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EFFECT OF QUENCHING MEDIA VARIATIONS ON THE HARDNESS AND MICROSTRUCTURES OF AISI O1 TOOL STEEL

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ABSTRAK

Baja perkakas AISI O1 banyak digunakan dalam industri manufaktur untuk produksi berbagai jenis pahat, cetakan, dan aplikasi lain yang membutuhkan ketahanan aus yang tinggi. Ketahanan aus identik dengan kekerasan yang tinggi, kombinasi tersebut dapat diperoleh dengan proses perlakuan panas *hardening-tempering* dan perlakuan *cryogenic*. Namun perlakuan *cryogenic* membutuhkan nitrogen cair yang relatif mahal. Oleh karena itu penelitian ini bertujuan untuk mengetahui media pendingin yang menghasilkan kekerasan tinggi, yang mendekati nilai kekerasan hasil perlakuan *cryogenic* yaitu 69 HRC. *Hardening* dilakukan dengan memanaskan baja hingga suhu 880 °C dan ditahan selama 30 menit, kemudian dilanjutkan dengan *quenching* menggunakan udara bebas, oli SAE 10, air ditambah 15% garam, dan air es. Struktur mikro sampel uji diamati dengan mikroskop optik dan kekerasan diuji dengan alat uji kekerasan *Rockwell*. Hasil uji menunjukkan struktur mikro berubah dari pearlite dan ferrite menjadi bainit dan martensit setelah *hardening-quenching*. Suhu media *quenching* yang semakin rendah menghasilkan kekerasan yang lebih tinggi. *Quenching* air es menghasilkan struktur martensit penuh dan kekerasan tertinggi sebesar 66,37 HRC. Air es merupakan media *quenching* yang dapat menghasilkan kekerasan yang hampir mendekati kekerasan hasil perlakuan *cryogenic*.

Kata kunci: baja perkakas, hardening, struktur mikro, kekerasan.

ABSTRACT

Tool steels *AISI O1 are widely used in the manufacturing industry to produce a wide variety of tools, moulds, and other applications requiring high wear resistance. Wear resistance is identic with high hardness, and the combination can be obtained by hardening-tempering and cryogenic treatment. However, cryogenic treatment requires liquid nitrogen, which is relatively expensive. Therefore, this study aims to determine whether to cool to produce high hardness, which is close to the hardness value of 69 HRC due to cryogenic treatment. The hardening process was carried out by heating the steel at a temperature of 880 °C and holding it for 30 minutes, then quenching using air, oil SAE 10, water with 15% salt, and ice water. The microstructure of the test sample was observed with an optical microscope, and the hardness was tested with a Rockwell hardness tester. The test results showed that the microstructure changed from pearlite and ferrite to bainite and martensite after hardening-quenching. The lower the quenching media temperature, the higher the hardness. Ice water quenching resulted in a fully martensitic structure, and the highest hardness was 66.37 HRC. Ice water is a quenching medium that can produce hardness almost close to the hardness of cryogenic treatment.*

Keywords: *tool steel, hardening, microstructure, hardness.*

1. INTRODUCTION

Heat treatment is an important technique to change the desired mechanical properties of any metal, especially steel. Although heat treatment is an old approach, it is still widely used worldwide. Moreover, the continuous demand for various kinds of steel in manufacturing, construction, and automobile companies makes heat treatment an essential research topic even in the present scenario. Many industries apply quenching to steel to increase its hardness. In addition, some use cold treatment after quenching.

Quenching of tool steels may be done in water, oil, salt bath or air, depending upon the chemical composition and section size of the product. The quenching medium is so selected that its cooling rate is sufficient to achieve the maximum possible hardness. Since excess severity of quenching may lead to warpage or cracking of the heat-treated stock, martempering is sometimes recommended to minimize distortion, especially in the case of extremely thin sections of work-hardening a variety of tool steels. Normally, tool steels' quenched microstructure comprises a mixture of martensite, retained austenite, and un-dissolved carbides [1]. Water is used as a quenching medium because it can reduce the temperature to 600 ºC/s at 18 ºC. Salt (NaCl) added to the cooling medium can increase the cooling rate. When salt dissolves in water, it can increase the cooling rate to 1100 ºC/s at 18 ºC [2]. The hardness of steel will increase as the salt content is added to the water as a quenching medium [3][4]. Meanwhile, oil is most widely used as a quenching medium because it minimizes distortion and cracking after quenching [5][6].

