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Study of circulated nanofluids ZnO based-particle to improve hardness in quenching AISI 4140

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Abstract

The world community still covets hard and strong materials for various applications. One of them is that AISI 4140 material widely plays a vital role as a material for engineering goods. The material needs to be quenched to get a more complex and stronger material. The cooling speed of the material being quenched is the main factor in forming a material with hard and strong properties. Nanofluid, which has a high ability to absorb heat, can be used as a cooling medium to replace pure water, oil, and brine, which are widely used today. Research is necessary to answer the new paradigm of the potential use of nanofluid technology as a cooling medium in the quenching process. The research method to be carried out was an experiment. The stages of research activities were preliminary studies, material sample preparation, nanofluid preparation, research tool setup, testing, analysis, and conclusions. The research variables used were ZnO nanoparticle material with nanofluid concentrations of 0.1% and 0.3%, and the base fluids were water, oil, and brine. The results obtained were the best concentration of 0.3% ZnO-water nanofluid coolant with an AISI 4140 material hardness value of 677 kgf/mm^2.

Keywords

Circulate nanofluids, ZnO based-particle, AISI 4140

Introduction

The need for more complex and more robust metal materials continues to be expected by the world community to this day. Hard and strong materials are highly desired by all parties, including for structures and engineering applications. Strength is the ability of a material to accept applied stress without causing the material to break [1] . Factors that influence the hardness results in heat treatment are chemical composition, heat treatment, coolant, and temperature [2]. Engineering goods such as process industrial tools, machines, structures, and others certainly require these properties, especially in the Karawang Regency area. Karawang, surrounded by eleven industrial areas, certainly hopes for a solution to this development [3]. The success of this development will directly impact the development of the industrial sector and support small and medium enterprises. Of the various types of metal available and circulating on the market, AISI

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4140 plays a vital role in various engineering components because of its suitability for multiple applications. AISI 4140 plays a role, including as a foundation material and structure in the process industry, process industry machine equipment frames, crankshafts, aircraft frames, steel nuts, and rollers, which are applications of AISI 4140 which are used in heat-treated conditions [4]. Material Medium carbon steel AISI 4140 is a metal alloy containing C 0.41, Si 0.30, Mn 0.70, Cr 1.10, Mo 0.20 [5]. AISI 4140 has the properties of high fatigue strength, abrasion, impact, toughness, and dimensional strength [6]. Apart from chemical composition engineering, a hard and strong material can be obtained using heat treatment. The heat treatment process used is the quenching process.

Quenching can increase the hardness and strength of a material by heating the metal to its recrystallization temperature and cooling it quickly. The faster the cooling process, the more complex and stronger the material properties. In the rapid cooling process, cooling media such as water, oil, and brine have been the mainstay until now. This is because the cooling medium is considered to have good heat absorption capabilities. The cooling medium minimizes residual stresses, reduces distortion, and provides the required heat transfer rate. The cooling medium is usually water, brine, and salt baths [7]. Based on research by Korad and Palbon [8], the level of hardness in carbon steel using the surfactant quenching method (brine oil + surfactant), water is below 20 HRC for water cooling medium and 40 HRC for superquench. However, on the other hand, the rapid development of nanotechnology worldwide is encouraging new paradigm changes in various applications in the fields of science and technology. One of them is that it allows the creation of cooling media with a much higher ability to absorb heat. One of the AISI 4140 applications on crankshaft and gear can be seen in Figure 1.

Figure 1. Application of AISI 4140 to crankshaft and gear.

The cooling medium is nanofluid. Nanofluids play an essential role in heating and cooling media these days. Nanofluids are fluids synthesized by dispersing solid particles, fibers, or tubes with 1–100 nm lengths in traditional heat transfer fluids [9]. Conventional fluid transfers such as water, ethylene glycol, and metal fluids are widely used. Still, there are shortcomings in improving thermal properties due to the suspension nature of micro-sized particles. This causes the suspension to clog the channel due to poor stability and rheological properties [10]. Nanofluids have high heat capacity (Cp) absorption properties compared to ordinary cooling materials. This is because nanofluids mix nano-sized material particles so that they are dispersed into the base fluid. It is the dispersed nanoparticle solid that increases the heat transfer capability of the nanofluid. Various nanoparticles have been developed, but several types of nanoparticles have the property of increasing the ability to cool media and are readily available on the market. The nanoparticles are Zinc Oxide (ZnO).

ZnO is a semiconductor material that has electron charge carrier properties or is often called an n-type semiconductor. Its properties as a blocking agent for ultraviolet light, high electron mobility, wide energy gap, and high exciton energy make ZnO widely used in industry as an essential primary material [11]. Meanwhile, the basic fluid is oil or lubricant, polymer solution, distilled water, ethylene glycol or propylene glycol, and other cooling media. Ciloglu and Bolukbasi [12] investigated the cooling medium using nanofluids with various volume fractions of Al2O3, SiO2, TiO2, and CuO nanoparticles, showing that the nanoparticles used in nanofluids greatly influence the cooling process.

Method

Research Method

The research method used is experimental. Experiments were carried out on the specified variables: the nanofluid type, nanofluid concentration, and flow rate of nanofluid circulation in the quenching cooling medium carried out on AISI 4140 material. This research has variables, namely the concentration of nanofluid and flow rate of circulating nanofluid on the cooling medium quenching on AISI 4140 material. The nanoparticle material dispersed in the base fluid tested is Zinc Oxide (ZnO) with a nanofluid circulation flow rate. A more detailed explanation of variable testing can be seen in Table 1.

Table 1. Research variable testing table.

