REVIEW ON HEAT TREATMENS OF CARBON STEEL ALLOYS

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ABSTRACT

In the current paper, the main purpose of carbon steel quenching was reviewed by different cooling media for a set of researches, where will be mentioned to the change that happen of the metal in order to obtain new properties according to the required applications. The water and oil were used as the two main media of quenching most often to obtain rapid quenching after heating to austenitic temperature in most studies, but two these media were used in various forms such as the use of salt solution or cooled and hot water in addition to that can used engines oil, vegetable oil, various polymeric fluids and others. From previous studies and types of quenching media mentioned in this review, some of mechanical properties such as hardness and tensile strength improved when using water rather than oils while toughness property increase at cooling in polymer fluid. However, the goal of quenching were obtained an increase in the value of hardness, impact strength, tensile strength, wear resistance and improved other required properties according to the certain manufacturability and industry requirements.

Key words: carbon steel, quenching media, hardness, impact strength, tensile strength, wear resistance. Microstructure.

INTRODUCTION

Some components of machine which made from steel was processed by one of heat treatment procedure. Quenching was much used for steel to refinement the microstructure and improve the mechanical properties which involve hardness, impact and tensile strength [Ejiko and Ibikunle, 2024]. With the development of the industry currently, the demand for steel in the manufacture of many machine parts increases, which leads to improving the mechanical properties of steel through heat treatment processes and surface improvement [Agung et al, 2023]. Many different quenching media like oil, water and air were used for carbon steel to observation the tensile strength, hardness, ductility and other mechanical properties [Khalid et al, 2023].

Carbon element is strength, hard and brittle, also it has some mechanical and thermal properties like ductility, machine-ability, weld-ability, corrosion resistance, thermal and electrical conductivity and magnetic permeability, that lead to a poor in several applications. When it is compound with iron, the situation is different and has applications in many areas. Steel usually, is an alloy of iron and carbon, the carbon content up to a maximum of 1.5%, but with increasing of carbon content above 1.5 %, in this state is called a cast iron. Steel can be classified as a carbon steels and alloy steels. Therefore it requires several treatments for carbon steel such as heat treatment process to improve toughness, ductility and other properties depending on industrial applications. Heat treatment process working to change some mechanical properties of a material into other useful properties [U. K. Sing and Manish, 2009, S. A. Tukue et al,2014, Sattar et al, 2019].

Generally, the heating and cooling of carbon steel was conducted by many researchers under different conditions. The main aim of heat treatment of carbon steel was to improve selected properties which are required for some applications. The samples were heated under the critical temperature of metals and cooled by different media with controlled sequence of heat treatment processes. Then, the results showed improvement of toughness, ductility and microstructure [Sattar, 2018]. The effect of heat treatment temperature on some mechanical properties such as ductility, corrosion resistance, hardness of dual phase steel has proven an increase in tensile strength with increase of martensite volume fraction at 48.2%. The result of corrosion resistance of dual phase steel was more than that of plain carbon steel [Omid et al, 2019].

The aim of heat treatment in some applications such as shafts, blades of axes, screws, was to alter the grain size and relive the internal stress of the metal to soft its microstructure. Hardness, tensile and impact strengths of EN 9 steel were changed by annealing, normalizing and quenching processes. [U. Achutha et al, 2017]. To obtain required mechanical and physical properties by grain size refining of microstructure of metal or alloys, the heating and cooling were conducted. The heat treatment on low carbon steel (AISI 1020), lead to improve microstructure and hardness of metal [S. M. Mahbobue et al, 2016].The hardening and tempering of Mn-Fe alloy have been carried out in special circumstances, where they have given a good microstructure and hardness [Nuha, 2010]. Using different quenching media for AISI 1018 was achieved, also very fast cooling processes by (ice water, ice salt water) was given improvement of hardness, yield strength and ultimate tensile strength respectively [Sara, 2019].

Quenching of medium carbon steel to investigate the hardness and impact was conducted by three types of processes (annealing, quenching and tempering). The results showed highest of hardness with quenching by water and the tempering was proved an increasing of ductility and toughness [Noor et al, 2016]. The processes of hardening, quenching and tempering were achieved for 52CrMoV4 spring steel. Ductility and strength were observed good results after test of hardness and tensile [VJ Matjeke et al, 2018]. Annealing, normalizing, hardening and tempering were conducted for NST 37-2 steel [0.55%C, 0.28%Si, 0.92%Mn, 0.012%P, 0.007%S and with minimum content of(Cr, Ni, Cu, Mo and V) to change its physical and mechanical properties. The results showed a change in ductility and toughness, which was higher with annealing process but the hardness and tensile strength were lower [Bilal et al, 2018].

The concept of carbon steel quenching is very wide. In this study, will be discussed some of heat treatment processes, their purpose and the conditions in which the work were carried out. Often, will be briefly discuss to some researches that dealt the heat treatment of carbon steel, in terms of procedures and working conditions and the results of the researchers in this area.

LITERATURE REVIEW

To protect the parts of machine that are affected by the external environment heat treated was used through controlling the temperature of tempering and quenching of steel to obtain good wear resistance and good impact toughness. The loss of wear observe at quenching by air more than oil quenching at temperature of quenching above 1000 ̓ C . The heat treatment processes has possibility to change the quantity and forming of backward austenite in the low carbon steel. Quenching temperature up to 950 ˚ C influence on increasing the impact toughness of steel also effectiveness of forming the pearlite and martensite phases [Yiran et al, 2023].

By using modern quenching methods for example quenching by acid for carbon steel which it has proven more effective in changing the mechanical characteristics than using the traditional methods like air and water quenching . Using acid solution as a quenching media of 5083 Al alloy and medium carbon steel by changing the rate of water in three solutions, the first solution contain 1% HCl and 99% water while water rate reduce by 0.2 % at the others, when increase the rate of acid HCl show good hardness, tensile and yield strength simile of specimen that cooling by water as shown in the table (1) [Mossaab et al, 2022].

Quenching steel by water media help in forming structure of martensite and ferrite desirable to get very good mechanical features and lowering the temperature of annealing. Figure (1) explain how the heat treatment period effect on hardness values of martensite and ferrite as well as with below critical quenching water and annealing very good mechanical properties were obtain for steel [Growene et al, 2018, Pengsheng et al, 2023].

Heat treatment of 1030 steel and then quenching by water compared with oil and poly vinyl chloride can improve yield, ultimate strength and hardness in addition microstructure especially when quenching succeed tempering but refinement of pearlite and ferrite phases decrease as shown in figure (2) [Bassam and Intesar, 2018, Wanhui and Gang, 2023].

When using different types of cooling media like oils, water and air for compare their impact on mechanical properties and microstructure of medium carbon steel. The specimen that quenching by air soak up more energy before breaking whereas the specimens that quenching by water soak up less and have structure of martensite with good hardness, strength and microstructure especially in marinade quenching as well as the same thing happened in oils media in case of hardness and microstructure have martensite with little ferrite and pearlite as noted in figure (3), figure (4) with table (2) below represent the result of tensile test and each line what it means [Javvardhan et al, 2023].

