Mechanical Investigation on Different Cooling Media of Induction Hardening Treatment AISI 1015 Steel

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***Abstract*—AISI 1015 steels have been vigorously used to numerous automotive parts. Unfortunately, it has several mechanical shortcomings due to poor hardness, wear resistance, and strength. To tackle its crucial problem, the AISI 1015 steels have been treated by induction hardening treatment at 850 ºC which subsequently cooling to the ambient temperature using different cooling media of water, salt bath, and oil. The mechanical properties of the as-prepared AISI 1015 steels were then investigated involving spectrometry, microstructure observation, hardness, wear, and tensile test. The AISI 1015 treated steels after induction hardening in water cooling media exhibited intriguing microstructure of vast pearlite encircle ferrite matrix. The sample also garnered significant enhancements of hardness, wear resistance, and tensile properties. These superior mechanical characteristics are attributed to the induction treatment using water cooling media which boost crystalline structure transformation deliberately. Therefore, this research affords significant promise for improved mechanical properties of the AISI 1015 steels.**

Keywords—AISI 1015 Steel; Induction Hardening; Mechanical Properties

I. Introduction

Due to high industrial demand, AISI 1015 steel, designated by the American Iron and Steel Institute, is widely regarded as a key material for automotive parts production such as rods, bolt, drag link, and so forth. AISI 1015 steel, widely known as low-carbon alloy steel, owns typical mechanical property of good machineability which easily transforms to various shapes for industrial applications. However, it remains another poor mechanical characteristics especially hardness and wear resistance [1]. These mechanical phenomena play the main role of gradual deterioration at surface during friction load which accelerate damage time such as for gear and shaft components. Therefore, a specific treatment is urgently required to enhance the mechanical properties of AISI 1015 steel.

Several treatments for AISI 1015 steel, specifically using heat input, have been devoted to improve its mechanical properties. For instance, Namdev et. al. developed inter-critical heat treatment involved water quenching to improve the mechanical and wear properties of AISI 1015 steel [2]. The results showed improved tensile and hardness properties of 1045.57 MPa and 32 HRc, despite remains decreased ductility when the temperature higher. Besides, Silva et.al. studied effect heat treatment on anti-wear coated on AISI 1015 steel which depicted refined grains (martensite laths) microstructure to gain better wear resistance of 0.15 mm^3/mm [3]. The emergence of improved microstructure also significantly enhance hardness properties of 466 HV. From the studies aforementioned, it clearly seen that specific heat treatment is highly recommended to boost mechanical characteristics of AISI 1015 steel.

Induction hardening, known as typical heat treatment which involved induction heat from electrical coil and subsequent quenching process, has widely applied to numerous mechanical components to enhance its properties [4]. During the process, multi stages of physical transformation occur inside the material involved electromagnetic, phase transformation, and stress-strain evolution. These alterations accelerate higher hardness and wear resistance level blend with good toughness and strength. However, high residual stress was

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considered as hindrance to gain optimum mechanical characteristics which can prevent the cooling rate by using appropriate cooling media [5].

Herein, the main objective of this research was aimed to investigate mechanical characteristics of AISI 1015 steels during induction hardening using different cooling media towards microstructure, hardness, and wear resistance behaviors. Cooling media consists of pure water, salt bath, and oil which have different cooling rate effects to influence physical and dimensional transformation of the AISI 1015 steels. The findings from this research will contribute to the knowledge of improvement technique for AISI 1015 steels to elevate their mechanical properties.

II. Materials and Methods

The experimental process which conducted in this research is depicted in the flowchart as follows:

