercially available graphite and activated carbon particle. As for the base fluid, distilled water and common engine oil were compared. The concentration of the dispersed particle was 0.1, 0.3, and 0.5 weight percent. The highest hardness was achieved at 728 HV on the 0.1% activated carbon particle in water base fluid. Meanwhile, using graphite, the highest hardness achieved was at 639 HV on the 0.1% particle in the water base fluid. The result may suggest that activated carbon could improve the cooling rate better due to its impurities. As expected, quenching by dispersed graphite particles in oil-based resulted in lower hardness on all variables.

Keywords: Graphite, Activated Carbon, Quenching, Heat Treatment, S45C

INTRODUCTION

Currently, vast research regarding efficient heat transfer fluids with significantly higher thermal conductivities than the currently available fluids is being conducted [1]. Nanofluids are engineered suspensions of nanoparticles with an average size below 100 nm in a working fluid such as water, oil, or ethylene glycol [2]. When dispersed uniformly, nanoparticles have proven to improve the thermal properties of the host fluids [3,4]. Thus, nanofluid technology, a new combined interdisciplinary field of nanoscience, nanotechnology, and thermal energy, has developed largely to create a uniform dispersion and stable suspension of nanoparticles in host fluids to achieve the best possible thermal properties at the lowest possible concentrations. This technology is also considered to have a wide prospect with applications ranging from electronic, transportation, solar energy, nuclear reactor, quenching, and high-powered lasers industries. Currently, nanofluids are further developed for application in the quenching industries due to their enhanced heat transfer performance as a quenching medium. Furthermore, nanofluids help influence the cooling rate of the quenching process [5] and could be altered as aimed through the suspended nanoparticle composition.

This research aimed to compare graphite carbon and activated carbon particle as dispersed particles in oil and water base fluid. This fluid was used as a quench medium for S45C carbon steel. The effect of the different types of particles and base fluid was observed through the final hardness of the carbon steel after quenching.

MATERIALS AND METHODS

In this research, graphite particle was purchased from Sigma-Aldrich. For comparison, commercially available activated carbon particle was also used. Carbon steel S45C grade was used as the steel sample for quenching. The steel sample has a half-rod shape with a diameter of 1 inch and a thickness of 1 cm.

Energy Dispersive X-Ray Spectroscopy (EDS) was used to check the composition of both carbon particles. Meanwhile, Optical Emission Spectroscopy (OES) was used to observe the chemical composition of the carbon steel sample. Tables 1 to 3 show graphite, activated carbon, and carbon steel composition.

TABLE 1. Chemical Composition of Graphite Carbon Particle

Element	**C**	**Cu**
Weight %	99.9	0.01

TABLE 2. Chemical Composition of Activated Carbon Particle

Element	**C**	**O**	**Si**	**Al**	**Fe**	**Ca**	**S**	**Ti**	**Mg**	**Zn**
Weight %	77.0	19.0	1.5	1.0	0.5	0.4	0.2	0.1	0.1	0.1

TABLE 3. Chemical Composition of S45C Carbon Steel

Element	**Fe**	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**	**Al**	**Co**	**Cu**
Weight %	98.3	0.47	0.287	0.718	0.026	0.005	0.028	0.005	0.005	0.02	0.003	0.018

A planetary ball mill was conducted for both carbon types to reduce the particle size. Milling was done at 500 rpm for 15 hours. The particle dimension was measured by Particle Size Analysis. The final average particle size for the graphite was 7.8μm, while for the activated carbon was 0.3μm. Activated carbon naturally had a porous morphology. The milling process could reduce the activated carbon dimension more than the graphite, hence the smaller particle dimension [6].

The carbon particle was then dispersed into the base fluid. As for the base fluid, distilled water, and commercial engine oil, SAE 5W-40 was utilized. In this research, the percentage of carbon was 0.1, 0.3, and 0.5 % added in the base fluid. To ensure the uniform dispersion of particles in the fluid, ultrasonic was conducted for 15 minutes. This particle-dispersed fluid was then used as a quench medium.

The carbon steel sample was heat treated at 1000°C for one hour and then was quenched in the particle-dispersed fluid. Figure 1 shows the heat treatment profile for all samples. Vickers hardness testing and metallography were conducted to observe and compare the characteristics. The Vickers microhardness was done using MicroMet 5100 Series and following ASTM E384 standard.

