Evaluation of Mechanical Properties by Grain Refining of Low Carbon Steel Under Various Cooling Media

P Rajendra, Pradeep K V Kumar and K R Phaneesh

March 17, 2021

Evaluation of mechanical properties by grain refining of low carbon steel under various cooling media

Rajendra P[1], Pradeep Kumar K V[2], K R Phaneesh[3],

[1,2,3]Department of Mechanical Engineering, Ramaiah Institute of Technology, Bengaluru 560054, Karnataka, India.

*pradeepkv@msrit.edu

Abstract. The determination of the property of low carbon steel depends primarily on the cooling medium, recrystallized temperature and critical cooling rate. The higher the cooling temperature, the greater the probability of forming coarse grains of the martensite crystal structure and the lower the cooling rate, the greater the likelihood of forming fine grains of an evenly spaced pearlite and martensite crystal structure. The cooling medium specifically influences the microstructure of the cooling material and the analysis of the microstructure is carried out by adding various cooling mediums, such as ice water, water (at 25^0 C), oil (SAE 15W-30) and boiling water (at 100^0 C). The cooling rate primarily depends on the fluid viscosity. The viscosity is greater, leading to fine grain, and vice versa. The cooling temperature must be lower than the critical cooling rate, because only improvements in the development of fine grains and the hardening of the strain and residual stresses must be altered. The specimen is characterized by various mechanical tests i.e. microstructure inspection, hardness, tensile and impact. to evaluate the properties of the material used in the specific applications.

Keywords: Heat Treatment, Critical cooling Temperature, cooling medium and Microstructure.

1. Introduction

Materials science and engineering (MSE) is an interdisciplinary area of science and engineering that investigates and modifies the composition and structure of materials over time in order to improve their properties through synthesis and processing. The study of a material's structure is one of the most interesting aspects of materials science. Even if the overall composition of a material does not vary, its structure has a significant impact on many of its properties. Steel is the most widely used of all metals. Steel, according to the World Steel Association, is an iron-carbon alloy containing less than 2% carbon and 1% manganese. It also contains some other elements like manganese and silicon and traces of impurities like Sulphur and phosphorus. Steel has a wide range of applications in daily life. Among the goods, steel with outstanding features is the finest. The steel was categorized into low carbon steel, medium carbon steel, high carbon steel on the basis of carbon content.

Low carbon steels (0.002 - 0.25 percent carbon) represent a significant portion of total steel production due to its low cost and versatile properties comparable to that of iron, making them suitable for a wide range of engineering applications. In this type, they are used for vehicles, furniture, refrigerators, tinplate, and roofing. Structural steel has a C content of 0.15 to 0.25 percent and is used for structural purposes such as pillars, channels, and angles in construction. According to studies, the size of the earlier austenite grain plays a role in determining the strength and durability of steels. The strength and toughness of steels improve as the grain size is refined but the mechanism of the process is not entirely clear for martensitic steels. Steel may be strengthened in a variety of ways, including solid solution, dispersion, grain boundary strengthening (grain refinement), dislocation strengthening, and textural strengthening. Grain refinement, characterized as the reduction of the size of grains inside a material, is the only strengthening mechanism that improves strength and ductility. Grains are areas of a material where the atoms are oriented in a specific way.

The findings of this study will be beneficial to the iron and steel industries because they will enable steel producers to produce products with fine grains, high impact strength, and durability. It shows a novel method of reinforcing steel for enhanced service strength. The heat treatment has been used for grain refinement. This work provides a documented procedure for carrying out heat treatment on mild steel. The method is locally adaptable as it can be carried out in any local metallurgical laboratory thereby providing steel makers a very good and easily accessible alternative to altering the microstructural composition of their products. The process is also very economical as it saves time, energy and cost as compared to the conventional diffusional (slow heating) heat treatment.

2. Materials and Methods

The procedure of material heat treatment involves heating and guided cooling in order to attain desired mechanical and microstructural properties. To achieve this, the materials were first prepared based on the tests specifications to be carried out before heat treatment. After heat treatment, various tests such as hardness test, tensile tests, Charpy V-notch impact test and microstructural examinations were carried out.

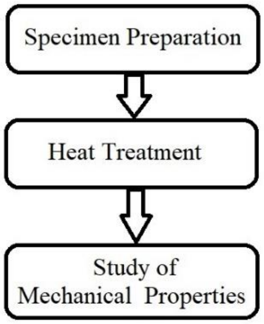

Figure 1. Methodology

2.1 Specimen preparation

The preparation of the specimen is the experiment's first and most important task. The procedure for preparing the sample involves cutting, machining and labeling. First, the samples were cut into the various test specimen lengths. The next step in material preparation is machining. The specimens were machined to the required dimensions according to the specification for the tests to be carried out. The specimens needed for hardness test and Optical Microscopy had their surfaces planed. Machining was done with the aid of Lathe machine available at Ramaiah Institute of Technology Workshop. Five set of samples were produced for the various tests to be carried out.

2.2 Heat treatment

After machining, the sets of specimens were labeled A, B, C, D and E. Set A represents the untreated specimen (as received). Set B shows the specimen that was heated and then quenched in boiling water (at 100°C). Set C depicts a specimen that's been heated and then quenched in water (Room temperature). Set D portrays a specimen that has been heated and then quenched in ice water (0°C). Set E portrays a specimen which has been heat treated and then quenched in oil (SAE).

Figure 2. Electric Furnace

Table 1. Sets of specimens.