Different types of media (brine, oil and water) was investigate to study their effectiveness on microstructure and mechanical properties like hardness, tensile strength, ductility and toughness of alloy steel to product elevated strength ingredients. The water media had the greatest effect on improving the strength and hardness while the toughness observes in oil media quenching [E. O. Adevyemi and O. E. Folorunse, 2014, Satya et al, 2019, Jianling et al ,2015, J. O. Agunsoye et al, 2019].

Polyethylene glycol based liquid was used as a quenching media of stainless steel to study its effect on microstructure and mechanical properties. From tests finding minimum strength, minimum hardness and maximum elongation in addition grain sizeable comparison to quenching by air and water which was produced finer microstructure and more transformation of martensitic [D. A. Fadare et al, 2012].

Coarse structure and less hardness were showing in case of air quenching compared with water media which view fine structure and high hardness while the oil media give the medium results of grain structure and hardness[Farzad and Mahmoud, 2017].
Improve the strength and fracture toughness and microstructural design of 0.25C steel with Si, Mn, Cr and Mo additions was employed by using water as a quenching liquid and tempering at different temperatures. By increasing temperature of tempering in range of 200 to 400 ˚ C lead up to lower in strength and higher in toughness but in 500 ˚ C the tensile and yield strength decreases [Panel E. et al, 2023].
A cyclic oil quenching (COQ) method was achieved of medium carbon steel to prevent the intense residual strain and getting refine grains that offered eminent tensile strength above 1690 MPa with modest ductility [Panel Xiuxia et al, 2023].
The confirmed of deposit of CuNiAl-rich particles of ultra –high low carbon steel was getting by direct quenching and tempering (DQ-T) process to analyze the effect it on pointing of fine grains with high dislocation density used simulation by phase field method [Panel Wen et al, 2022].
The quenching samples were investigate to study the effectiveness of various tempering time and temperature of AISI 1040 steel on behavior of mechanical properties. The results were proven reverse relation between the hardness and ultimate tensile strength with tempering time and temperature, where increase tempering time and temperature the hardness and ultimate tensile strength decrease while showing increase in elongation however by constant the temperature and increase in time indicate maximum ductility due to reorder of grain structure [Nilesh and Mandal, 2023].
Figure (5) explain the effect of quenching and partitioning processes on change resistance of wear and strength as a base of hardness, at Q and P350 specimen found higher hardness despite of the wear and strength as a lower case therefore better collection of strength, wear resistance and hardness properties were in Q and P450, 550 specimen that related with being of ferrite-bainite and tempering of matensite [Mohammed et al, 2023].
Heat treatment effect on tensile strength and hardness of quenching of medium carbon steel in water and polymer solution was investigate. Water quenching media give best results of strength and hardness than polymer quenching media because of high cooling rate as shown in figures (6) & (7) [Sattar, 2018].
The quenching of low carbon steel in oil lead to highest ductility more than quenched in water. The rapidity of austenitic result to increase the strength of steel due to decrease of the crystalline grain size, but the ductility was decreasing with rapid cooling. The mechanical properties such as tensile strength, impact strength and ductility were improved with heat treatment processes [P. O. Offor et al, 2010, J. Abou-Jahjah et al, 2001, O. O. Daramola et al, 2010].
Figure (8) showed the microstructure of SAE 1025 steel before and after heat treatment. SAE1025 content[0.26%C, 0.08%Si, 0.34%Mn, 0.64%Cu, 0.07%S and 0.11%P]. The ferrite with as-received sample in the grain boundaries of pearlite grains, this case was called a ferrite-austenite duplex phase. But with annealing process, there is spatial distribution of ferrite at the grain boundaries. Normalizing process was gave an uniform fine grains with large size of ferrite and pearlite, also with hardening process the ferrite dispersed was widely of SAE 1025 Steel [O. O. Joseph et al, 2015].
The heating of metal without reach to molten temperature and cooling by controlled sequence steeps to alter its properties were the main purpose of that processes. In other words, they can be used to improve the hardness, ductility, durability, increased

metal susceptibility to machining and operation, remove internal stresses after operations and other manufacturing operations conditions [U. K. Singh and Manish, 2009, Siti and Norazlianie, 2019].

The effect of heating and cooling on the cutting force and surface machining of steel with different cutting conditions were investigated as shown in figure (9). The processes for first group of samples were heated at austenitic temperature, then cooling by (Polyethylene glycol M. W.400). Second group were heated at austenitic temperature and cooling at still air, the effect of heat treatment on cutting and machinability was obvious [Sattar, 2019].

The heating with uniform temperature and soaking at that temperature, then cooling to room temperature with different media on medium carbon steel was investigated. Specimens has been heated at 850°C and hold at 45 minutes, then quenched in four types media after that had been tempered 60 minute at 200°C, 400°C, and 600°C. Table (3) showed the results of surface roughness with hardness and impact of metal in four quenching media. Quenching by cold water give better result of microstructure and hardness. A polymer that has a better effect than oil after cold water in tempering and quenching processes. [Sattar, 2018].

Figure (10) appeared the effect of oil and water quenching for (low, medium and high) carbon steel on impact toughness . Impact toughness of high carbon steel reduce when quenched in oil than water but seen reverse behavior in low and medium carbon steel, where impact toughness increase 89% in oil and 48% in water of low than medium carbon steel [Bilal Mohammed et al, 2018, Hemant et al, 2023].

Different heat treatment processes were gave different results of hardness and impact properties of steel, highest hardness was obtained with quenching and tempering in water than air as shown in figure (11). The microstructure after tempering was reduced brittleness by increasing ductility and toughness [Noor et al, 2016].

The hardness, tensile and yield strength were improved with quenching by marula oil (oil is product from tree in Africa) more than oil engine, the reason for that was the rapid rate of cooling and appropriate temperature of austenitic over 900 ˚C as shown in figures (12),(13) & (14) [Oluwagbenga et al, 2019].

Unmixed water and salt solution were used as two quenching mediums to cool the AISI 1045 steel. The results after quenching were showed increasing of hardness in salt solution than unmixed water but the toughness decreasing. Increase in intensity of salt and time of holding causes higher rate of cooling and advanced the transformation phase to build up the martensite which lead higher hardness and lower in toughness [I. Basori et al, 2019].

When comparing the engine oil and water as trade quenching media with different oils (Olive, cotton seed and palm kernel), it was found that trade media gave good hardness and strength while the cotton seed, olive and palm kernel oils were butter used for promote the toughness property [M. Dauda et al, 2015].

Water in three cases (normal, hot, cold) and oil were used as a quenching media of steel AISI 1039 to investigate some of properties include impact and tensile strength, hardness and wear rate. From the result found when water in cold case and raise the heat treatment temperature achieved the best result in term of hardness and tensile strength, while decrease the impact strength and rate of wear as shown in figure (15). Water in hot case give highest value of elongation and rate of wear after performed the process of stress release that of cold water [Zeyd, 2016].

Different process of heat treatment like carburizing, annealing, tempering and quenching are employed on carbon steel to achieve better mechanical properties and good microstructure. Figure (16) explain how the hardness varied with each heat treatment process with and without tempering. In low tempering temperature will get good toughness but don't loss in hardness while if tempering temperature increase lead to decrease the hardness and toughness increase. Hardness increase in case of water quenching than air and oil quenching media as shown in figure (17) [Utkarsh et al, 2019].