Cold treatment is widely used for high-precision parts and components because it enhances austenite transformation to martensite [7]. Cryogenic treatment is divided into three types: cold treatment (–80°C), mild cryogenic (–140°C), and deep cryogenic (–160°C) [8]. Cryogenic treatment is an additional process to the conventional heat treatment of tool steels initially intended to transform the residual austenite in the microstructure and improve the wear resistance. The process involves cooling the materials down to liquid nitrogen temperature (77 K) [9][10], holding them for a specific time, and then heating them to room temperature, followed by final tempering [12]. In addition, deep cryogenic treatment can increase wear resistance and hardness because it can eliminate residual austenite and distribute carbide more homogeneously [11][12].

The most important tool steel is cold work tool steel, widely applied to various types of chisels, dies, and other applications requiring high wear resistance at low cost [13][14]. Cold work tool steel consists of three types, AISI type O, A and D. Type O is hardened by oil quenching, type A is quenched by air, and type D is a tool steel with high levels of carbon and chromium [15]. AISI O1 tool steel is a cheap metal with high hardness and wears resistance due to its high carbon content and different elements, such as chromium (Cr) and silicon (Si). In addition, tungsten (W) alloying elements can increase the high abrasion resistance and sharp edges [16].

Tool steel needs high strength and toughness to resist penetration and exhibit better shock-absorbing capacity. Heat treatment with quenching and tempering plays a vital role in achieving these combined properties [17]. The hardening temperature of AISI O1 tool steels is 780–870 °C [18]. Hardening-quenching can increase steel's hardness and wear resistance [19], but cryogenic treatment is the most effective between quenching and tempering [8]. The quenching media's cooling rate greatly affects the heat-treated material's final properties. Therefore, selecting the quenching medium and controlling the cooling rate is vital to achieving the desired properties [20]. Cryogenic treatment is more effective in increasing the hardness of tool steel [8], but cryogenic treatment requires liquid nitrogen, which is quite expensive. Therefore, this study aims to determine the cooling medium that produces high hardness, close to the hardness value resulting from the cryogenic treatment of AISI O1 tool steel.

2. METHODOLOGY

The material used in this research is commercial steel-type O1. The sample size is presented in Figure 1. with a diameter of 22 mm and a height of 20 mm, and the chemical composition is in Table 1. The hardness of O1 tool steel before heat treatment was 10.24 HRC. Figure 2. shows the results of observations of the microstructure of O1 tool steel before heat treatment, the microstructure of pearlite, which is shaped like a fingerprint consisting of ferrite (light) and cementite (dark).

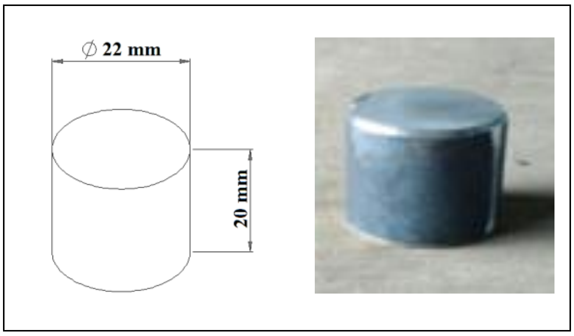

Figure 1. The size of the sample used for hardness test and microstructure observation

Table 1. The chemical composition of the steel used in the study and standard

Elements	C	Si	Mn	P	S	Cr	V	W
Standard (%)	0.85 – 0.95	0.2 – 0.4	1 – 1.3	<0.035	<0.035	0.4 – 0.6	0.2	0.4 – 0.6
Used (%)	0.905	0.196	1.05	<0.005	0.0070	0.468	0.0058	0.378

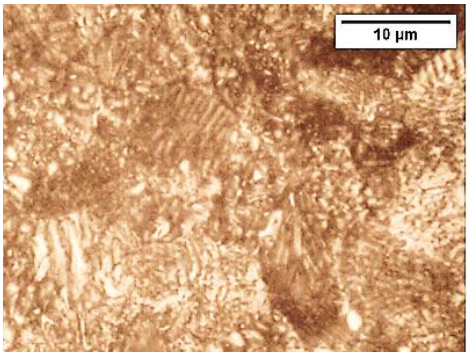

Figure 2. AISI O1 tool steel microstructure before heat treatment

The hardening process is shown in Figure 3. The steel is heated to 880 ºC, and held for 30 minutes, followed by rapid cooling. Figure 4. is a heat treatment furnace used to heat the test sample. The cooling media are air, oil SAE 10, water with 15% salt (salt solution), and ice water. Tests were carried out two times, before and after heat treatment. Tests before heat treatment include chemical composition tests, hardness tests, and microstructure observations. While the tests after heat treatment only hardness tests and the microstructure observations. An emission spectrometer machine tests the chemical composition. Hardness testing was carried out using the Rockwell scale C or HRC. The indentation uses a diamond cone with an angle of 120º, and a load of 150 Kgf/1471.5 N according to the ASTM E 18-97a Rockwell hardness standard [21]. The microstructure was observed with an optical microscope. The etching material uses nital with a mixture of 5 ml of HNO_3 and 100 ml of ethanol/methanol (95%) according to the ASTM E 407-99 standard [22].