Sample	Set (A)	Set (B)	Set (C)	Set (D)	Set (E)
Heat Treatment	Untreated specimen (as received)	Boiling water quenching (100°C)	Water quenching (Room Temperature)	Ice water quenching (0°C)	Oil quenching (SAE)

Figure 3. Test specimens

2.3 Mechanical Testing

2.3.1 Hardness Testing

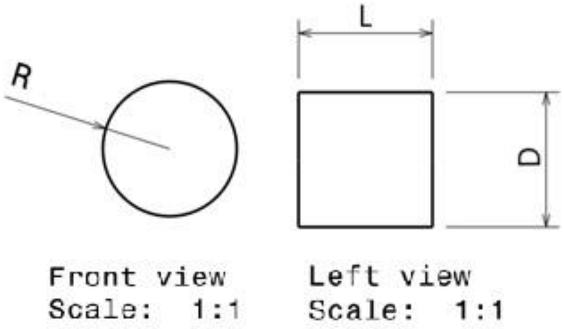

Figure 4. Dimensions of hardness test specimen.

To assess the hardness of the specimens before and after heat treatment, the Vickers hardness test was performed. The applied load was 10 kgf for 15 seconds during this test. At least three readings were taken for each specimen, and then average value of pyramid indenter diameter was measured.

Using the following equation, the Vickers hardness number was determined.

$$VHN=1.8544\times F/d^2 \ (\mathrm{kgf/mm^2}) \qquad (1)$$

Table 2 Dimensions of hardness test specimen

Symbol	Description	Dimension (mm)
R	Radius	75
L	Length	100

Figure 5. Vickers hardness testing machine.

2.3.2 Tensile Testing

According to ASTM-E8; the dimension of the specimen for a tensile test is as shown in figure below.

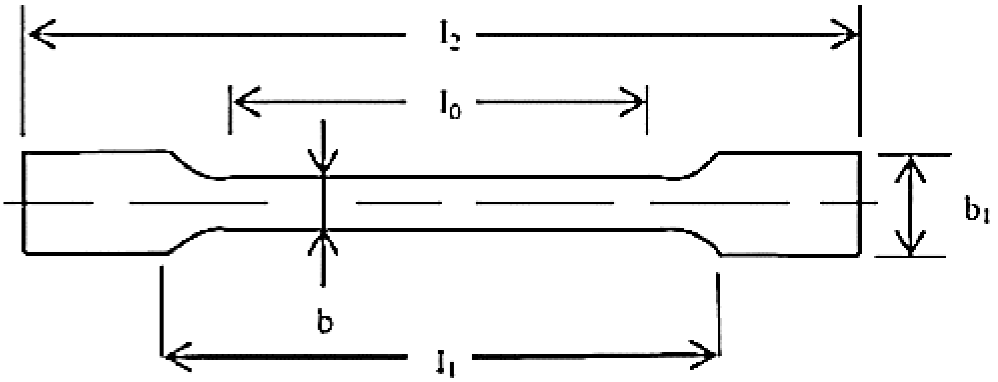

Figure 6. Dimensions for tensile testing specimen

Table 3. Tensile test specimen specification

Symbol	Description	Dimension (mm)
I_0	Gauge length	75
I_1	Grip distance	100
I_2	Overall length	300
b	Minor Diameter	12.5
b1	Major Diameter	20

The universal Testing machine was used to perform the tensile test. Mechanical properties such as tensile strength, yield strength, ductility, and modulus of elasticity were calculated after the specimens were removed before they collapsed. The specimens were tensile tested before and after heat treatment.

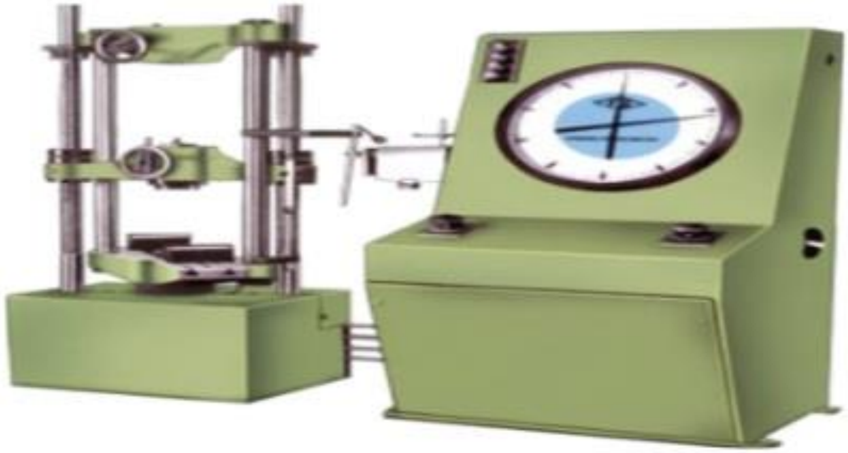

Figure 7. Universal Testing Machine

2.3.3 Impact Testing

The samples were tested using the standard Charpy V-notch Impact test bar. According to ASTM A370, ISO148 and EN 10045-1, the standard specimen size for Charpy impact testing are 10 mm by 10 mm by 75 mm with 45° angular grove at the middle with a depth of 2 mm.

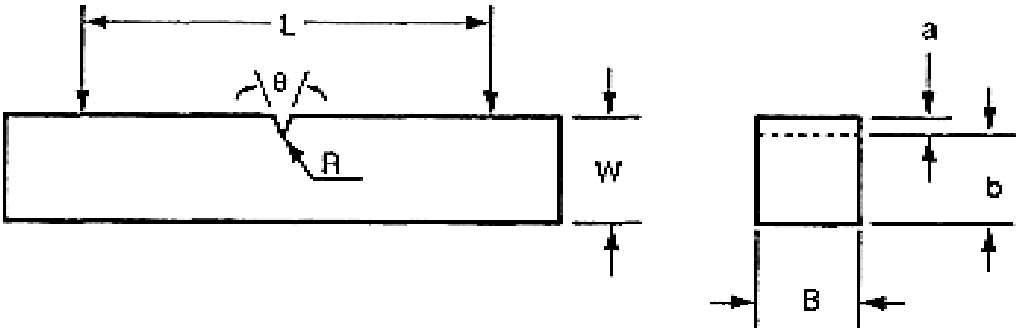

Figure 8. Dimensions of impact test specimen.