Three types of quenching liquid (spent engine oil SPE, coconut water and pap water) were used to attitude the microstructure and strength of medium carbon steel. Specimens has been heat treated by furnace and soaking for three times (30, 45 and 60) minutes and end cooling in these three liquids. Microstructure of coconut and pap water specimens showing the phase of ferrite in minimum martensite best than specimens quenching in engine oil which lead to maximum yield and ultimate strength as shown in figure (18) & (19) respectively [Peter et al, 2018].

Six typed of quenching media divided in two group, one group includes industrial oil, water and marinade as a traditional quenching media, second group includes polymer, vegetable oil and rolling mill coolant emulsion as a non- traditional quenching media were used to study their effectiveness on microstructure that immediately influence on mechanical properties of EN9 steel. EN9 consist of [(0.54% C), (0.21% Si), (0.73% Mn), (0.015% max) P & S. From result high value of martensite was shown at quenching in rolling mill emulsion as well free from oxide with maximum hardness can achieved while in water quenching get structure from martensite and keep austenite with oxide observed. Lath martensite and little value of keeping austenite was observes in marinade quenching which lead to maximizing hardness and strength of steel. Polymer quenching shows martensite structure with few value of ferrite while vegetable oil get no oxide and distortion specimens [Bhavesh , 2020].

CONCLUSIONS

In general, from the above can be concluded the following:

- By heating and cooling carbon steel, some properties are improved at the expense of others properties, these were according to the required property and the type of application.
- The properties such as tensile strength, hardness and impact strength with quenching process were increased but with low value of ductility and toughness.
- The quenching by cold water and machines oil was very fast which causes internal cracks, while with polymeric solutions and vegetable oils can be avoided this state because the cooling was fast at beginning and then, it is slower than it is with water and machines oil.
- Wear resistance and some mechanical properties were improved with quenching by oil more than other quenching media.
- Briefly, Water in state of cold and mixed with salt as quenching media improve the hardness and tensile strength but reduce impact strength and toughness properties compared with other quenching media.
- Generally, the conditions of heat treatment were according to required property of manufacturing component and type of applications in industries.

Table 1. Hardness, elongation and tensile, yield strength of C45 steel at various HCl solution. [Mossaab et al, 2022]

Quenching solution	Yield strength MPa	Tensile strength MPa	Elongation %	Hardness HV
water	909.51	977	7.26	540.81
0.1 HCl	822.45	970.21	9	556.17
0.3 HCl	801.90	998.8	8.36	729.45
0.5 HCl	954.81	1037.52	8.42	832.85

Table 2. Means of lines of figure 4. [Mossaab et al, 2022]

line	Quenching conditions
________	air
_ _ _ _ _ _	water
....	oil
--- - - --- - - ---	brine

Table 3. Tests of hardness, impact strength and surface roughness after quenching in three media. [Sattar, 2018].

Type of test	Results of as received alloy	Air	Oil	Cold water	Polymer
Hardness (HV)	187	189.7	316	437.6	354.5
Impact (J)	32.3	97	86.5	37.6	70
Roughness (µm)	2.536	2.237	0.316	0.193	0.248

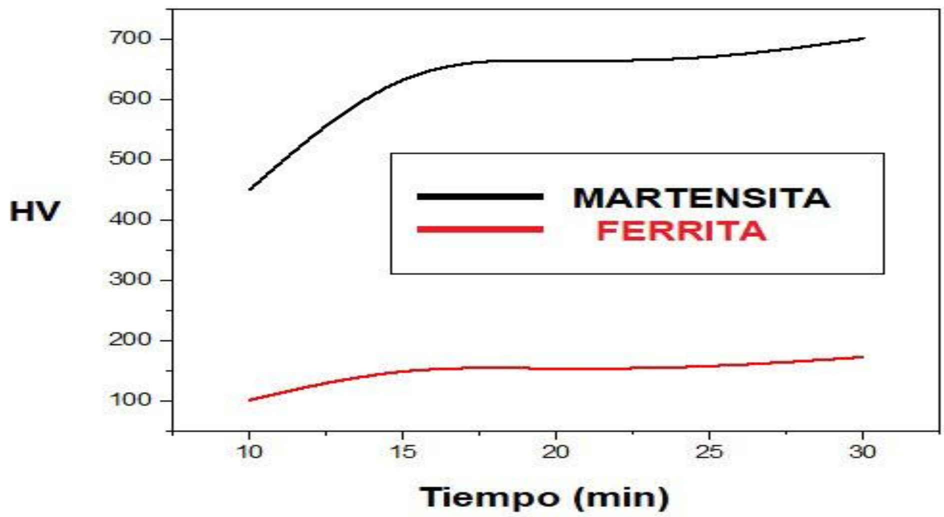

Fig. 1. Heat treatment period Vs hardness of steel. [Growene et al, 2018]

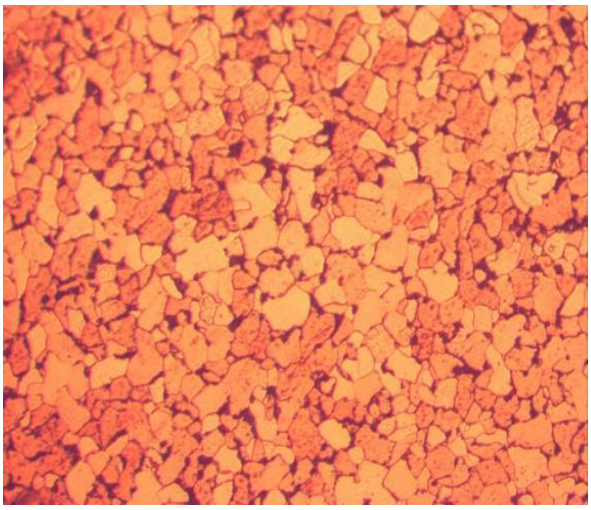

Fig. 2. Ferrite and pearlite phases of steel. [Bassam and Intesar, 2018]

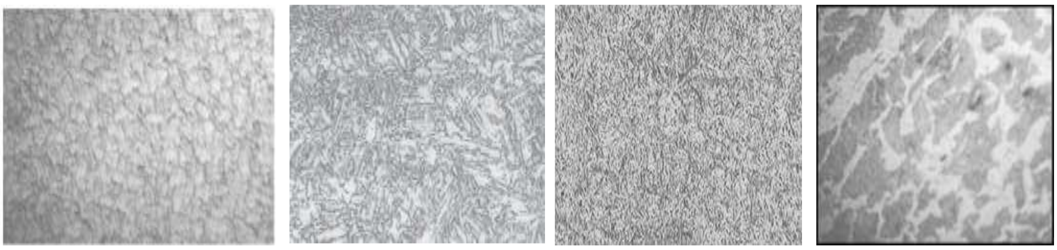

Fig. 3. The matensite structure of oil, water, marinade and air quenching media respectively. [Javvardhan et al, 2023]