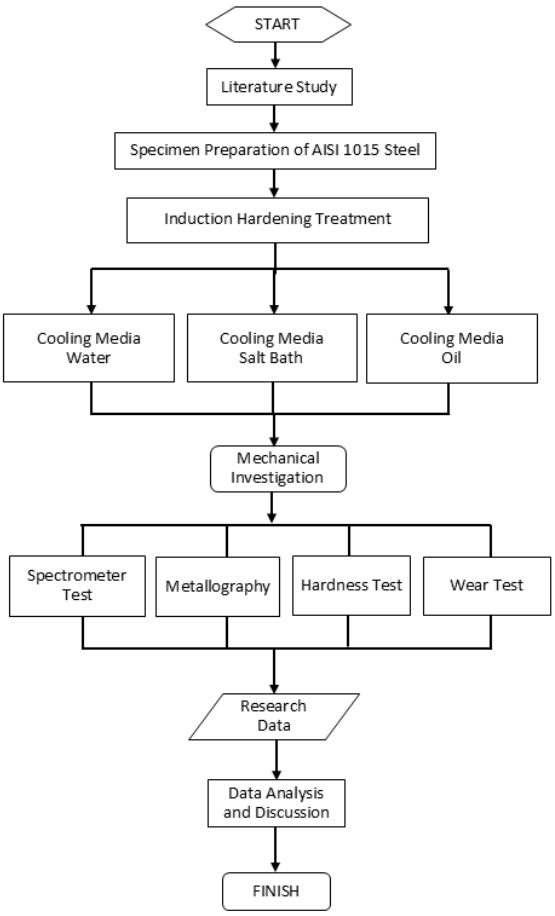

Figure 1. Experimental Process of Research

AISI 1015 steels were used in this research is commercial steels which are cut by 10 mm diameter and measured the precise chemical composition by using ARL 3460 Optical Emission Spectrometer at ambient temperature of 22ºC. Afterwards, three samples of AISI 1015 steels were also prepared for the induction hardening treatment. The process of induction hardening has been performed by heating the samples at 850ºC (austenizing temperature) for 15 minutes by using DIH-1500W Portable Flameless Induction Heating Machine, then subsequent by quenching in different cooling media of water, salt bath, and oil until room temperature.

The microstructure analysis was evaluated by using Olympus BX51M optical microscope to detect phase transformation of the samples. The Vickers hardness test was performed by using Microhardness Tester Mitutoyo HM-122, following the standard ASTM E-384, conical diamond indenter, and adjustment of major load 0.2 kgf in 10 second. The wear resistance characteristics were investigated by friction force test using pin-on-disc technique. At the test, the samples play as stationery pin against rotating disk based on the standard ASTM G-99. The tensile properties were evaluated by using VTS Electro-hydraulic Servo Universal Testing Machine along with the standard ASTM E-8.

III. Results and Discussion

A. Chemical Composition

Quantitative chemical composition studies were performed via spectrometry test to measure the accurate chemical element that contained in the samples. Table 1 displays the chemical composition of the samples which are used in this research.

Apparently, the measured chemical composition of the samples was dominantly formed by the chemical element of 0.152 % C and 99.547 % Fe. This result demonstrates the chemical composition of the samples was associated with the standard American Iron and Steel Institute (AISI) 1015 steel [6].

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Table 1. Chemical Composition of the Samples

No.	Element	Composition (%)
1	C	0.152
2	Si	0.014
3	Mn	0.114
4	P	0.009
5	S	0.013
6	Ni	0.01
7	Cr	0.01
8	Mo	0.018
9	V	0.001
10	Cu	0.041
11	W	0.013
12	Ti	0.001
13	Sn	0.003
14	Al	0.053
15	Pb	0.001
16	Fe	99.547

B. Microstructure of The Induction Hardening Treated Steels

Microscopic observation was examined to determine phase transformation caused by induction hardening treatment of AISI 1015 steel using different cooling media. Phase transformation of the samples would conceive several signs and indications for next mechanical investigation. Figure 2 demonstrates microstructure of all AISI 1015 treated steels with different cooling media.

It is clearly seen that all samples emerge the dual phase of ferrite (bright shade) and pearlite (dark shade) which are mainly the basis of low carbon alloy steel. Figure 1(a) shows typical microstructure of AISI 1015 non-treated steel which consists of tiny ferrite-pearlite uniformly. Likewise, the induction hardening treated to the samples with different cooling media, it culled the fraction of phases more dowdily. Figure 2(b) depicts microstructure of AISI 1015 treated steel with oil cooling media that contains lath pearlite inside ferrite matrix due to the heat treatment effect to crystalline structure become more active that enables to transform [7]. Figure 2(c) displays microstructure of AISI 1015 treated steel with water cooling media. It can be enumerated that the assemblage of ferrite-pearlite matrix which bigger pearlite grain conquers predominant microstructure of the sample. This multitudinous pearlite is linked to increase multifarious mechanical properties namely hardness, wear resistance, and strength [8]. Figure 2(d) presents AISI 1015 steel after induction hardening in salt bath cooling media which promotes the formation of ferrite and coarse pearlite. Distinct transformation of microstructure has been observed as impact of induction hardening treatment for AISI 1015 steels. Furthermore, the mechanical investigation was conducted to gain broad and deep insights involved hardness, wear, and tensile test.