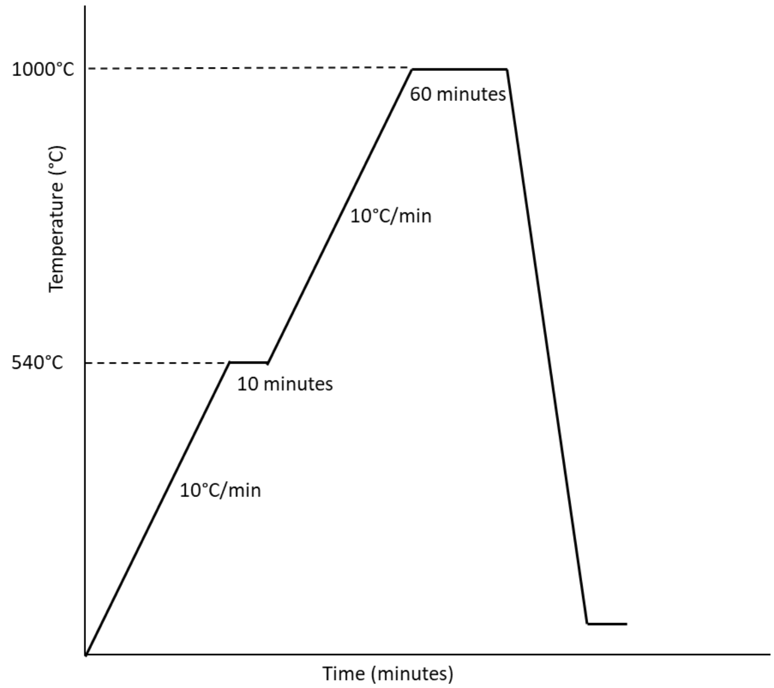

FIGURE 1. Heat Treatment Profile for All Samples

RESULT AND DISCUSSION

Figure 2 shows the hardness comparison between the steel quenched in a quench medium from graphite and activated carbon dispersed. For reference, the hardness of steel without heat treatment was 174 HV. This hardness value is the lowest compared to other samples after heat treatment. This is due to the quenching process implemented in the heat treatment, which is considered the most important heat treatment cycle for increasing hardness and strength [7]. During the treatment, steels are heated to a high temperature to facilitate the transformation to austenite before rapid cooling in a quenching media to generate higher hardness transformation products [8].

The value of the S45C sample that underwent heat treatment and then quenched with pure water is 594 HV. This was lower than the steel quenched with 0.1% dispersed particles. By quenching in the fluid with 0.1% dispersed particles, the hardness could increase up to 639 HV and 728 HV for graphite and activated carbon, respectively. However, more particles in the fluid showed a lower cooling rate by observing the lower hardness depicted in Figure 2. At 0.3% and 0.5% dispersed particles, all of the steel samples showed even lower than those quenched in pure water. This phenomenon indicated that too much-dispersed particle creates a particle agglomeration which could slow down the cooling rate, hence the lower hardness. From the figure, it can also be seen that quenching with activated carbon dispersed particles resulted in higher hardness than graphite. The explanation for this could come from the impurities in the activated carbon. As mentioned previously, activated carbon has several metallic impurities which could improve the general thermal conductivity of the quench medium. Higher thermal conductivity could increase the cooling rate and higher steel hardness.

The comparison between different base fluids can be seen in Figure 3. From this figure, it can be concluded that oil has a much lower cooling rate than water, as expected. The trends also continue on all graphite percentages. The highest hardness was still coming from the least addition of particles which was 0.1%. Particle agglomeration could be the cause of lower hardness on a higher percentage of a dispersed particle as well. The highest hardness for the steel quenched in oil with dispersed particles was 505 HV. For reference, the hardness of steel quenched in oil without particles was 363 HV. This means the particle could still improve the cooling rate of the oil. However, a similar result can be seen in higher particle percentages. At 0.3% and 0.5% of particle addition in oil, the steel hardness decreases lower than in oil.