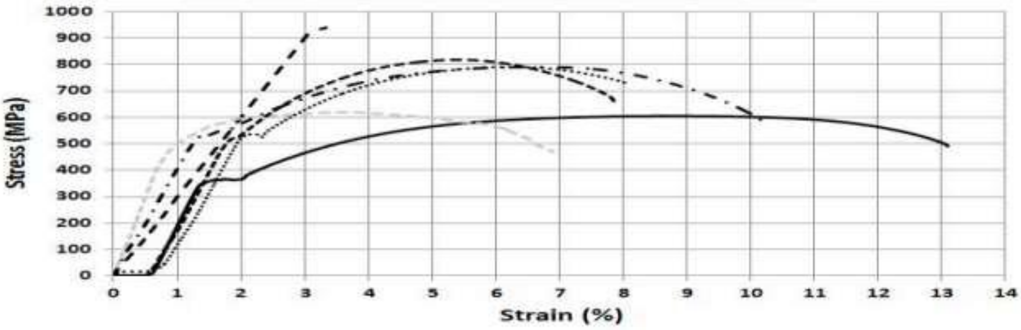

Fig. 4. Results of tensile strength in different quenching media. [Javvardhan et al, 2023]

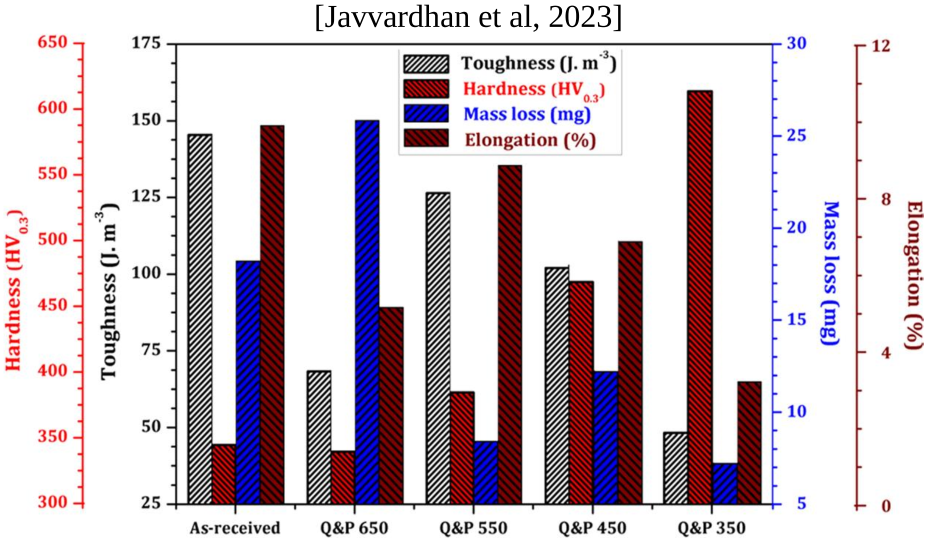

Fig. 5. Quenching effect on wear and other properties. [Mohammed et al, 2023]

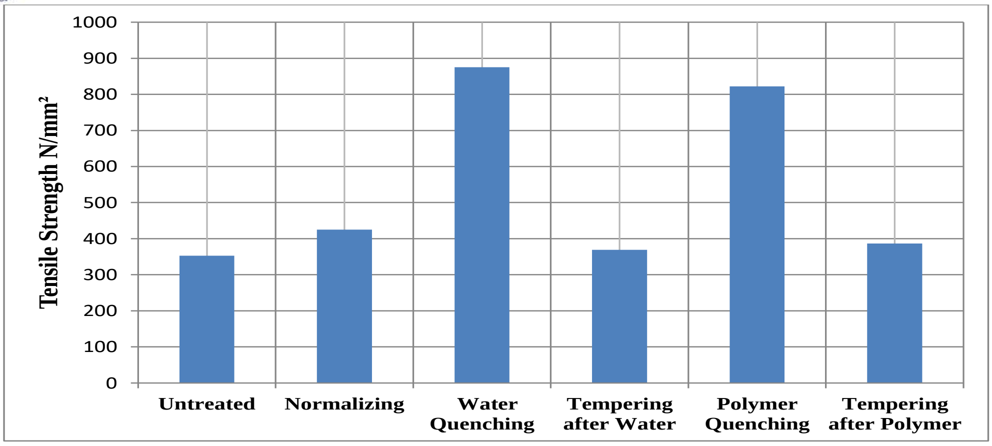

Fig. 6. Tensile strength for untreated and heated samples. [Sattar, 2018]

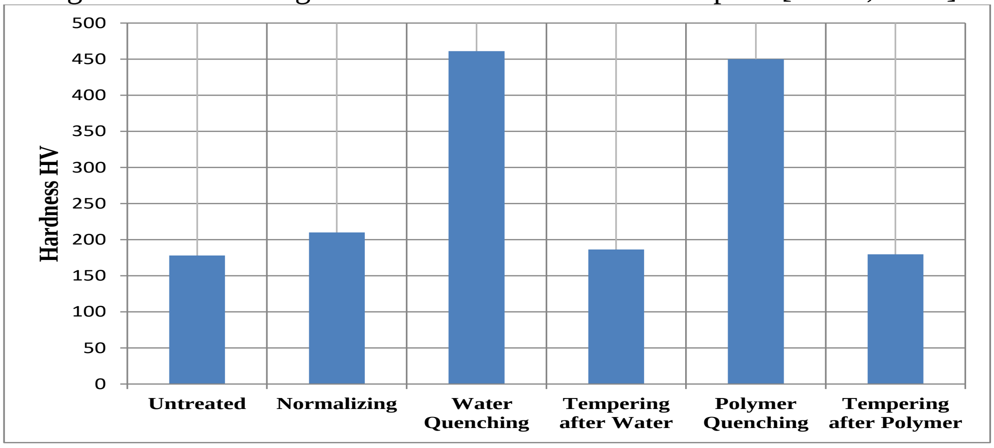

Fig. 7. Hardness for untreated and heated samples. [Sattar, 2018]

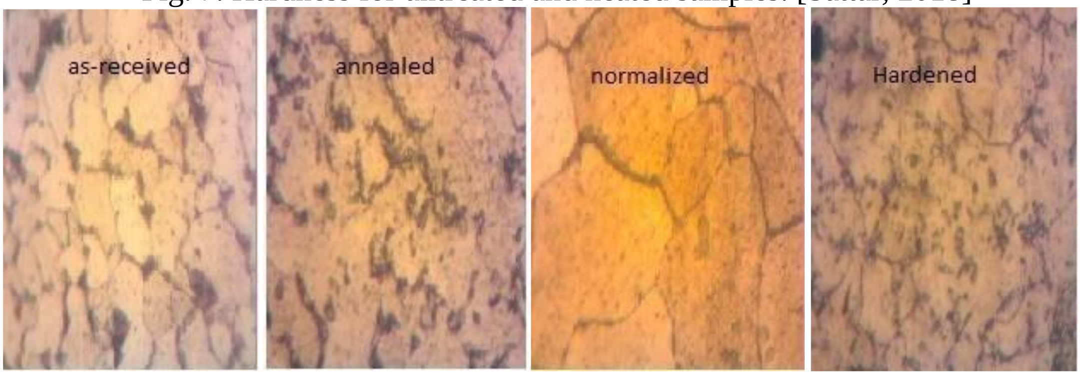

Fig. 8. Microstructure of SAE 1025 steel before and after heat treatment processes. [O. O. Joseph et al, 2015]