Table 4. Dimensions of impact test specimen

Symbol	Description	Dimension (mm)
L	Length	55
θ	Groove Angle	45º
W=B	Width	10
b	Depth Below Groove	8
a	Groove Depth	2

The procedure involved supporting the sample between two bars and breaking it by the action of a swinging pendulum. From the amount of swing of the pendulum, the energy dissipated in breaking the sample is obtained electronically. The test was conducted twice on each sample and the mean of the impact energy was calculated from the results of the two tests.

Figure 9. Impact testing machine used

2.4 Sample Preparation for Metallographic Examination.

Sample preparation is the primary stage involved in metallographic examination processes. This includes grinding, polishing, etching before final examination under the metallurgical microscope.

2.4.1 Grinding and Polishing

Figure 10. Process of grinding and polishing

Grinding is used to build a perfectly flat and smooth surface. SiC papers of various grades were mounted on the grinding machine in the following order: 220, 320, 400, and 600, i.e. from coarse to fine. To remove the grits and prevent overheating, the grinding was performed under running water. The samples were rotated 90 degrees as they progressed from one grit size to the next. This is done to mitigate the scratching effect of the earlier grit size grinding. A universal polishing machine was used to finish the polishing process.

A polishing cloth (selvyt cloth) was mounted on the polisher for the initial polishing stage, which was swamped with a one micron SiC solution, followed by the final polishing stage, which was swamped with a 0.5 micron SiC solution until a mirror-like surface was obtained, then washed and dried.

2.4.2 Etching.

Etching was then used to expose the lines distinguishing the polished surface's boundaries. Etching is a targeted strike on grain boundaries, which are a high-energy, high-dislocation-density field. The reflective surface was etched with a 2percent NITAL solution (2 percent Nitric Acid and 98 percent Ethyl Alcohol). The sample was then washed, dried, and analyzed under a 400X magnification optical microscope, with images captured.

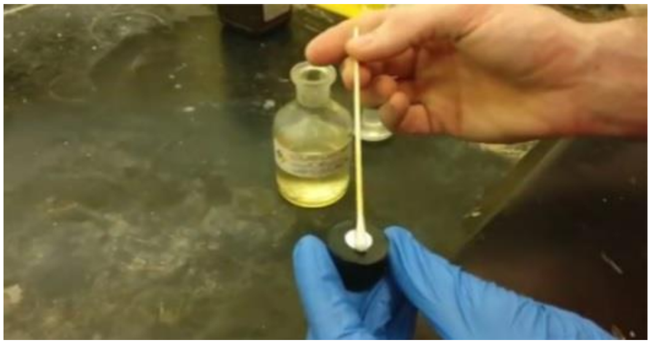

Figure 11. Application of Etchant.

3. Results and discussions

3.1 Hardness Test

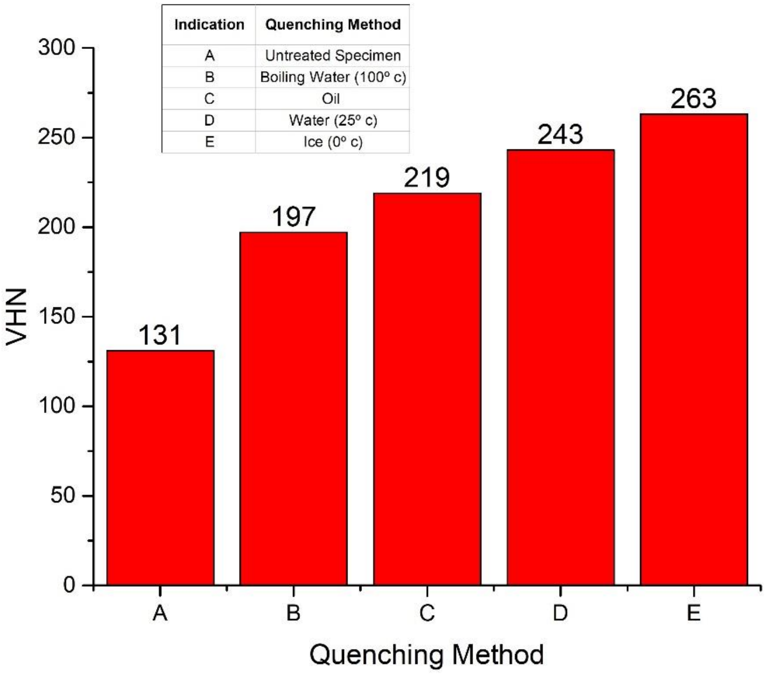

Figure 12: Results of hardness test

The test results are as shown in the Figure 12. From the above figure, we can conclude that as the heat-treatment temperature decreases, Vickers hardness number increases. The Vickers hardness number obtained for untreated specimen is found to be 131VHN. The Vickers hardness number obtained for specimen heat treated with Boiling water is found to be 197.1 VHN. The Vickers hardness number obtained for specimen heat treated with water at room temperature is found to be 243.8 VHN. The Vickers hardness number obtained for specimen heat treated with Ice water is found to be 263.4 VHN. The Vickers hardness number obtained for specimen heat treated with Oil is found to be 219 VHN.