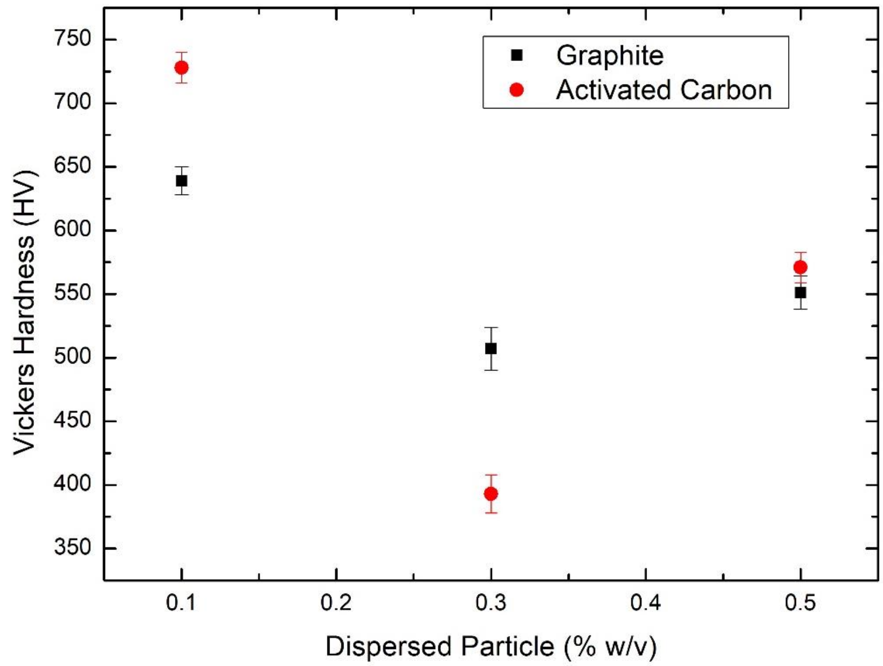

FIGURE 2. Steel Hardness Comparison after Quenched with Graphite and Activated Carbon Quench Medium [9,10]

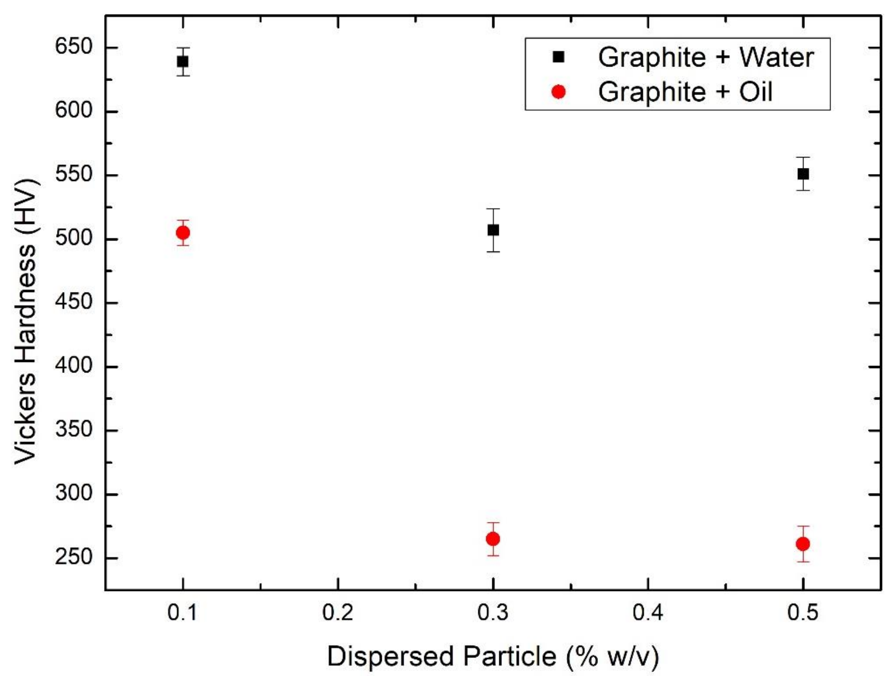

FIGURE 3. Steel Hardness Comparison after Quenched with Water-based and Oil-based Quench Medium with Dispersed Particle [9,11]