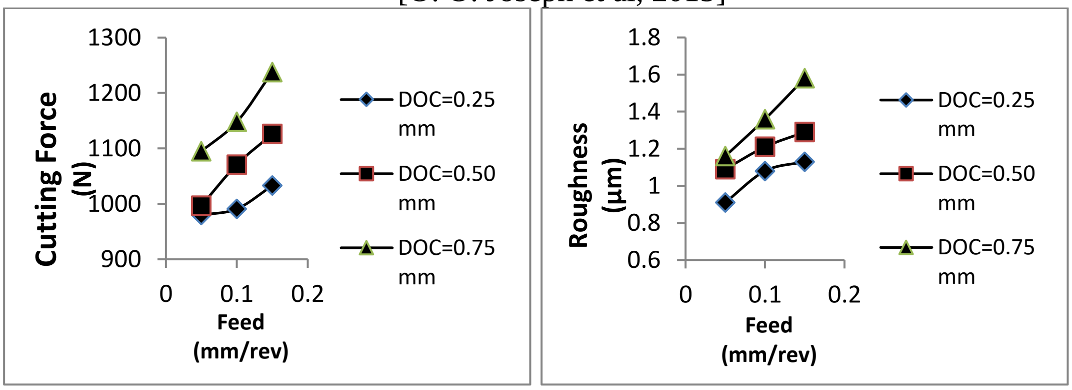

Fig. 9. Cutting force and roughness Vs. feed for quenched state at 100rpm speed. [Sattar, 2019]

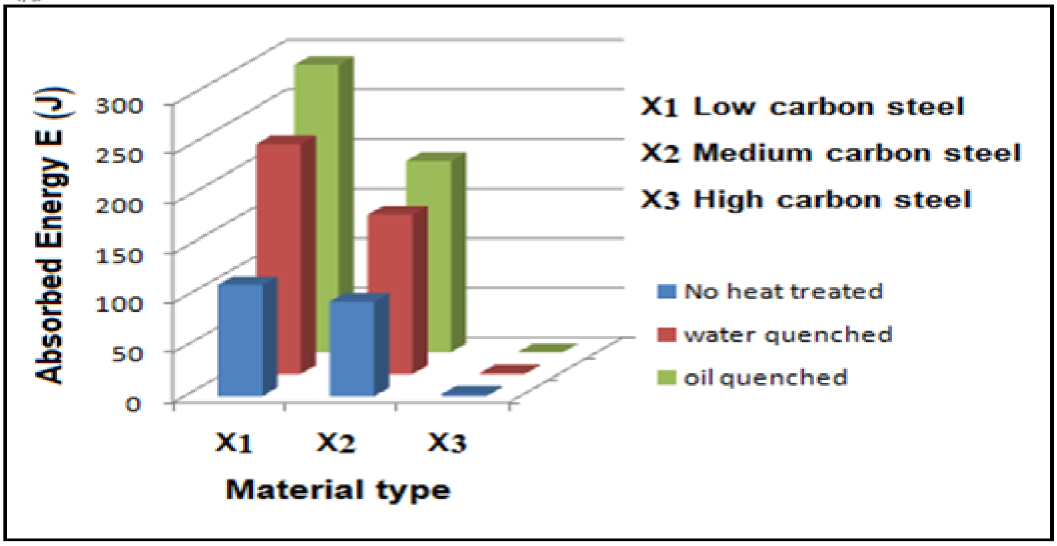

Fig. 10. Absorbed energy for tree type of steel after quenching. [Bilal et al, 2018]

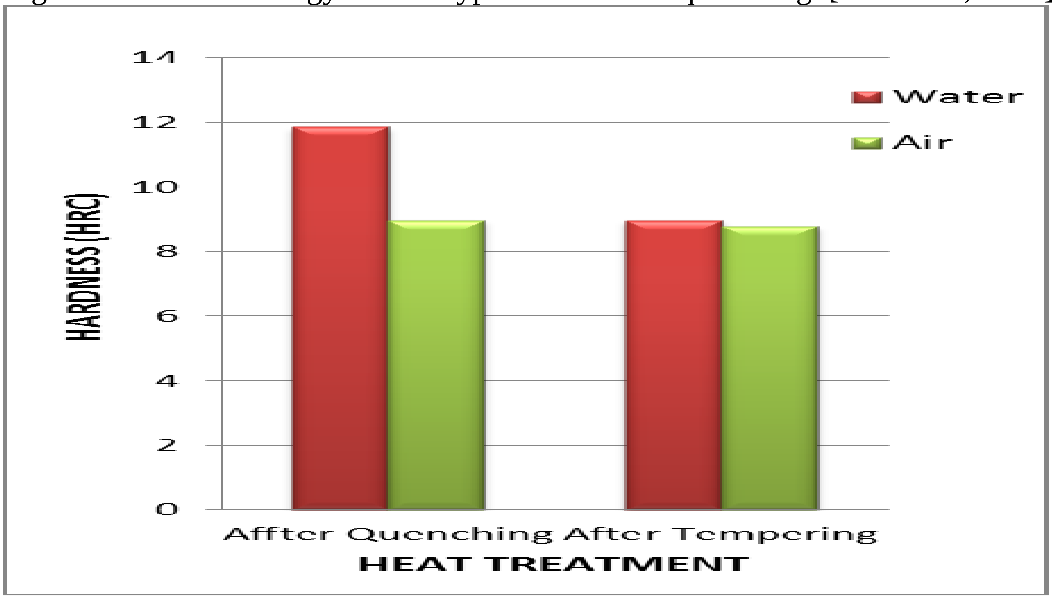

Fig. 11. Results of hardness with different heat treatment. [Noor et al, 2016]

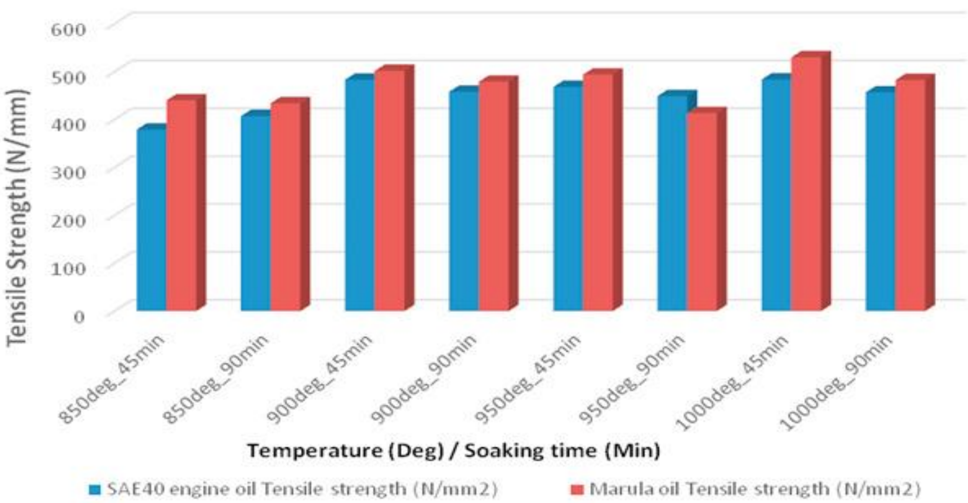

Fig. 12. Tensile strength after quenched in engine and marula oil.
[Oluwagbenga et al, 2019]