Table 5. Hardness test results

Heat treat method	Values
Untreated Specimen	131
Boiling Water	197.1
Water @25º C	243.8
Ice Water	263.4
Oil	219

The Vickers hardness number obtained for untreated specimen is found to be 131 VHN. For the specimen which was heat-treated with boiling water, after performing Vickers hardness test it was found to be 197.1 VHN which is 50.55% more than that of the untreated specimen. For the specimen which was heat-treated with water, after performing Vickers hardness test it was found to be 243.8 VHN which is 85.49% more than that of the untreated specimen. For the specimen which was heat-treated with ice water, after performing Vickers hardness test it was found to be 263.4 VHN which is 100.68% more than that of the untreated specimen. For the specimen which was heat-treated with oil, after performing Vickers hardness test it was found to be 219 VHN which is 67.17% more than that of the untreated specimen

3.2 Tensile Strength

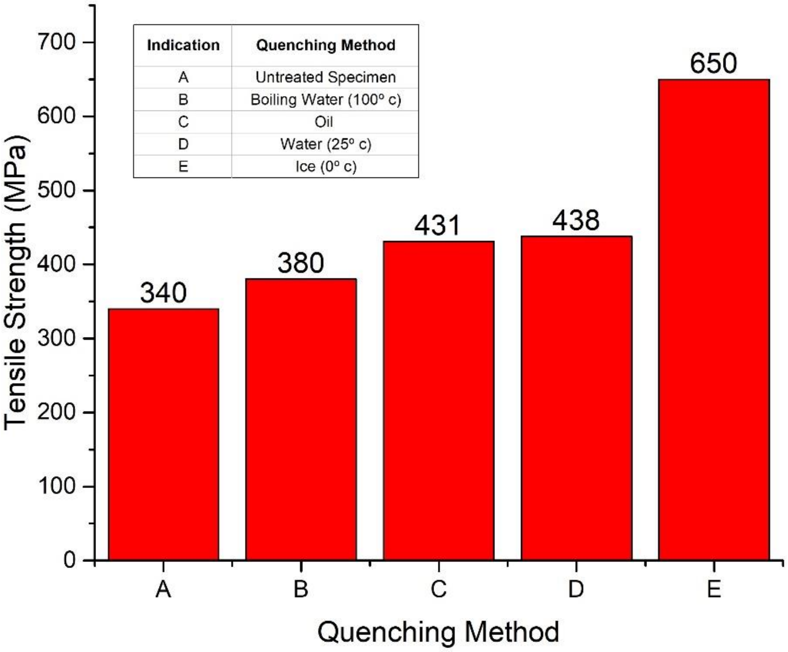

Figure 13. Tensile test results

The test results are as shown in the graph. From the graph can conclude that as the heat-treatment temperature decreases Ultimate tensile strength increases. The Ultimate tensile stress obtained for untreated specimen is found to be 340 MPa. The Ultimate tensile stress obtained for specimen heat treated with boiling water is found to be 380 MPa. The Ultimate tensile stress obtained for specimen heat treated with water at room temperature is found to be 438 MPa. The Ultimate tensile stress obtained for specimen heat treated with Ice water is found to be 650 MPa. The Ultimate tensile stress obtained for specimen heat treated with Oil is found to be 431Mpa.

For the specimen which was heat-treated with boiling water, after performing Ultimate tensile test it was found to be 380 MPa which is 11.76% more than that of the untreated specimen. For the specimen which was heat-treated with water, after performing Ultimate tensile test it was found to be 438 MPa which is 28.82% more than that of the untreated specimen. For the specimen which was heat-treated with ice water, after performing Ultimate tensile test it was found to be 650 MPa which is 91.17% more than that of the untreated specimen. For the specimen which was heat-treated with oil, after performing Ultimate tensile test it was found to be 431 MPa which is 26.76% more than that of the untreated specimen.

Table 6. Tensile strength of different specimens

Heat treat method	Values (MPa)
Untreated Specimen	340
Boiling Water	380
Water @25º C	438
Ice Water	650
Oil	431

The test results are as shown in the graph. From the graph can conclude that as the heat treatment temperature increases Impact energy increases The Impact energy obtained for untreated specimen is found to be 112 J. The Impact energy obtained for specimen heat treated with Boiling water is found to be 290 J. The Impact energy obtained for specimen heat treated with water at room temperature is found to be 232 J. The Impact energy obtained for specimen heat treated with Ice water is found to be 214 J. The Impact energy obtained for specimen heat treated with Oil is found to be 267 J.

