JURNAL IPTEK
MEDIA KOMUNIKASI TEKNOLOGI
homepage URL : ejurnal.itats.ac.id/index.php/iptek

The Mechanical Properties and Microstructure Analysis of Carbon Structural Steel After Quenching in Circulated Water Medium

Afira Ainur Rosidah[1], Vuri Ayu Setyowati[2], Suheni[3], Muhamad Febrianto[4]

[1,2,3,4]Department of Mechanical Engineering, Institut Teknologi Adhi Tama Surabaya, Indonesia

ARTICLE INFORMATION

Jurnal IPTEK – Volume 26 No. 1, May 2022

Page:
1 – 6
Published Date :
31 May 2022

DOI:
10.31284/j.iptek.2022.v26i1.1139

ABSTRACT

The use of carbon structural steel in construction is widely developed. It is important to do research continuously in order to get the optimum mechanical and physical properties of a material. Heat treatment which includes heating and quenching is a process that can be carried out to improve mechanical properties. A rapid cooling rate is used to obtain higher strength and hardness. This research studied the effect of quenching using a circulated water medium with water flow rate variations in structural steel Q235, Q255, and Q275 on their mechanical properties and microstructure. The heat treatment process was done with hardening at 1150 ℃ and roll milling at austenitizing temperature, then quenching using a circulated water medium with a water flow rate of 225, 238, 247 m^3/h. The tensile and hardness test results showed that water flow rate and carbon content in steel give an effect on strength and hardness. The highest tensile strength and hardness value were achieved by Q275 steel with a flow rate of 247 m^3/h, which are 73,49 kgf/mm^2 and 298 HVN, respectively. Meanwhile, the microstructures resulted in the presence of the mixture of martensite and pearlite, as well as ferrite in every sample with an increase in the composition of martensite and pearlite in Q275 steel with a flow rate of 247 m^3/h.

Keywords: *Circulated water; Carbon structural steel; Mechanical properties; Microstructure; Quenching.*

EMAIL

[1]afiraar@itats.ac.id
[2]vuri@itats.ac.id
[3]irsuheni@gmail.com
[4]febri150517@gmail.com

PUBLISHER

LPPM- Institut Teknologi Adhi Tama Surabaya
Alamat:
Jl. Arief Rachman Hakim No.100,Surabaya 60117, Telp/Fax: 031-5997244

ABSTRAK

Penggunaan baja struktural karbon dalam industri konstruksi semakin berkembang sehingga penting untuk terus dilakukan penelitian guna mendapatkan sifat mekanik dan fisik bahan yang optimal. Perlakuan panas adalah salah satu proses yang dapat dilakukan untuk meningkatkan sifat mekanik. Proses ini meliputi pemanasan pada temperatur *austenisasi* dan pendinginan cepat (*quenching*). Pendinginan dengan laju pendinginan yang cepat digunakan untuk menghasilkan material dengan kekuatan dan kekerasan yang lebih tinggi. Penelitian ini mempelajari pengaruh *quenching* dengan medium air tersirkulasi dengan variasi debit aliran air pada baja struktural Q235, Q255, dan Q275 terhadap sifat mekanik dan perubahan struktur mikronya. Proses perlakuan panas dilakukan dengan *hardening* pada temperatur 1.150^{o}C, *roll milling* pada temperatur *austenisasi*, kemudian *quenching* pada medium air tersirkulasi dengan variasi debit aliran 225, 238, 247 m^3/h. Hasil uji tarik dan kekerasan menunjukkan bahwa debit aliran air dan kadar karbon pada baja berpengaruh terhadap kekuatan dan kekerasan. Nilai kekuatan tarik dan kekerasan tertinggi didapatkan pada baja Q275 dengan variasi debit 247 m^3/h, yaitu masing-masing sebesar 73,49 kgf/mm^2 dan 298 HVN. Sedangkan hasil struktur mikro menunjukkan adanya struktur campuran *martensit* dan perlit, serta *ferit* pada setiap sampel dengan komposisi *martensit* dan perlit semakin banyak pada baja Q275 dengan variasi debit 247 m^3/h.

Kata kunci: Air tersirkulasi; Baja struktural karbon; *Quenching*; Sifat mekanik; Struktur mikro.

INTRODUCTION

Carbon structural steel is a widely used material in construction. This material is also known as mild or plain carbon structural steel [1]. In Indonesia, carbon structural steel with Chinese standard GB/T 700 is commonly used. Steel using this standard is notated with a Q letter in the beginning and followed by three numbers. Q letter is an abbreviation for *Qu Fu Dian* in Chinese which means yield point and three numbers show the minimum yield strength value in the unit of MPa. Structural steel which is followed by further processing can be used for reinforcing steel in a concrete structure.