No.	Basic Fluid	Nanoparticle concentration	Flow rate of nanofluid circulation (kg/s)
1	Raw	-	-
2	water	0.1%	0.2
3		0.3%	0.2
4	Oli	0.1%	0.2
5		0.3%	0.2
6	Brine	0.1%	0.2
7		0.3%	0.2

Data Collection and Analysis Techniques

The data collection technique records observations from experimental data regarding nanofluid concentration with nanofluid mass flow rate. This data is used to calculate the cooling rate of the cooling medium and understand its effect on the hardness and strength of the resulting AISI 4140 material. Data is taken from research tool setups designed to perform the quenching process according to the specified variables. Samples from quenching with each variable condition were then tested for Vicker hardness.

Results and discussion

In the preliminary study stage, it was found that Zinc Oxide (ZnO) material could influence the cooling process [3]. Preparation of nanoparticle material and manufacture of nanofluids is carried out by dispersing the base fluid and the nanoparticle concentration being tested. The base fluid and nanofluid created are used as a cooling medium for the quenching process. In the stages of making the tool set up, the quenching testing tool set up consists of two large parts, namely the heating tool part and the circulating quenching tool part. Using gas fuel heating, a heating device is used to heat material samples to recrystallize temperature. The recrystallization temperature is controlled using an infrared thermometer. Meanwhile, a circulating quenching tool is used for the sample material quenching process. The sample material is cooled with a circulating medium utilizing a pump, six base fluid concentrations, and the created nanofluid. The heating device and circulating cooling device can be seen in Figure 2.

(a)

(b)

Figure 2. (a) heating device, (b) circulating quenching device.

In the material sample preparation stage, the material AISI 4140 (C 0.41; Si 0.30; Mn 0.70; Cr 1.10; Mo 0.20) [7] was obtained, which had been formed according to the standards used for testing. Preparation of test samples for AISI 4140 material was quenched, and seven types of circulating quenched samples were obtained. Material samples were tested for Vicker hardness and metallographic examination at B4T Bandung. Test samples for the six cooling media compositions can be seen in Figure 3.

Figure 3. The results of the circulating quenching test samples.

Comparative data on variations in nanofluid concentration and quenching cooling media on AISI 4140 material can be seen in Figure 4.

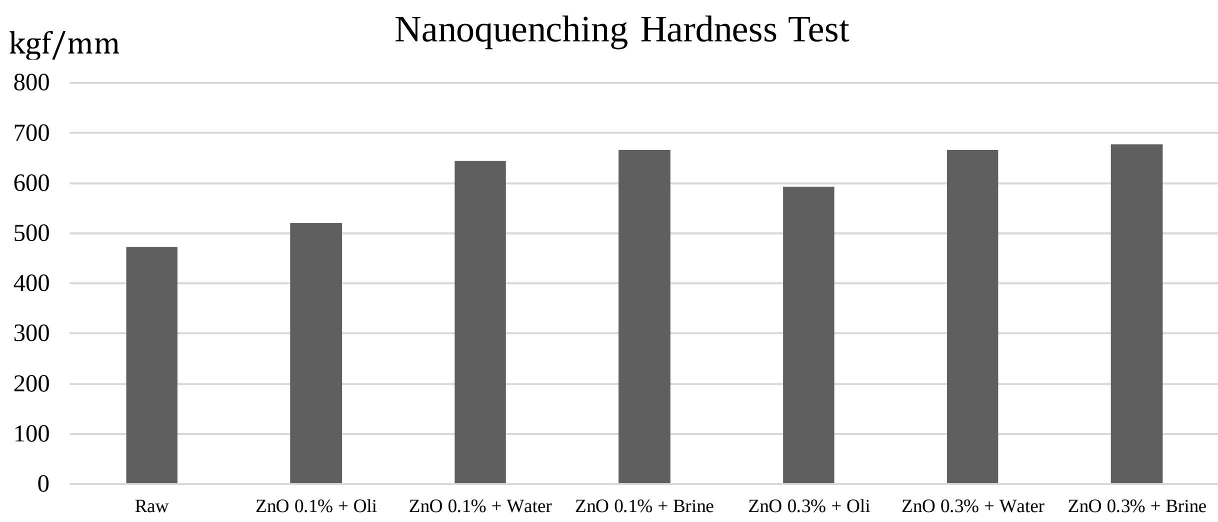

Figure 4. Nanoquenching hardness test result.

Based on the results of the nano quenching hardness test, it was found that the presence of nanofluids can increase the strength of the material. This can be seen in the raw graph, which means that not using nanofluids is lower than the results of other tests. This is because the cooling medium uses nanofluids with various nanoparticle volume fractions, showing that the nanoparticles used in nanofluids greatly influence the cooling process. In research conducted by Ding [13], the dispersive method and transient and steady heat transfer coefficients were used to vary the concentration of nanofluids under natural convection conditions. Variations in concentration indicate an increase in material hardness in the same fluid. Figure 4 shows that the hardness of the material with ZnO with water as a cooling medium is greater than that of oil at each concentration. This is because the oil-cooling media has a higher viscosity when compared to water-cooling media, causing the cooling process to be slower than water-cooling media [14]. The hardness test results with brine cooling media were higher than water and oil, namely 666 kgf/mm^2 at a concentration of 0.1% and 677 kgf/mm^2 at 0.3%. Brine cooling media has a lower viscosity with less liquid consistency, so it cools faster than oil and water. This is by research using brine media showing that the higher the salt content, the higher the level of hardness [15].

Conclusion

Based on the research results, adding nanofluids increases the cooling process and material hardness. Increasing the nanofluid concentration causes the cooling process to grow and the best concentration of ZnO-brine nanofluid coolant is 0.3% with an AISI 4140 hardness of 677 kg/mm^2.

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