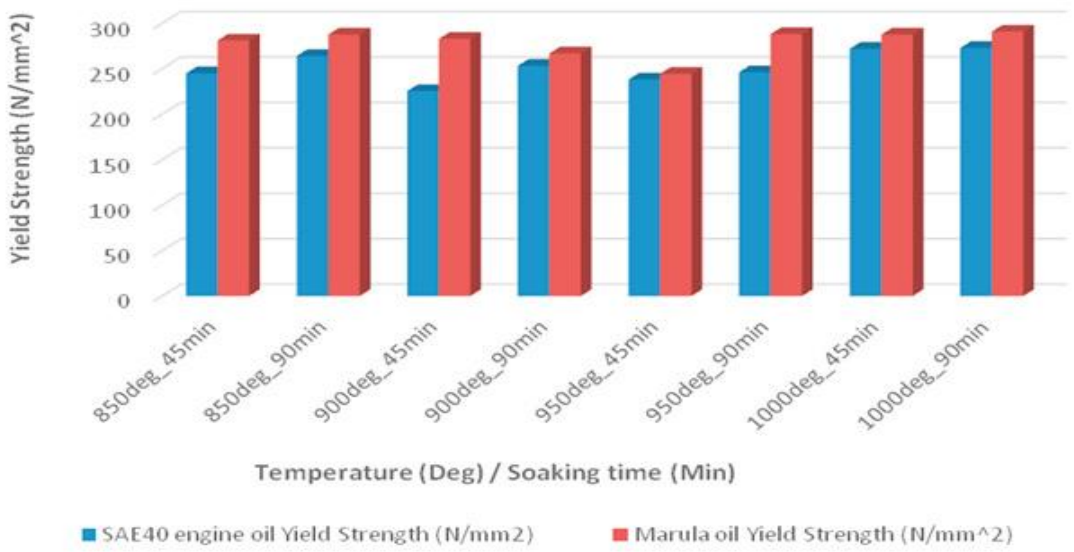

Fig. 13. Yield strength after quenched in engine and marula oil. [Oluwagbenga et al, 2019]

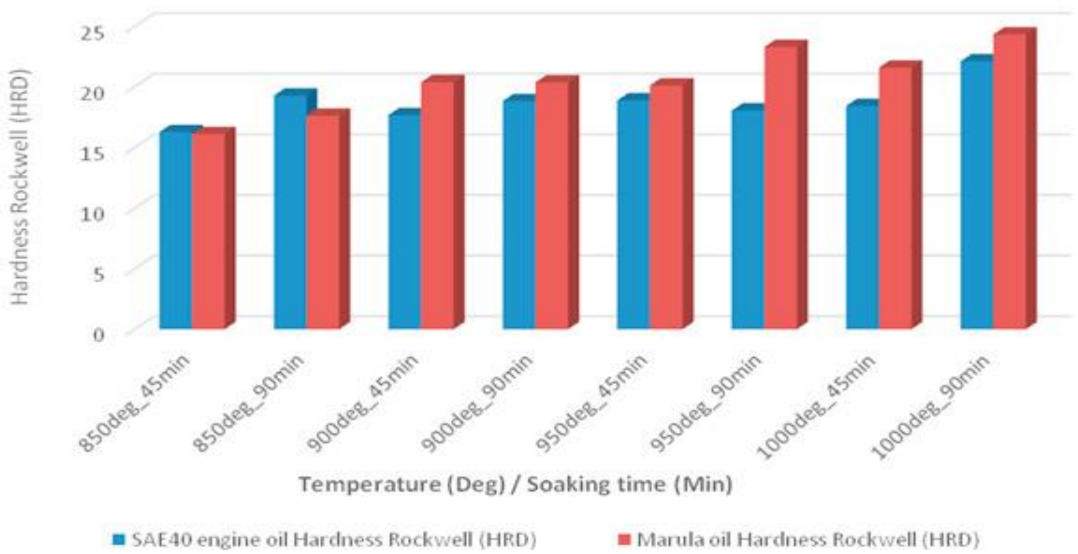

Fig. 14. Hardness after quenched in engine and marula oil. [Oluwagbenga et al, 2019]

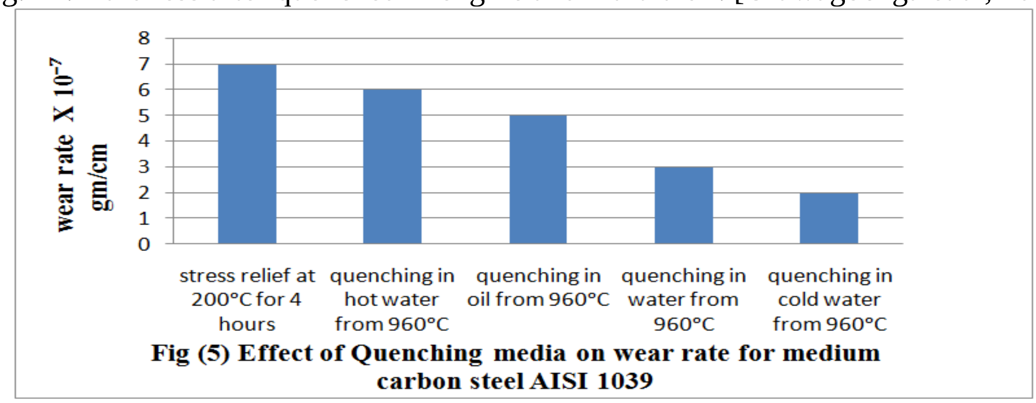

Fig. 15. Rate of wear for medium carbon steel in different quenching media. [Zeyd, 2016].

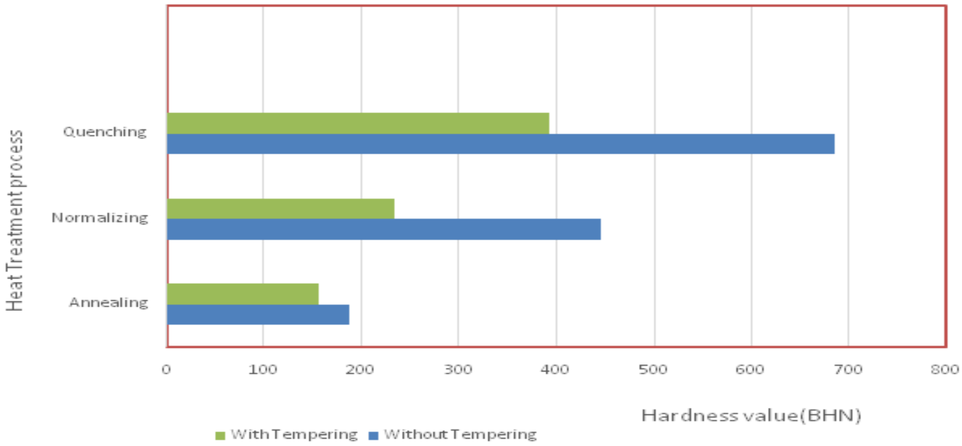

Fig. 16. Hardness variation at different process of heat treatment. [Utkarsh et al, 2019]