With the development of the industrial field, structural steel in concrete which is used for construction and multilevel building is demanded to have good mechanical and physical properties. Multiple processes such as heat treatment are able to be done on structural steel to obtain better strength and toughness. There are many different ways of doing heat treatment on a material. One of the commonly done ways is hardening with heating until a certain temperature, then it is followed by quenching. Quenching is included in the heat transfer process by means of cooling at a fast rate to produce higher strength and hardness. The achieved material hardness is determined by carbon concentration and cooling rate [2]. The quenching medium affects the martensite formation and its hardness value. From some of the commonly used media, water is the most efficient medium, followed by aqueous polymer, oil, and air [3]. Besides, quenching with circulated water as the medium is also able to escalate the cooling rate. So, it can increase the higher hardness value of a material. This is due to the rapid flow of the cooling medium is directly able to touch the entire material, remove the bubbles, and spray droplets allowing a faster heat transfer [4], [5].

This study is concerned with the effect of circulated water as the quenching medium with the variation of water flow rate on Q235, Q255, and Q275 steel on their mechanical properties and microstructures. The quenching process was carried out after the materials were subjected to some processes, such as hardening and rolling. Q235, Q255, and Q275 steel were chosen due to their wide range of use as structural steel on construction and buildings.

LITERATURE REVIEW

Structural Steel

Structural steel is a commonly used material for buildings, bridges, ships, and offshore equipment, such as a piping network. Its composition is dominated by carbon (C) and manganese (Mn) content with a ferrite and pearlite microstructure which generally has important properties such as weldability and brittle fracture resistance [1]. Structural steel has 0.15-0.30% of carbon content, so it is also called mild structural steel, plain carbon structural, or low alloy steel. This type of material has predictable properties and refers to various standards and codes assigned by several institutions. One of the standards used is the Chinese standard GB/T-700 2006, this standard is referred to as carbon structural steel with the combination of the Q letter, three digits number which indicates the minimum yield strength, and other letters indicate the grade of the material [6].

Quenching

In the quenching process, the steel is heated to its austenitizing temperature and cooled rapidly. The main purpose of austenitizing is the formation of single-phase austenite, dissolved carbon, and other phases. The austenitizing temperature must be high enough to form homogenous austenite and low enough to avoid overgrowth grains. The austenitizing temperature and time, as well as the cooling rate, are the major parameters of quenching. The cooling rate is related to the medium used in the quenching process, the most common media are oil, water, aqueous solution, and brine. Quenching medium selection depends on the required steel hardness and cooling rate to obtain the desired microstructure [7].

Water is the most efficient quenching medium, moreover, the use of an agitated medium, circulated, or flow affects the heat transfer rate. The quenching effectivity elevates with the increase in the rate of agitation, circulation, or flow at the medium [3]. The previous study states that the higher rate of circulation and agitation at the quenching medium escalates the mechanical properties of the steel [4], [8].

Microstructure After Rapid Cooling on Low Carbon Steel

Low carbon steel with a different heat treatment process will change the steel microstructure, thereby affecting its mechanical properties. The heat treatment process includes heating and cooling. The rapid cooling or quenching in carbon steel results in martensite structure, whereas slow cooling near-equilibrium produces ferrite and pearlite structure. This is due to the fast cooling; less diffusion transformation occurs then resulting in the formation of martensite which has high hardness. In opposite when the cooling is slow, more diffusion transformation occurs which results in a low hardness value [9].

In previous research, Sazali et.al. carried out a heat treatment process for low carbon steel with carbon content ranging from 0.05 to 0.20%. The heat treatment was done by heating the materials until 1,000^{o}C, then rapidly cooled in a water medium. The fast cooling using a water medium resulted in the martensite structure [9]. Similar research to low carbon steel with quenching also showed that a fast-cooling rate produced a mixture of martensite and pearlite or ferrite structure. The appearance of martensite after fast cooling has been shown to increase the strength and hardness of low carbon steel [10], [11].