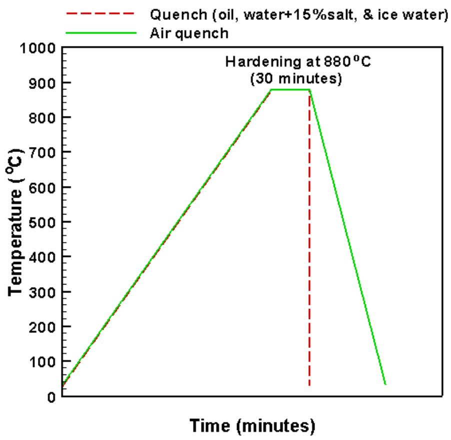

Figure 3. Hardening process

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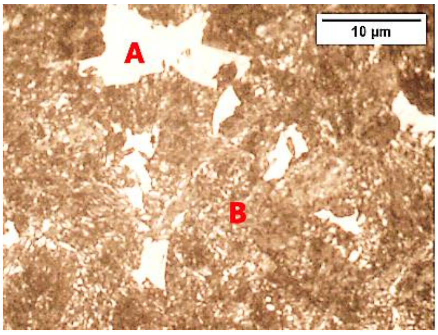
Figure 4. **Heat treatment furnace**

3. RESULTS AND DISCUSSION

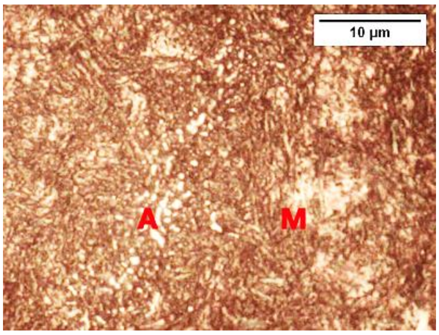
3.1. Microstructure

Figure 5. shows the microstructure of AISI O1 tool steel after heat treatment. Figure 5.a. is the microstructure of the sample cooled by air, and the structure consists of bainite (dark) and residual austenite (light). A low percentage of austenite was retained after heat treatment, known as retained austenite. It is soft, which causes a reduction in product life [23]. Bainite is a composite structure between ferrite and cementite, just as the pearlite structure is a layer between ferrite and cementite. However, bainite has a finer crystal structure than pearlite and is visible when viewed with an electron microscope [24]. Although they are both types of AISI tool steel, type O differs from type D. AISI D2 is quenched with air and has a martensite structure [20], whereas O1 only has a bainite structure. It happens because the time for martensite formation in AISI D2 steel is wider or longer than that of AISI O1. The high chromium content causes a longer martensite formation time [26]. AISI D2 contains 11-13% Cr, while AISI O1 only includes 0.4 - 0.6% Cr.

Figure 5.b. is the sample's microstructure quenched with oil SAE 10. The microstructure consists of martensite and residual austenite. Martensite is a dark colour, and austenite is a speck of bright white. Quenching using water with 15% salt produces a martensite structure, as shown in Figure 5.c. shows. The cooling rate of ice water is high-speed so that martensite can form without residual austenite, likely in Figure. 5.d. Quenching using oil, water with 15% salt, and ice water produce the same microstructure as the results of previous researchers. Where steels with high carbon content and low alloying elements have a low amount of residual austenite after quenching [8].



(a)



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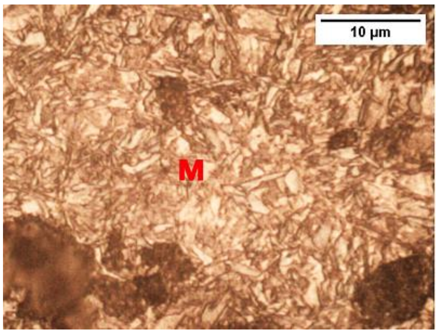