3.3 Impact Test

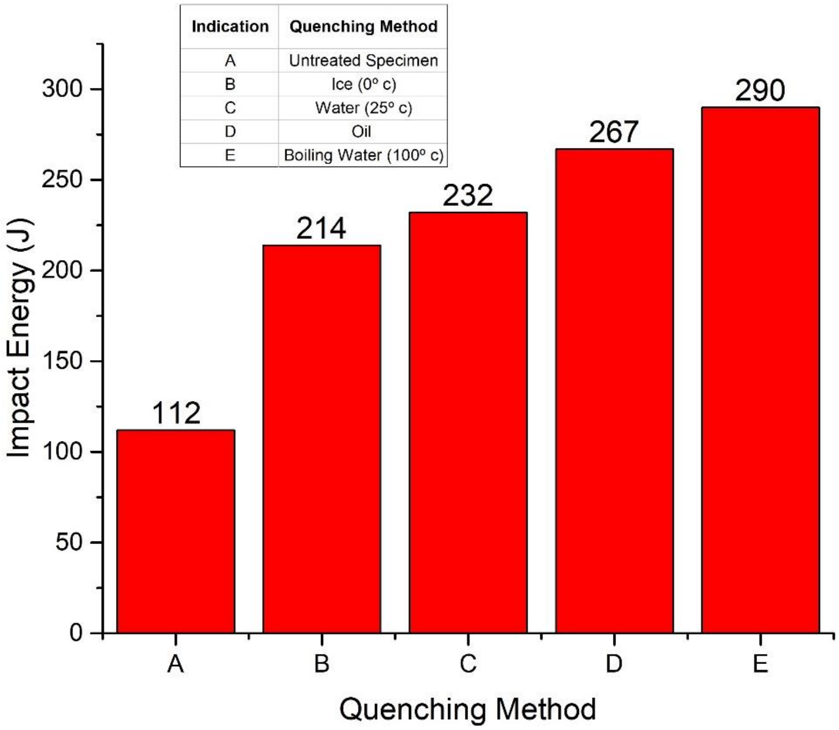

Figure 14. Results of Impact test

Table 7. Impact energy of different specimens

Heat treat method	Values (J)
Untreated Specimen	112
Boiling Water	290
Water @25º C	232
Ice Water	214
Oil	267

The Impact Energy obtained for untreated specimen is found to be 112 J. For the specimen which was heat-treated with boiling water, after performing Impact Energy test it was found to be 290 J which is 158.79% more than that of the untreated specimen. For the specimen which was heat-treated with water, after performing Impact Energy test it was found to be 232 J which is 107.14% more than that of the untreated specimen. For the specimen which was heat-treated with ice water, after performing Impact Energy test it was found to be 214 J which is 91.14% more than that of the untreated specimen. For the specimen which was heat-treated with oil, after performing Impact Energy test it was found to be 267 J which is 138.4% more than that of the untreated specimen.

Conclusions

- Ice water, more than any other quenching medium, induces the formation of martensite phase, according to microstructure analysis. In comparison to other quenching media, ice water yields a higher value in a hardness test. Because of its higher cooling rate, ice water enhances mechanical properties. Hardness, yield strength, and tensile strength are all boosted by ice water.
- The aim of heat treatments on metals and alloys is to validate the microstructure and obtain the desired mechanical properties in terms of ductility, hardness, durability, and strength. The microstructure of materials has a strong influence on these properties. Since different cooling rates result in different phases during a treatment process, phase transitions must be carefully monitored.
- The ductility, hardness, durability, and strength values vary depending on the phase. Everything is organized in a logical fashion. We would see how alloying elements and cooling rates influence the microstructure, as well as how the microstructure of a specimen affects the hardness values, using this experiment.
- The hardness of an alloy increases as the rate of composition of the alloying material or cooling rate increases. As a result, we discovered that if we can control the structure, we can use heat treatment methods to obtain the desired mechanical properties. From the results of hardness test, we can clearly conclude that heat treating the specimen followed by ice water quenching would give more hardness which is the desirable property.
- From the results of ultimate tensile test, we can clearly conclude that heat treating the specimen followed by ice water quenching would give more tensile strength which is the desirable property.

- From the results of impact energy test, we can clearly conclude that heat treating the specimen followed by boiling water quenching would give more stiffness which is the desirable property.
- Depending on the type of application, one can choose the medium for the heat treatment of the specimen which would give the desirable properties.

References

[1] Philip TV, Thomas J, Cafffery M (1961) Properties and selection - Iron, Steels and high Performance Alloys. ASM Hand Book Vol-1, ASM International, Ohio.
[2] Momoh M, Bamike BJ, Saliu AM, Adeyemi OA (2015) Effects of Polyethylene Glycol on the Mechanical Properties of Medium Carbon Low Alloy Steel. Nig J Tech Devlop 12.
[3] Designation: E8/E8M – 09. Standard Test Methods for Tension Testing of Metallic Materials.
[4] Becherer BA, Witheford TJ (1961) Heat Treating of Ultra-high-strength Steels. ASM Hand Book Vol-4, ASM International, Ohio.
[5] Odusote JK, Ajiboye TK, Rabiu AB (2012) Evaluation of Mechanical Properties of Medium Carbon Steel Quenched in Water and Oil. AUJT 15: 218-224.
[6] Zipperian DC (2016) Pace Technologies, Metallographic Specimen Preparation basic.
[7] Ahmed OJ (2011) Study the effect of polymer solution and oil quenchants on hardening automotive camshaft. J Thi-Qar University 6: 134-146.
[8] Ericsson T (1991) Principle of Heat treating of Steels. ASM Handbook, Ohio.
[9] Classification and Designation of Carbon and Low Alloy Steel (1990). ASM Handbook.
[10] Carbon Steel Handbook (2007) Electric Power Research Institute, Palo Alto, California.
[11] Philip TV, Mccaffrey TJ (1990) Ultrahigh strength steels. ASM Handbook, Ohio.
[12] Ramesha CM (2003) A study on suitability criteria of steels with lower alloy contents for semi critical application maintaining reliability and structural integrity by process modifications 2003-2010. ASM Handbook “Heat Treating”.
[13] Eshraghi-Kakhki M, Golozar MA, Kermanpur A (2011) Application of polymeric quenchants in heat treatment of crack-sensitive steel mechanical parts: Modeling and experiments. Materials and Design 32: 2870-2877.
[14] Higgins AR (2004) Engineering Metallurgy - Part 1 - Applied Physical Metallurgy. (7th Ed) Edward Arnold, England.
[15] Khanna OP (2009) Material Science and Metallurgy. Dhanpat Rai Pub (P) Ltd.
[16] Martin JW, Doherty RD, Cantor B (1997) Stability of Microstructure in Metallic Systems (2nd edition). Cambridge: Cambridge University Press, UK.
[17] Ndaliman MB (2006) An Assessment of Mechanical properties of Medium Carbon Steel under Different Quenching Medium. AUJT 10:100-104.
[18] Chandan BR and Ramesha CM, Evaluation of Mechanical Properties of Medium Carbon Low Alloy Forged Steels Quenched in Water, Oil and Polymer.”
19] Senthilkumar, T., Ajiboye, T.K. 2012. Effect of heat treatment processes on the mechanical properties of medium carbon steel. Journal of Minerals and Materials Characterization and Engineering, 11.
[20] Chris Shade & Tom Murphy, Microstructure and Mechanical Properties of Micro alloyed Pm Steels.