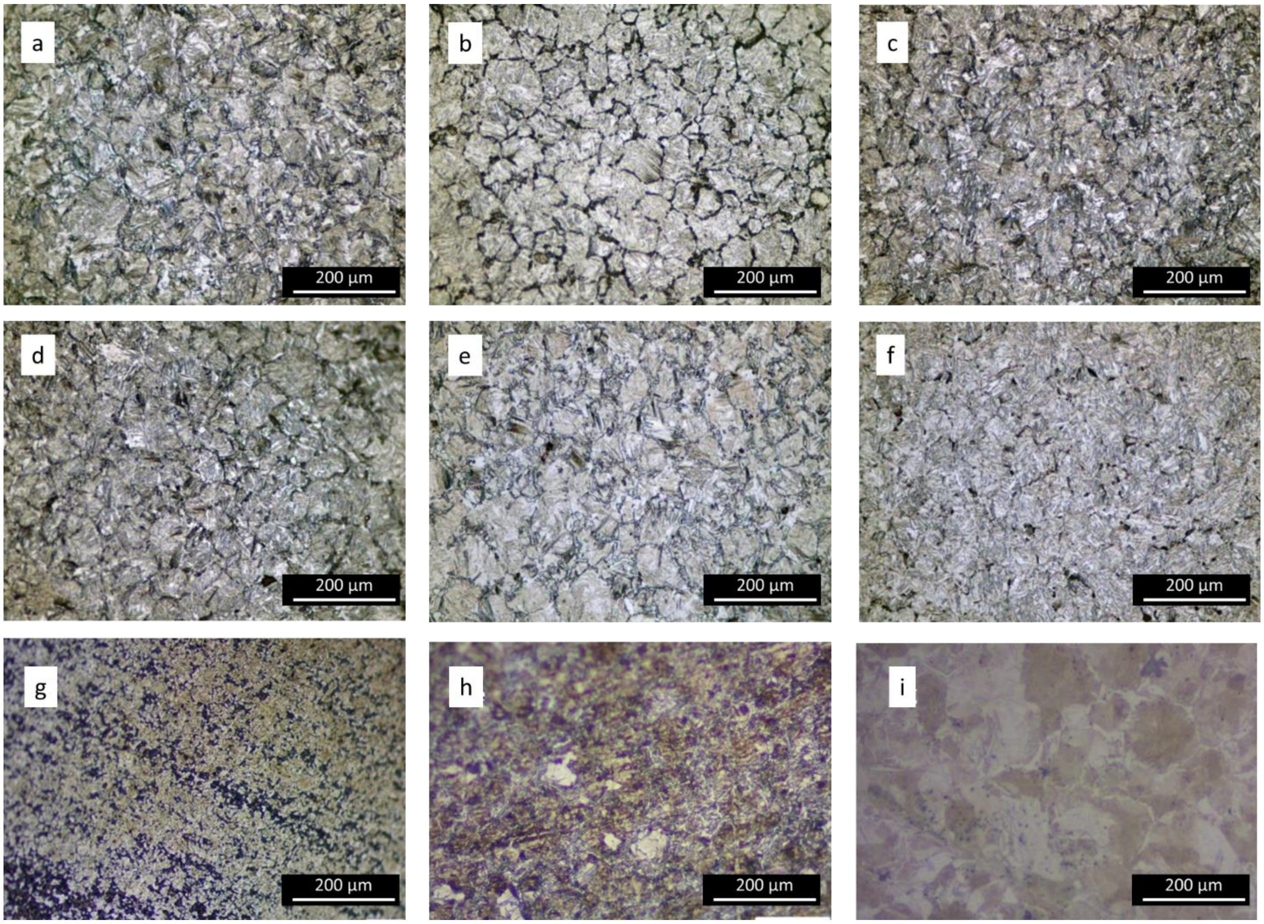

FIGURE 4. Microstructure of Steel after Quenching with Different Quench Medium: (a) 0.1% Graphite, (b) 0.3% Graphite, (c) 0.5% Graphite, (d) 0.1% Activated Carbon, (e) 0.3% Activated Carbon, (f) 0.5% Activated Carbon, (g) 0.1% Graphite in Oil, (h) 0.3% Graphite in Oil, (i) 0.5% Graphite in Oil [9,10,11]

Microstructure observation in Figure 4 showed the visually different combination of the martensite phase. The martensite phase was shown as a dark-colored needle-like morphology. The bright white phase in the figure could indicate the presence of retained austenite. The grey area might an indication of a bainite structure. Although the amount of the martensite phase is different in a water-based quench medium, the distribution is quite similar. Meanwhile, the microstructure in the steel quenched with an oil-based quench medium showed more differently. Many rounded-shaped phases can be seen in the microstructure. The phase with a round shape could be ferrite or cementite. The round-shaped structure could also affect the lower hardness of the steel.