METHODS

The materials used were Q235, Q255, and Q275 steel with the composition of each material shown in Table 1. Moreover, the tools needed were a camera, ruler, vernier caliper, HT-2102 tensile testing machine, Brinell Rockwell Vickers Hardness Tester HBRV 187.5A, metal cutting machine, grinding and polishing machine, Olympus BX51M-RF optical microscope, sandpapers, alumina paste, as well as nital etching solution. This research is divided into several steps. The steel specimens with 10 mm in diameter were cut in lengths of 50 cm, 10 mm, and 5 mm, additionally, each length was prepared in 9 samples. The specimen with a length of 50 cm was used for the tensile testing, meanwhile, the specimen with a length of 10 mm was used for the hardness testing, and the length of 5 mm for the microstructure testing.

After the cutting process, the heat treatment process was applied to start with hardening which was performed at 1,150^{o}C with a holding time of 60 minutes. Then roll milling was carried out at the austenitizing temperature and cooled in a circulated water medium under room temperature with a flow rate of 225, 238, and 247 m^3/h. Following the heat treatment and fast cooling, three kinds of testing were performed, that were tensile testing, hardness testing, and metallography. The tensile testing was done using tensile test standard SNI 2052:2017, meanwhile, the hardness testing was done using the Vickers method with a diamond indenter, a load of 100 kgf, and a loading time of 10 seconds. The metallography was carried out using ASTM E407-07 standard with some stages, such as polyester resin mounting, polishing with a grinding machine, nital solution etching (*ethanol:nitric acid* = 19:1), and observing with an optical microscope.

Table 1. The composition of Q235, Q255, and Q275 steel (in %).

Material/Element	C	Mn	Si	P	S
Q235	0.131	0.592	0.201	0.029	0.032
Q255	0.248	0.684	0.245	0.031	0.046
Q275	0.295	0.790	0.296	0.033	0.040

(a)

(b)

(c)

Figure 1. The specimens of (a) the tensile, (b) the microstructure, and (c) the hardness test.

RESULTS AND DISCUSSION

Effect of Circulated Water as Quenching Medium on The Mechanical Properties

The mechanical properties of the steel were represented by the results of tensile and Vickers hardness testing. Table 2 shows the effect of circulated water as a quenching medium on the tensile test results including yield strength, tensile strength, and elongation. The value of yield and maximum tensile strength tends to increase which is directly related to the increase in carbon concentration of the samples and the water flow rate value. Meanwhile, the elongation value decreases, inversely related to the value of yield and maximum tensile strength. The Q275 steel sample in the quenching process with the water flow rate of 247 m^3/h has the highest maximum tensile strength of 73,49 kgf/mm^2 with an elongation value of 14,1%. This indicates that the Q275 steel after the quenching process at a water flow rate of 247 m^3/h has more powerful properties than other steel samples. This is because the Q275 steel has the highest carbon concentration compared to Q235 and Q255 steel, as well as the determination of a higher water flow rate also results in a faster cooling rate. In accordance with the previous study, a fast cooling rate affects the less transformation when the carbon diffuses so that the carbon atoms will prevent the dislocation from moving and then increase the tensile strength [10].

The results of the hardness test using the Vickers method are shown in Table 3. The highest hardness value 298 HVN is achieved by the Q275 steel sample with a flow rate of 247 m^3/h as the quenching medium. The hardness value of the samples enhances gradually for every enhancement of the water flow rate. This is due to the higher value of the water flow rate, so, the cooling rate is faster and able to increase the hardness value. Moreover, the high hardness value is influenced by the carbon concentration difference for every steel. The higher carbon concentration makes the hardness value increase. Corresponding to the study conducted by Adebayo et al, the value of strength and hardness of steel enhances with enhancing the cooling rate but shows the inversely related elongation value [11].

Table 2. The tensile test results of steels after quenching in circulated water medium with water flow rate variations.

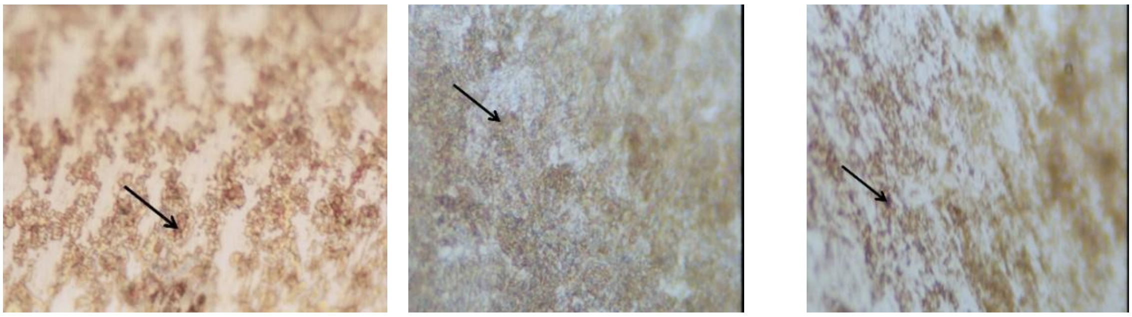
Material	Flow Rate (m^3/h)	Yield Strength (kgf/mm^2)	Maximum Tensile Strength (kgf/mm^2)	Elongation (%)
Q235	225	41.72	56.29	25.00
	238	43.81	58.35	22.63
	247	45.02	60.60	22.50
Q255	225	47.93	62.00	21.00
	238	48.94	60.99	21.50
	247	51.26	68.02	20.50
Q275	225	54.74	67.88	14.30
	238	56.42	70.11	15.65
	247	58.47	73.49	14.10