[21] Sarah Jalal Mosa, Effect of Different Quenching Media on Mechanical Properties of Aisi1018 Low Carbon Steel.

[22] Noor Mazni Ismail, Nurul Aida Amir Khatif, Mohamad Aliff Kamil AwangKecik, Mohd Ali Hanafiah Shaharudin, The effect of heat treatment on the hardness and impact properties of medium carbon steel.

[23] Orhadahwe, Thomas Aghogho, Effect of Cyclic Rapid Heating on The Mechanical Properties and Microstructure of Mild Steel.

[24] Influence of Heat Treatment On the Absorbed Energy of Carbon Steel Alloys Using Oil Quenching and Water Quenching by Kirkuk University.

[25] Song, Z.: Effect of Heat Treatment on the Microstructure and Mechanical Properties of Steel, University of Science and Technology Beijing, Dept. of M.S.E, 40531165.

[26] Rajan, T.V. and Sharma, C.P.: Heat Treatment Principles and Techniques, Revised edition, New Delhi, Prentice-Hall of India Private Limited, 109, 1994.

[27] Himuro, Y., Kainuma, R. and Ishida, K.: Martensitic transformation and shape memory effect in ausaged Fe-Ni-Si alloys, ISIJ Int., 42, 184–190, 2002.

[28] Durlu, T.N.: Effects of high austenitizing temperature and austenite deformation on formation of martensite in Fe-Ni-C alloys. J. Mater. Sci., 36, 5665–5671, 2001.

[29] Offor, P.O., Daniel, C.C. and Obikwelu, D.O.N.: Effects of Various Quenching Media on the Mechanical Properties of Intercritically Annealed 0.15wt%C – 0.43wt%Mn Steel, NJT, 29(2), 76–81, 2010.

[30] Ndaliman, M. B.: An Assessment of Mechanical Properties of Medium Carbon Steel under Different Quenching Media, AU J.T., 10, 100, 2006.

[31] Odusote, J.K., Ajiboye, T.K. and Rabiu, A.B.: Evaluation of Mechanical Properties of Medium Carbon Steel Quenched in Water and Oil, AU J.T., 15(4), 218–224, 2012.

[32] Senthilkumar, T. and Ajiboye, T.K.: Effect of Heat Treatment Processes on the Mechanical Properties of Medium Carbon Steel, JMCE, 11(2), 143–152, 2012.

[33] Dong-Li, F., Yueming, X. and Xiaohui, T.: Heat Treatment Technical Data Manual, Second Edition, Beijing, Mechanical Industry Press, 2006.

[34] Fadare, D.A., Fadara, T.G. and Akanbi, O.Y.: Effect of Heat Treatment on Mechanical Properties and Microstructure of NST 37-2 Steel, JMMCE, 10(3), 299–308, 2011.

[35] Xu-Ding, S. and Han-Guang, F.: Effects of heat treatment on properties of multielement low alloy wear-resistant steel, China Foundry, 4(1), 18–21, 2007.

[36] Yue, C., Zhang, L., Liao, S. and Gao, H.: Kinetic Analysis of the Austenite Grain Growth in GCr15 Steel, JMEP, 19, 112–115, 2009.

[37] Jung, B.B., Lee, H.K. and Park, H.C.: Effect of grain size on the indentation hardness for polycrystalline materials by the modified strain gradient theory, IJSS, 50(18), 2719–2724, 2013.

[38] Khzouz, E.: Grain Growth Kinetics in Steels, Project Number: RDS 21381, 2011.

[39] Bella, K.A., Hassan, S.B., Abdulwahab, M. 2007. Effects of tempering on the microstructure and mechanical properties steel. Journal of Applied Sciences research, 3(12), pp.1719-1723.

[40] Offar, P.O., Daniel, C.C., Obikwelu, D.O.N. 2010. Effects of various quenching media on the mechanical propertied of intercritically annealed 0.15 wt.% C-0.43wt% Mn steel. Nigerain Journal of technology, 29 (2), pp.76-81.

[41] Joshua, T.O., Alao, O.A., Oluyori, R.T. 2014. Effects of various quenching media on the mechanical properties of inter-critically annealed 0.267%C – 0.83% Mn steel. International Journal of engineering and advanced technology, 3 (6), pp.121-127.