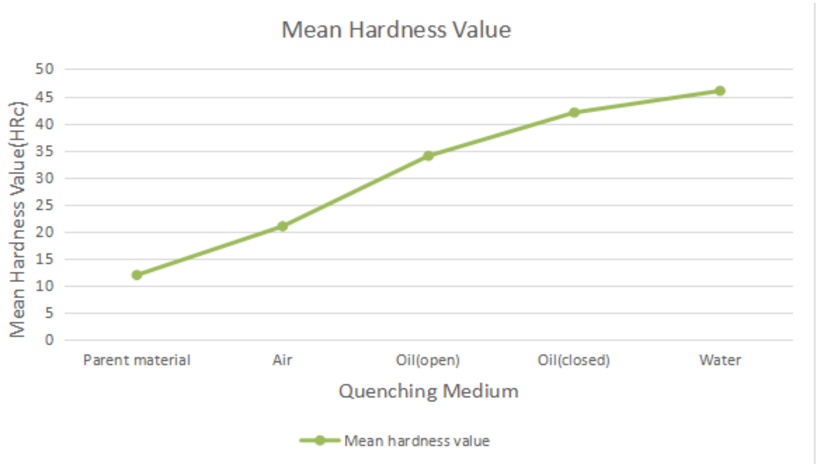

Fig. 17. Hardness variation at air, oil and water quenching media. [Utkarsh et al, 2019]

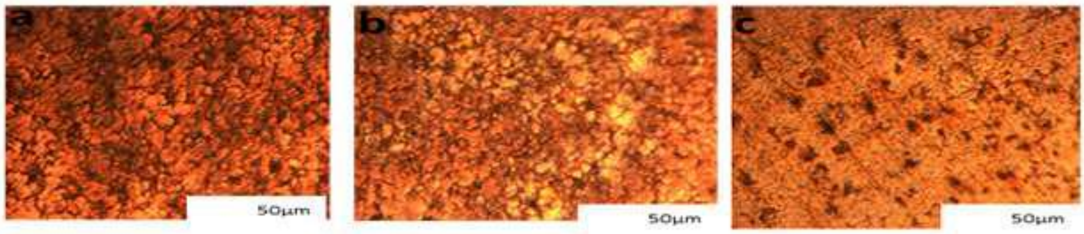

Fig. 18. Quenching specimens in coconut water of 30, 45 and 60 min respectively. [Peter et al, 2018]

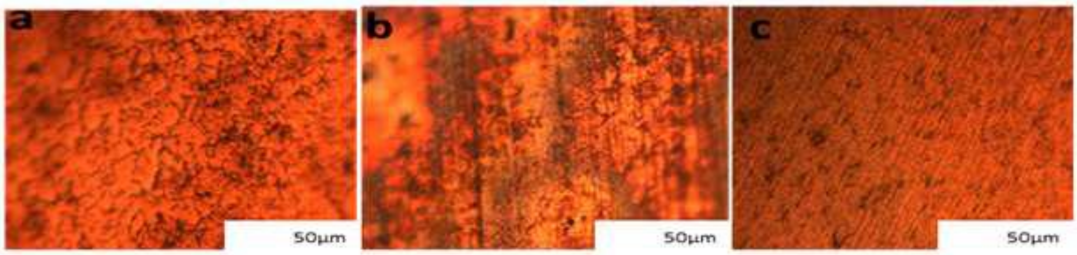

Fig. 19. Quenching specimens in pap water of 30, 45 and 60 min respectively. [Peter et al, 2018]

REFERENCES

Adekunle A. Adeleke, Peter P. Ikubanni, Adeolu A. Adediran, O. Agboola, Taye S. Olabamiji, Oluwaseun J. Ogunsolaand Chibuike Ibeawuchi. "Tensile strength and microstructure behavior of medium carbon steel quenched in some selected media", International Journal of Civil Engineering and Technology (IJCIET), Vol. 9, Issue 10, pp. 2148–2156, 2018.

Agung Supriyanto, Bambang Hari Priyambodo, Margono and Rizqi Ilmal Yaqin. "Study of characteristics for physical and mechanical properties of mild steel normalizing and shot Peening treatment product", Suara Teknik journal, Vol. 14, No. 2, PP 18-22, 2023.

Bassam Ali Ahmed and Intesar Naif Frhan. "Effect of quenching media on mechanical properties of medium carbon steel 1030", Journal of University of Babylon, Engineering Sciences, Vol. 26, No. 2, pp. 214-222, 2018.

Bhavesh R. Rana, Kamlesh M. Rana and Vandana J. Rao. "Study the effect of various quenching media on hardening behavior of EN 9 steel", International Journal of Engineering Applied Sciences and Technology, Vol. 4, issue 10, pp. 253-259, 2020.

Bilal Mohammed Qasim and Ayad F. Hameed. "Influence of heat treatment on the absorbed energy of carbon steel alloys using oil quenching and water quenching", Journal of Mechanical Engineering Research and Developments (JMERD), Vol. 41, No. 3, pp. 43-46, 2018.

Blaoui Mohammed Mossaab, Abdelwahab Zerrouki, Mourad Nouioua, Hassan Guendouz, Hammoudi Abderazek and Ali Bouchoucha . "Anew quenching method to improve the mechanical properties of metals", Advances in Materials and Processing Technologies, 2022. doi.org/10.1080/2374068x.2022.2077526.

D. A. Fadare, O. Y. Akanbi and M. O. Bodunrin. " Effect of quenching media on microstructure and mechanical properties of AISI 1045 steel", Leonardo Electronic Journal of Practices and Technologies, 2012

Ejiko S. O., Fatona A.S. and Ibikunle R. A. "Investigation of quenching on microstructure and mechanical properties of mild steel", IOSR Journal of Engineering (IOSRJEN) , Vol. 14, Issue 4, PP 29-38, 2024.

E. O.Adeyemi and O. E. Folorunse. "Investigation of the effect of quenching media on the mechanical properties of medium carbon steel", Journal of Minerals and Materials Characterization and Engineering, 2014.

Farzad Niknamm Hassan Rahimi and Mahmoud Abbasi. "Influence of quenching media on hardness and microstructure of 34CrNiMo6 steel", Archives of Civil and Mechanical Engineering, 2017.

Growene W Queiros, Jorge Bermejo, Laura Garcia Sanchez, Jose M. Gomez de Salazar and Antonio J Criado. "Improvement of the mechanical properties of 30MnB5 wear-resistant steel by subcritical annealing and water quenching, improving its life cycle analysis", Journal of Material Sciences and Engineering, 2018. doi: 10.4172/2169-0022.1000494.

Hemant Panchal, Moksha Patel and Devanshi Bhaliya. "Effect of heat dissipation on the final properties of steel upon quenching: a reviw", International Journal of Creative Research Thoughts (IJCRT), Vol. 11, Issue 9, 2023. ISSN: 2320-2882.

I. Basori, W D Pratiwi and S T Dwiyati. "Effect of salt quenching on the microstructures and mechanical properties of AISI 1045 steel ", Journal of Physics: Conference Series, 1402 (2019) 055102, Indonesia.

Jayvardhan P. Patil, Y. G. Chaugule, Sanket N. Shinde, Rohan J. Panade, Prasad S. Atigre and Sajan B. Kamble. "A Review on effect different quenching media on properties of steel", International Researh Journal of Modernization in Egineering Technology and Science, Vol. 05, Issue: 05, 2023.