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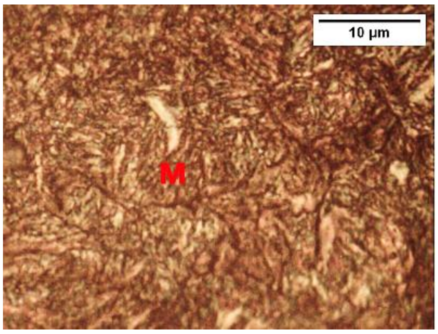

(d)

Figure 5. Microstructure of AISI O1 tool steel after hardening-quenching, (a) air, (b) oil, (c) water with 15% salt, and (d) ice water

3.2. Hardness

Table 2. shows the hardness of AISI O1 tool steel after hardening-quenching, where each sample was tested at 5 points. Air quenching is unsuitable for AISI O1 tool steel because its slow cooling rate does not achieve optimal hardness. Air quenching only increased hardness by 284.02%, from 10.24 HRC to 39.31 HRC. Hardness is affected by changes in microstructure, from pearlite before heat treatment to bainite and the remaining austenite after quenching, where bainite is harder than pearlite. This result differs from type D, where the hardness of the quench with air reaches 61.61 HRC [20]. In addition, the hardness correlates with the structure formed, where air-cooled AISI D2 forms martensite and AISI O1 only begins bainite. Martensite will affect mechanical properties because it has a high hardness and strength but is brittle [19][25]. Oil SAE 10 can increase the hardness by 518.52%, which is 63.31 HRC. Water with 15% salt can increase the hardness up to 528.39%, which is 64.32 HRC. The hardness produced by oil SAE 10 and water with 15% salt is almost the same, with only 1 HRC difference. This hardness is the same as the results of previous researchers. The hardness of AISI O1 tool steel after quenching is 63 HRC [8].

Table 2. Hardness of AISI O1 tool steel after quenching

Quenching medium	Quenching media temperature (°C)	Hardness (HRC)	Deviation	% increase
Raw material		10.24	0.19	-
After hardening				
Air	32.6	39.31	0.22	284.02
Oil SAE 10	34.4	63.31	0.19	518.52
Water with 15 % salts	29.9	64.32	0.19	528.39
Ice water	3.9	66.37	0.25	548.40

After hardening-quenching, the highest hardness of AISI O1 tool steel was achieved with ice water, followed by water with 15% salt and oil SAE 10. Figure 6. shows the relationship between the temperature of the quenching medium and the hardness of AISI O1 tool steel after quenching. Based on the graph in Figure 6. the lower the temperature of the quenching media, the higher the hardness. Water with 15% salt and oil SAE 10 has a slower cooling rate than ice water which produces martensite with low residual austenite. Whereas air produces the slowest cooling and produces only bainite. Previous researchers stated that the lower the temperature of the quenching medium, the faster the object's temperature decreases [24]. The rapid cooling rate results in high hardness [26] because it produces martensite [27]. The microstructure greatly influences the mechanical properties, where bainite has lower hardness and wear resistance than martensite [28]. The higher the hardness, the higher the wear resistance [29][30][31].

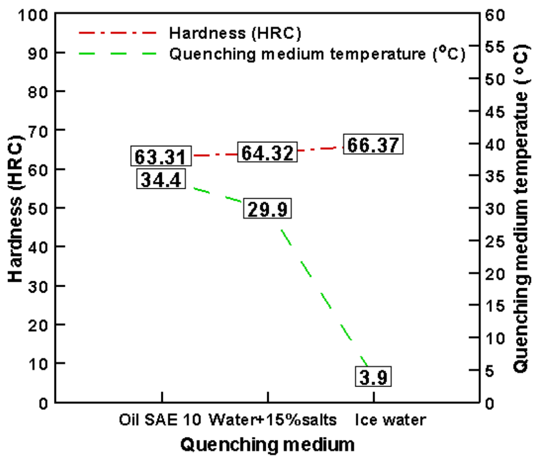

Figure 6. The relationship between quenching media temperature and hardness

4. CONCLUSION

The effect of quenching media variations on the hardness and microstructures of AISI O1 tool steel has been studied experimentally. The steel is hardened at 880°C and held for 30 minutes, followed by quenching using air, oil SAE 10, water with 15% salt, and ice water. Based on the test results, it can be concluded that the lower the quenching media temperature, the higher the hardness. Ice water produces a high-speed cooling rate, forming martensite without residual austenite and obtaining a high hardness of 66.37 HRC, almost close to the hardness of the cryogenic treatment. Air quench is unsuitable for AISI O1 tool steel because it only forms bainite with more residual austenite than other quenching media and produces the lowest hardness of 39.31 HRC. Ice water is a quenching medium that can produce hardness almost close to the hardness of cryogenic treatment.

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