[42] Odusate, J.K., Ajiboye, T.K., Rabiu, A.B. 2012. Evaluation of mechanical properties of medium carbon steel quenched in water and oil. Journal of minerals and materials characterization and engineering, 11, pp.859-862.
[43] Tanwer, A.K. 2014. Effect of various heat treatment processes on mechanical properties of mild steel and stainless steel. American international Journal of research in science, technology, engineering and mathematics, 8 (1), pp.57-61.
[44] Chandan, B.R., Ramesha, C.M. 2017. Evaluation of mechanical properties of medium carbon low alloy forged steel quenched in water, Oil and polymer. Journal of material science and engineering, 6 (2-6), pp.1-5.
[45] Miernik, K., Bogucki, R., Pyta, S. 2010. Effect of quenching techniques on the mechanical properties of low carbon structural steel. Archives of foundry engineering, 10 (3), pp.91-96.
[46] Tanwer, A.K. 2014. Effect of various heat treatment processes on mechanical properties of mild steel and stainless steel. American international Journal of research in science, technology, engineering and mathematics, 8 (1), pp.57-61.
[47] Offar, P.O., Daniel, C.C., Obikwelu, D.O.N. 2010. Effects of various quenching media on the mechanical propertied of intercritically annealed 0.15 wt.% C-0.43wt% Mn steel. Nigerain Journal of technology, 29 (2), pp.76-81.
[48] Salman, K.D., Ahmed, B.A., Farhan, I.N. 2018. Effect of quenching media on mechanical properties of medium carbon steel media on mechanical properties of medium carbon steel 1030. Journal of university of Babylon Engineering Science, 26 (2), Pp. 214-222.
[49] AISI 1018 Mild /Low carbon steel, 2012, "https://www.azom.comarticle".
[50] ASTM E8/E8M-09. 2009. Standard test methods for tension testing of metallic materials. ASTM International Conshohocken, PA, United states, American Association State.
[51] Bolton, W. 1899. Engineering Materials Technology. Butter worth Heinemann Oxford.
[52] Darammola, O., Actewuyi, B., Oladele, I. 2010. Effect of heat treatment on the mechanical properties of rolled mechanical carbon steel. Journal of minerals and Materials characterization and engineering, 9 (8), Pp. 693708.
[53] George, E.T. 2006. Steel heat treatment: metallurgy and technology CRC Press. Tayor and Framics group, Pp. 163.
[54] Ismail, N.M., Kalif, N.A.A., Kecik, M.A.K.A., Shaharudin, M.A.H. 2016. The effect of heat treatment on the hardness and impact properties of medium carbon steel. IOP Conf. Series: Material Science and Engineering, 114.
[55] Priyadarshini, S., Anad, S.K., Yadav, O. 2016. Effect of quenching medium on hardness of three grades of steel-AISI 1040 ,1050 and 4340. International Journal for research in Applied Science and Engineering Technology (IJRASET), 4 (1).
[56] Ashish Bhateja,Aditya Varma, Ashish Kashyap , Bhupinder Singh,2012."Study of the effect on the hardness of three sample grades of tool steel after heat treatment process",International Journal of Engineering And Science (IJES),Volume 1, Issue 2,pages 253-259,
[57] Alawode, A.J., 2002, Effects of cold work and stress relief annealing cycle on the mechanical properties and residual stresses of cold-drawn mild steel rod. M. Eng. Thesis, Mechanical Engineering Department, University of Ilorin, Nigeria.
[58] A. N. Isfahany, H. Saghafian and G. Borhani, "The effect of heat treatment on mechanical properties and corrosion behaviour of AISI420 Martensitic Stainless Steel," Journal of Alloys and Compounds, Vol. 509, No. 9, 2011.
[59] Adnan, Calik 2009. Effect of cooling rate on hardness and microstructure of AISI 1020, AISI 1040 and AISI 1060 steels. Int J of Physics Sciences, vol. 4(9), pp. 514 – 518.

[60] B.S.Motagi,Ramesh Bhosle 2012, “Effect of heat treatment on microstructure and mechanical properties of medium carbon Steel”,International Journal of Engineering Research and Development, Volume 2, Issue 1, July.

[61] D.A.Fadare, T.G.Fadara , O.Y.Akanbi, 2011 Effect of heat treatment on mechanical properties and microstructure of NST 37-2 Steel,Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.3, pp.299-308,

[62] Eric O., Sidjanin L., Miskovic Z. l 2004 Microstructure and toughness of cu- ni- mo austempered ductile iron; materials letters, Volume 58, Pages 2707– 2711.

[63] E. F. Strobel, N. A. Mariano, K. Strobel and M. F. Dionízio, 2012 “Effect of the heat treatment in the resistance corrosion of a martinsitic stainless steel CA6NM,” 2nd Edition, Mercosur Congress on Chemical Engineering.

[64] F. M. F. Al-Quran and H. I. Al-Itawi, 2010 “Effects of the heat treatment on corrosion resistance and micro hardness of alloy steel,” European Journal of Scientific Research, Vol. 39, No. 2.

[65] Harpreet Singh, Er.B.S.Ubhi, Er. Harvinder Lal. 2013 Improvement in the corrosion rate and mechanical properties of low carbon steel through deep cryogenic treatment”, International Journal of Scientific & Technology Research Volume 2.

[66] Jiang, B., and Yazheng, L. Microstructural characterization, strengthening and toughening mechanisms of quenched and tempered steel: Effect of heat treatment parameters. Materials Science and Engineering: A, 2017, 707: 306-314.

[67] Adamczy, J. and Grajcar, A. Heat treatment and mechanical properties of low-carbon steel with dual-phase microstructure. Journal of Achievements in Materials and Manufacturing Engineering, 2007, 22(2): 13-20.

[68] Santhikumar, T. and Ajiboye, T.K. Effect of heat treatment process on the mechanical properties of medium carbon steel. Journal of Mineral & Materials Characterization and Engineering, 2012, 11(2):143-152.

[69] Muszka, K., Majta, J. and Bienas, L. Effect of grain refinement on mechanical properties of micro-alloyed steels. Metallurgy and Foundry Engineering, 2006, 32(2): 87-97.

[70] Lv, Z.Q., Wang, B., Wang, Z.H., Sun, S.H. and Fu, W.T. Effect of cyclic heat treatments on spheroidizing behavior of cementite in high carbon steel. Materials Science and Engineering: A, 2013, 574: 143-148.

[71] Aweda, J.O. and Adeyemi, M.B. Determination of temperature distributions in squeeze cast aluminium using the semi-empirical equations’ method. Journal of Materials Processing technology, 2009, 209: 5751-5759.