Table 3. The hardness test results using Vickers method after quenching in circulated water medium with water flow rate variations.

Material	Flow Rate (m^3/h)	HVN
Q235	225	174
	238	187
	247	241
Q255	225	249
	238	252
	247	263
Q275	225	274
	238	287
	247	298

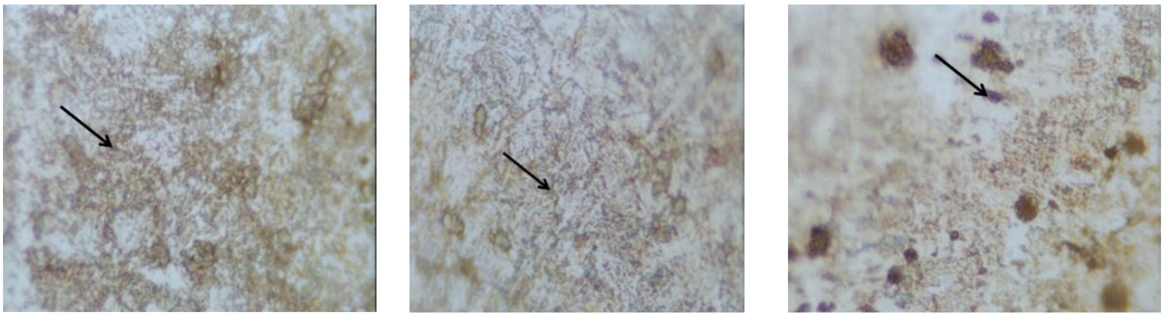
Effect of Circulated Water as Quenching Medium on The Microstructure

Figures 2 to 4 show the microstructure of the steel quenched in the circulated water medium with the flow rate variations at an approximate magnification of 200x. The microstructures of the carbon steel quenched in the circulated water medium indicate the presence of ferrite (bright area) and the mixture of coarse microstructure from martensite (pointed by arrows, darker area) and pearlite (slightly dark area). The higher value of the water flow rate, the less proportion of ferrite in the microstructure is visible. The increase in flow rate leads to a faster cooling rate. A faster cooling rate triggers the increase in martensite by accelerating the transformation from austenite to martensite, in accordance with Mosa's research [10]. Meanwhile, the Q275 steel with a flow rate of 247 m^3/h shows more proportion of martensite and pearlite than Q235 and Q255 steel. This is due to the Q275 steel having a higher carbon concentration than Q235 and Q255 steel, so, there is more undiffuse carbon during the transformation. The higher proportion of martensite and pearlite in the Q275 steel with the variation in the water flow rate of 247 m^3/h compared to other samples causes the highest tensile strength and hardness.



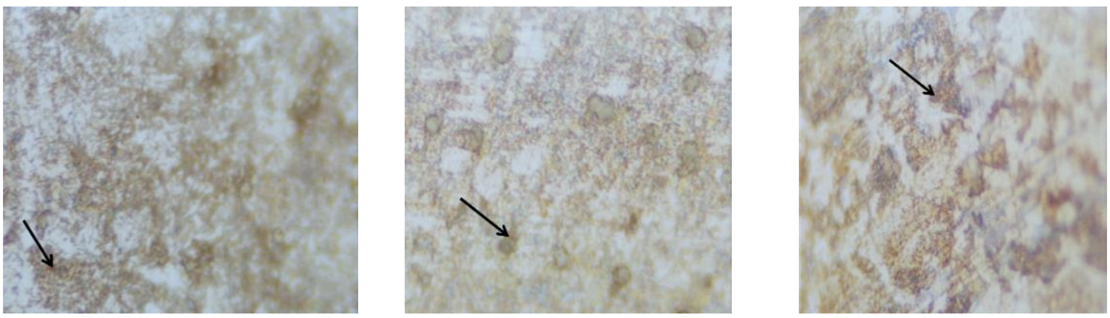
(a) (b) (c)

Figure 2. The microstructure of Q235 steel quenched with the variation in the water flow rate of (a) 225, (b) 238, and (c) 247 m^3/h.