CONCLUSION

From this study, it can be concluded that adding dispersed particles to the base fluid could increase the thermal conductivity of the fluid. The increase in cooling rate was indicated by the higher hardness of the steel. Interestingly comparing the graphite and activated carbon, the activated carbon could result in a higher steel hardness. This means the fluid has higher thermal conductivity using a dispersion of activated carbon particles than graphite particles. The higher thermal conductivity of activated carbon could come from metallic impurities. Metallic impurities could improve thermal conductivity better. However, increasing dispersed particles decreased the thermal conductivity.

Lower hardness could be found by adding more than 0.1% particles. Particle agglomeration could be the root cause of this phenomenon. Surfactant usage may be needed to ensure and increase the stability of the particle in the fluid.

Another result from this study was comparing water-based and oil-based quench mediums. As expected, the oil-based quench medium resulted in lower hardness than the water-based one. However, additional dispersed particles in oil could still increase the thermal conductivity. The steel showed higher hardness after quenching in oil with 0.1% particle. Unfortunately, more addition of particles in oil results in the same trend as water. At 0.3% and 0.5% particle addition, the steel hardness becomes lower than in oil without particles.

REFERENCES

[1] Fatmi, Sri Elsa; Dhaneswara, Donanta; Anis, Muhammad; and Ashari, Ahmad, "Investigation of The Effect of Corundum Layer on The Heat Transfer of SiC Slab," *Journal of Materials Exploration and Findings (JMEF)*: Vol. 1: Iss. 2, Article 1. DOI: 10.7454/jmef.v1i2.1012, 2022.

[2] V. Sridhara and L. N. Satapathy, "Al2O3-based nanofluids: a review," Nanoscale Research Letters, vol. 6, no. 1, p. 456, 2011.

[3] S. K. Das, S. U. Choi, W. Yu and T. Pradeep, Nanofluids: Science andTechnology, New Jersey: Wiley - Interscience, 2008

[4] Dhaneswara, D., Agustina, A.S., Adhy, P.D., Delayori, F. and Fatriansyah, J.F., The Effect of Pluronic 123 Surfactant concentration on The N2 Adsorption Capacity of Mesoporous Silica SBA-15: Dubinin-Astakhov Adsorption Isotherm Analysis. In *Journal of Physics: Conference Series* (Vol. 1011, No. 1, p. 012017). IOP Publishing. (April, 2018)

[5] Riza, R.I., Putra, W.N., and Harjanto, S. “Cooling rate observation in quenching process using carbon nanofluids for S45C carbon steel”. Key Engineering Materialsthis link is disabled, 2020, 833 KEM, pp. 13–17

[6] Fatriansyah, J.F., Situmorang, F.W. and Dhaneswara, D. , Ekstraksi silika dari sekam padi: metode refluks dengan NaOH dan pengendapan menggunakan asam kuat (HCl) dan asam lemah (CH3COOH). In *Prosiding Seminar Nasional Fisika Universitas Riau ke* (Vol. 3, No. 2018). (September, 2018)

[7] M. Kianezhad and S. A. Sajjadi , "Improvement of Quench Factor Analysis in Phase and Hardness Prediction of a Quenched Steel," Metallurgical and Materials Transactions A, vol. 44, p. 2053–2059, 2013.

[8] A. Yazdi, S. Sajjadi, S. Moosavi Nezhad and S. Zebarjad, "Prediction of hardness at different points of Jominy specimen using quench factoranalysis method," Journal of Materials Processing Technology, vol. 199, no. 1-3, pp. 124-129, 2008

[9] S. Harjanto, W. N. Putra, K. G. Ramahdita, S. Yahya and E. Mahiswara, "Characterization of water based nanofluid for quench medium," International Conference on Materials Engineering and Applications, vol. 348, no. 1, 2018.

[10] Kresnodrianto, S. Harjanto, W.N. Putra, G. Ramahdita, S.S.Yahya, E.P. Mahiswara, “Characterization of water based nanofluid for quench medium”, IOP Conf. Series: Materials Science and Engineering, 348 (2018), 012009.

[11] S.S. Yahya, S. Harjanto, W.N. Putra, G. Ramahdita, Kresnodrianto, E.P. Mahiswara “Characterization and Observation of Water-based Nanofluids Quench Medium with Carbon Particle Content Variation”, AIP Conference Proceedings 1964, 020006 (2018); doi: 10.1063/1.5038288