[72] Akinlabi, E.T and Akinlabi, S.A. Characterising the effects of Heat treatment on 3CR12 and AISI316 Stainless Steels. International Journal of Materials and Metallurgical Engineering, 2014, 8(2): 256-261.

[73] Roney, T.J., and Loker, D.R. Evaluation of quenching methods for the purpose of acoustic data collection. Procedia Manufacturing, 2017, 10: 1118-1128.

[74] Calcagnotto, M., Ponge, D., Adachi, Y. and Raabe, D. Effect of grain refinement on strength and ductility of dual-phase steels. Proceedings of the 2nd international symposium on steel science, 2009, Kyoto, Japan: 195-198.

[75] Grange, R.A. The rapid heat treatment of steel. Metallurgical Transactions, December 1971, 2(1): 65-78.

[76] Koscielna A. and Wojciech S. Effect of cyclic heat treatment parameters on the grain refinement of Ti-48Al-2Cr-2Nb alloy. Materials Characterization, 2009, 60: 1158-1162.

[77] Zheng, L., Xue-ping, R., Zhi-hong, L, Zi-ming L. and Min-Min, G. Effects of two different cyclic heat treatments on microstructure and mechanical properties of Ti-V microalloyed steel. Materials Research, 2015, 18(2): 304-312. [13] Boyce, B.L., Chen, X., Hutchinson, J.W., and Ritchie, R.O. The residual stress state due to a spherical hard-body impact. Mechanics of Materials, 2001, 33: 441-454.

[78] Saha, A., Mondal, D.K. and Maity, J. Effect of cyclic heat treatment on microstructure and mechanical properties of 0.6wt% carbon steel. Materials Science and Engineering: A, 2010, 527(16-17): 4001-4007.

[79] Smoljan B. An analysis of performance of combined cyclic heat treatment. Journal of Materials Processing Technology, 2004, 1(55): 1704-1707. [16] Lin H., Lui T. and Chen L. Effect of maximum temperature on the cyclic heating-induced embrittlement of high-silicon ferritic spheroidal-graphite cast iron. Materials Transactions, 2004, 45(2): 569-576.

[80] Xie, G., Zhang, J. and Lou, L. Effect of cyclic recovery heat treatment on surface recrystallization of a directional solidified superalloy. Progress in Natural Science: Materials International, ScienceDirect, 2011, 21: 491-495.

[81] Peng, C., He, Y., Huang, B. and Liaw, P.K. Effects of rapid heating cyclic heat treatment on microstructures and compression mechanical properties of TiAl-based alloy. Transactions of Nonferrous Metals Society of China, 2004, 14(3): 459-463.

[82] Khurmi, R.S., Gupta, J.K. 2008. Manufacturing process 6th Edition.

[83] Kamei, K., William, A.G., Koveile, L.S., Ahmad, N., Chakravorty, A., Davis, R. 2014. An Experimental Study of the Effect of Thermal Treatments & Charpy Impact Test Parameters on Impact Toughness of EN31 Steel" IOSR. Journal of Mechanical and Civil Engineering (IOSR-JMCE), 11, 17-22.

[84] Souki, I., Delagnes, D., Lours, P. 2011. Influence of heat treatment on the fracture toughness and crack propagation in 5% Cr martensitic steel. Science Direct, I.Souki et al, Procedia Engineering, 10, 631–637.

[85] Tavares, S.S.M., Abreub, H.F., Strohaeckerc, T.R., Silvad, M.B., Severo de Macêdod, M.C. 2016. Influence of Heat Treatments on the Impact Toughness of a Ti-stabilized 12%CrSuper martensitic Stainless Steel. Materials Research, 20, 469-473.

[86] Al-Qawabeha, U.F. 2017. Effect of Heat Treatment on the Mechanical Properties, Micro hardness, and Impact Energy of H13 Alloy Steel. International Journal of Scientific & Engineering Research, 8 (2), 100-104.

[87] Al- Murshdy, J.M. 2008. Effect of Heat Treatments on the Impact Toughness and Hardness of (2024) Aluminum alloy. Journal of Kerbala University, 6 (1) Scientific, 233-241.

[88] SECO. 2011. Warwick" Heat Treating Data Book" 10th Edition, 60-64.

[89] Ismail, N.M. 2015. The effect of heat treatment on the hardness and impact properties of medium carbon steel. Materials Science and Engineering, IOP Conference Series, 1-9.

[90] Seidu, S.O., Kutelu, B.J. 2013. Influence of Heat Treatment on the Microstructure and Hardness Property of Inoculated Grey Cast Iron. International Journal of Engineering and Technology, 3, 888-892.

[91] Isadarea, A.D., Aremob, B., Adeoye, M.O. 2013. Effect of Heat Treatment on Some Mechanical Properties of 7075 Aluminum Alloy. Materials Research, 16, 190-194.

[92] Tan, E., Ogel, B. 2007. Influence of Heat Treatment on the Mechanical Properties of AA6066 Alloy. Turkish Journal Engineering, Env. Sci., tub itak, 31, 53 – 60.

[93] Vermaa, A., Singh, P.K. 2013. Influence of Heat Treatment on Mechanical Properties of AISI 1040 Steel" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 10, 32-38.

[94] Radi, M.T., Lichter, E. 2016. The heat treatment analysis of E110 case hardening Steel. Journal of Engineering Science and Technology, 11, 407 – 415.
[95] Poolthong, N., Nomura, H., Takita, M. 2004. Effect of Heat Treatment on Microstructure and Properties of Semi-Solid Chromium Cast Iron. Materials Transactions, Japan Institute of metals, 45, 880-887.