(a) (b) (c)

Figure 3. The microstructure of Q255 steel quenched with the variation in the water flow rate of (a) 225, (b) 238, and (c) 247 m^3/h.



(a) (b) (c)

Figure 4. The microstructure of Q275 steel quenched with the variation in the water flow rate of (a) 225, (b) 238, and (c) 247 m^3/h.

CONCLUSION

Quenching using a circulated water medium with variations of the water flow rate is able to escalate the mechanical properties of Q235, Q255, and Q275 steel. With the higher water flow rate and carbon content in steel, the yield strength, maximum tensile strength, and hardness value increase as well, however, the elongation value decreases. The highest value of tensile strength is 73,49 kgf/mm^2 with the yield strength value of 58,47 kgf/mm^2 and the elongation 14,1%, as well as the highest value of hardness 298 HVN, were obtained in Q275 steel with the water flow rate of 247 m^3/h. The metallography results showed the appearance of ferrite, martensite, and pearlite structure in every sample. The proportion of martensite is higher with the increase in the water flow rate as the quenching medium and the carbon concentration. Q275 steel with a water flow rate of 247 m^3/h has more proportion of martensite and pearlite compared to other samples.

BIBLIOGRAPHY

[1] J. W. Martin, “Metals and Alloys,” in *Materials for Engineering*, 3rd ed., Woodhead Publishing, 2006, pp. 71–132.
[2] A. Pramono, “Karakterisrik Mekanik Proses Hardening Baja Aisi 1045 Media Quenching Untuk Aplikasi Sprochet Rantai,” *J. Ilm. Tek. Mesin Cakram*, vol. 5, no. 1, pp. 32–38, 2011.
[3] W. D. Callister and D. G. Rethwisch, *Materials Science and Engineering: An Introduction*, 8th ed. United States: John Wiley & Sons, Inc., 2009.
[4] G. H. Haryadi, “Pengaruh Kecepatan Air Sirkulasi Sebagai Medium Quenching Terhadap Kekerasan Dan Struktur Mikro Pada Baja Aisi 4140,” *ROTASI*, vol. 8, no. 1, pp. 24–33, 2006.
[5] G. E. Totten, J. L. Dossett, and N. I. Kobasko, “Quenching of Steel,” in *ASM Handbook, Steel Heat Treating Fundamentals and Processes*, vol. 4A, Metals Park, Ohio: ASM International, 2013.
[6] K. F. Chung, S. P. Chiew, and H. Y. Lee, *Professional Guide HKCMSA-P001: Selection of Equivalent Steel Materials to European Steel Materials Specifications*. Hong Kong Constructional Metal Structures Association, 2015.
[7] M. M. Nunes, E. M. Da Silva, R. A. Renzetti, and T. G. Brito, “Analysis of Quenching Parameters in AISI 4340 Steel by Using Design of Experiments,” *Mater. Res.*, vol. 22, no. 1, pp. 1–7, 2019.
[8] I. T. Muhammad, A. A. Ibrahim, and H. Ibrahim, “Investigation of the Effects of Agitation on the Hardening Characteristics of Medium Carbon Steel Quenched in Non-Edible Seed Oils Grown in Nigeria,” *Int. J. Adv. Sci. Res. Eng.*, vol. 5, no. 3, pp. 84–90, 2019.
[9] N. Sazali, W. Norharyati, W. Salleh, and I. N. Ibrahim, “The Influence of Thickness on Low Carbon Steel in Rapid Cooling Process,” *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 56, no. 2, pp. 175–182, 2019.
[10] S. J. Mosa, “Effect of Different Quenching Media on Mechanical Properties of AISI 1018 Low Carbon Steel,” *J. Mech. Eng. Res. Dev.*, vol. 42, no. 3, pp. 81–83, 2019.
[11] A. Adebayo, J. T. Stephen, and G. J. Adeyemi, “Effects of Local Cooling Media on the Mechanical Properties of Heat Treated Mild Steel,” *Eur. J. Eng. Res. Sci.*, vol. 3, no. 4, pp. 27–31, 2018.