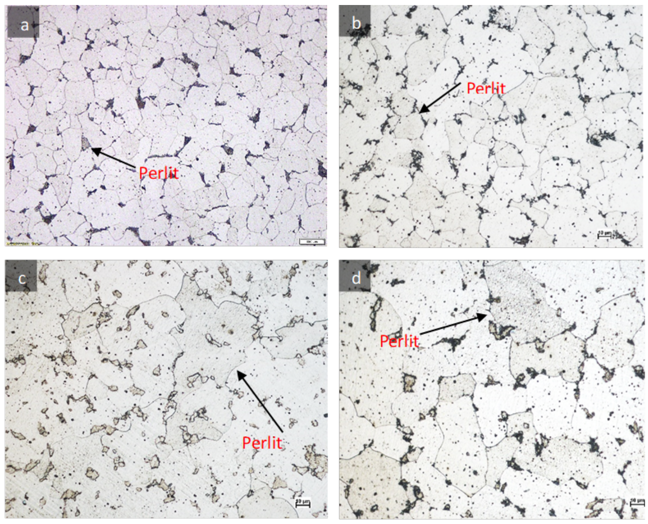

Figure 2. Typical microstructures of AISI 1015 treated steels with different cooling media; (a) non-treated, (b) oil, (c) water, (d) salt bath

C. Hardness Test Investigation

Hardness is pivotal mechanical property for metallic materials pinpointed to friction, abrasion, and contact

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usage [9]. In this research, hardness profile imprints the characteristics of samples towards friction load during indentation. Hardness test was evaluated using Vickers method which denotes as Hardness Vickers (HV). Figure 3 displays calculated hardness value of AISI 1015 treated steels.

The higher improvement in hardness value of AISI 1015 treated steel was 190.5 HV which use water cooling media. Meanwhile, the AISI 1015 treated steel with salt bath cooling media was observed at 186.4 HV following with the drops of 185.7 HV owned by AISI 1015 treated steel with oil cooling media. The lowest hardness value of 175.2 HV be responsible for AISI 1015 non-treated steel. A harden zone during induction treatment ascribed to more captive transformation ability of crystals structure AISI 1015 steel. It is also observed that the use of water cooling media makes a strong interface bonding between the matrix of ferrite-pearlite due to its low viscosity which capable to boost heat transmission encircle the samples [10].

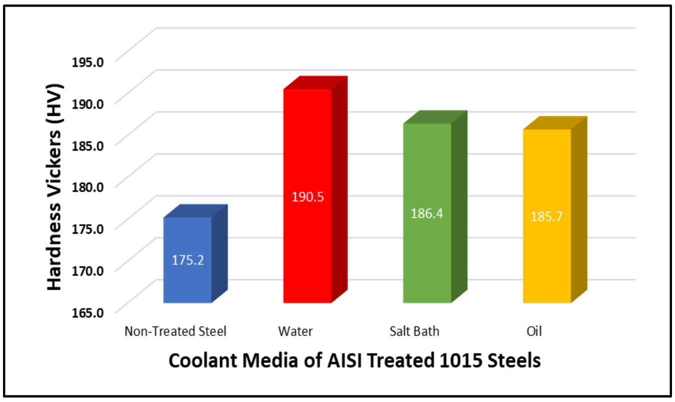

Figure 3. Calculated Hardness Value of AISI 1015 Treated Steels

D. *Wear Resistance Behavior*

Wear resistance is considered as prevalent performance criteria by numerous industries due to its specific applications. Wear resistance profile obtained from calculated wear rate data during wear test. The higher wear rate means that the samples have lower wear resistance behavior. Figure 4 presents calculated wear rate of AISI 1015 treated steels which vividly seen that different cooling media during induction hardening treatment affects wear rate of the samples.

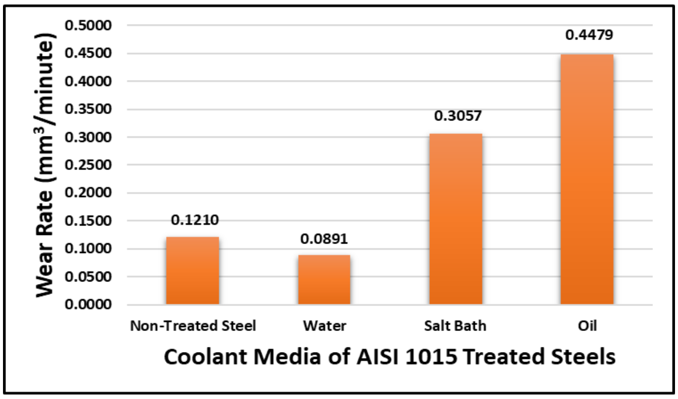

Figure 4. Calculated Wear Rate of AISI 1015 Treated Steels

The highest wear rate of the AISI 1015 treated steel with oil cooling media was approximately 0.4479 mm^3/minute; it decreased in AISI 1015 treated steel with salt bath cooling media of 0.3057 mm^3/minute. Furthermore, the lowest wear rate claimed by AISI 1015 non-treated steel of 0.121 mm^3/minute and AISI 1015 treated steel with water cooling media of 0.0891 mm^3/minute, successively. The increase in wear rate is strongly related to the degradation of hardness value. The relatively lower hardness value impacts the samples get eroded easily which possess poor wear resistance behavior [11], [12]. Accordingly, the AISI 1015 treated steel with water cooling media demonstrated robust wear resistance behavior compared to the other samples. This study provided obvious evidence to emphasize mechanical characteristics of AISI 1015 treated steels during friction, abrasion, and indentation operation.

E. *Tensile Properties*

Tensile properties play the main role to express the optimum strength of the metal alloy towards stress and load. Tensile properties also endow the metal alloy to own more resistant of fracture or breaking [13]. Representative tensile properties of the AISI 1015 treated steel derived from the engineering stress-strain curves are abbreviated as tensile and yield strength as demonstrated in Figure 5.

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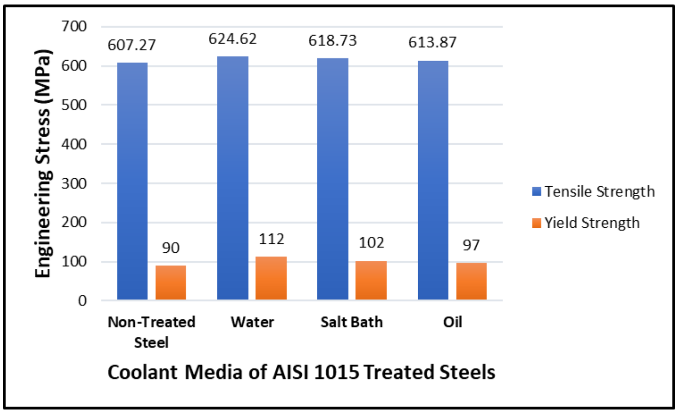

Figure 5. Tensile Test Result of AISI 1015 Treated Steels

It is observed that AISI 1015 treated steel with water cooling media possess slight enhancement tensile and yield strength (624.62 and 112 MPa) compared to the other samples. The improvement in tensile and yield strength is attributed to being on account of vast distribution pearlite in the microstructure of the AISI 1015 treated steel with water cooling media [14]. This also proves to the relatively higher tensile properties of the AISI 1015 treated steels ascribed from induction hardening followed by different coolant media which conducted in this research [15], [16].

IV. Conclusion

The mechanical investigation of different cooling media during induction hardening treatment of AISI 1015 steel was experimentally studied. Mechanical properties and microstructure of AISI 1015 treated steel were investigated using spectrometry test, optical microscopy, hardness test, wear test, and tensile test. The AISI 1015 treated steel using water cooling media shows slightly higher hardness, high wear resistance and tensile properties compared to another samples. This mechanical enhancement was ascribed to the microstructure transformation during induction hardening treatment which proficient to pave stronger ferrite-pearlite interface bonding. Thereby, the induction hardening treatment using water media render the superior mechanical improvement for AISI 1015 steel. To gain more advancement, future research strongly recommended to be expanded for various heating temperatures and comparative study of different samples for low carbon steels.

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