Jianling Li, Wenjuan Sun and Xiuli Gao. "The effect of different quenching media on the properties of austenitic stainless steel". Procedia Engineering, 2015.

J. O. Agunsoye, O. A. Fakolujo and I. O. Oladele. " Influence of quenching media on the microstructure and mechanical properties of heat-treated medium carbon steel", Materials Science Forum, 2019.

J. Abou-Jahjah, and J. Dobranszky. "Mechanical properties improvement of low carbon steel by combined heat treatments", First International Industrial Engineering Conference, 2001, Jordan.

Khalid Abdulhussein Hafedh, Zaman Khalil Ibrahim, Ahmed Ibrahim Razooqi, Malik M. Mohammed. "Protection of carbon steel from wear by quenching with nanotechnology to use it in dies parts", Journal of Applied Engineering Science, Vol. 21, No. 2, PP 637-643, 2023.

Mohammad Masoumi1, Edwan Anderson Ariza Echeverri, Andre Paulo Tschiptschin and Helio Goldenstein. "Improvement of wear resistance in a pearlitic rail steel via quenching and partitioning processing", Scientific Reports, 2019. doi.org/10.1038/s41598-019-43623-7.

M. Dauda, L. S. Kuburi, Devid Obada and Rl Mustapha. "Effect of various quenching media on mechanical properties of annealed 0.509Wt%C –0.178Wt%Mn steel", Nigerian Journal of Technology (NIJOTECH), Vol. 34, No. 3, pp. 506 – 512, 2015.

Nuha. H. AL- Hasan. "Study of annealing, hardening and tempering on hardness and microstructure of Mn-Fe alloy", Journal of Basrah Researches Sciences, Vol. 36, No. 3, pp 23-28, 2010.

Noor Mazni Ismail, Nurul Aida Amir Khatif, Mohammad Aliff Kamil Awang Keelik and Mohd Ali Hanafish Shaharudin. "The effect of heat treatment on the hardness and impact properties of medium carbon steel", IOP Conf. Series: Materials Science and Engineering, 114 (2016) 012108. doi:10.1088/1757-899X/114/1/012108.

Nilesh Kumar Mandal and Yinay Kumar Yada. "Experimental analysis of tempering temperature and time on mechanical properties of AISI 1040 steel", IJARIIE, Vol. 9, Issue 1, 2023.

O.O. Daramola, B. O. Adewuyi and I. O. Oladele. "Effects of heat treatment on the mechanical properties of rolled medium carbon steel", Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.8, pp.693-708, 2010.

Omid Abedinia. "Intercritical heat treatment temperature dependence of mechanical properties and corrosion resistance of dual phase steel", Materials Research, 2017. doi: http://dx.doi.org/10.1590/1980-5373-MR-2017-0969.

O.O. Joseph, RO Leramo and OS Ojudun. "Effect of heat treatment on microstructure and mechanical properties of SAE 1025 steel", Analysis by one-way ANOVA, J. Mater. Environ. Sci. 6 (1) (2015) 101-106, ISSN: 2028-2508 CODEN: JMESCN.
.

Oluwagbenga T, Johnson, Enoch N. Ogunmuyiwa, Albert U. Ude, Norman Gwangwava and Richard Addo- Tenkorang. "Mechanical properties of heat treatment medium carbon steel in renewable and biodegradable oil", Procedia Manufacturing 35 (2019) 229–235, 2nd International Conference on SMPM.

Pengsheng Hu, Yu Su, Jun Li and Zhicheng Zuo. " Texture and mechanical properties of quenching and partitioning steel", Materials Research Express, 2023. dio.org/10.1088/2053-1591/acd1d2.

Panel E. Tkachev, S. Borisov, A. Belyakov, T. Kniaziuk, O. Vagina, S. Gaidar and R. Kaibyshev. " Effect of Quenching and Tempering on Structure and Mechanical Properties of A Low – Alloy 0.25C Steel", Materials Science and Engineering , Vol. 868. 144757, 2023.

Panel Xiuxia Wang, Xianzhe Shi, Yuzhong Hui, Biao Chen, Bin Gan and Jianghua Shen. "Mechanical behavior and strengthening mechanism of a fine-grained medium carbon steel produces via cycle oil quenching", Materials Science and Engineering: A, Vol. 866, 144669, 2023.

Panel Wen Fu, Chengning Li, Ran Duan, Heshan Gao and Xi. "Formation mechanism of CuNiAl-rich multi structure precipitation and its effect on mechanical Properties for ultra-high Strength low carbon steel obtained via direct quenching and tempering process". Materials Science and Engineering: A, Vol. 833, 142567, 2022.

P. O. Offor, C. C. Daniel and D. O. N. Obikwelu. "Effects of various quenching media on the mechanical properties of inter-critically annealed 0.15Wt%C–0.43Wt%Mn Steel", Nigerian Journal of Technology, Vol. 29, No 2, 2010.

S.A. Tukur, M. M. Usman, Isyaku Muhammad and N. A. Sulaiman. "Effect of tempering temperature on mechanical properties of medium carbon steel", International Journal of Engineering Trends and Technology (IJETT), Volume 9, No. 15, pp 797-800, 2014.

Sattar Hantosh A. Alfatlawi, Nofel Z. Whieb and Wafa Mahdi Godia. "The experimental study on the machine conditions of heat treated medium carbon Steel using ceramic cutting tool", International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Vol. 9, Issue 4, 1143-1150, 2019.

Sattar Hantosh A. Alfatlawi."Influence the quenching and tempering on the microstructure, mechanical properties and surface roughness of medium carbon steel", The Iraqi Journal For Mechanical And Material Engineering, Vol.18, No.1, pp. 125-135, 2018.

S.M. Mahbobur Rahman, Kazi Ehsanul Karim and Md. Hasan Shahriar Simanto. "Effect of heat treatment on low carbon steel: an experimental investigation", Applied Mechanics and Materials, Vol. 860, pp. 7-12, 2016.

Sarah Jalal Mosa. "Effect of different quenching media on mechanical properties of AISI 1018 low carbon steel", Journal of Mechanical Engineering Research and Developments(JMERD), Vol.42, No. 3, 2019. doi.org/10.26480/jmerd.03.2019.81.83.

Satya Prakash Mishra, Niraj Nayan and Rituraj Mishra. "Influence of quenching medium on the mechanical properties of AISI 1040 steel". Journal of Materials Engineering and Performance, 2019.

Sattar Hantosh A. Alfatlawi. "The Effect of heat treatment on the machinability, tensile strength, hardness, ductility and microstructure of carbon steel(GOST 50) ", Journal of University of Babylon, Engineering Sciences, Vol. 26, No.4, 2018.

Siti Noradila Abdullah and Norazlianie Sazali, 2019, "A mini review on low carbon steel in rapid cooling process", Journal of Advanced Research in Applied Mechanics Vol. 63, Issue 1, pp. 16-22, 2019.

U. K. Singh and Manish Dwivedi. "Manufacturing Processes" second edition, New Age International (P) Ltd, rights@newagepublishers.com, New Delhi, 2009.

Utkarsh Trivedi, Rupender Nath Singh, Rishikant Sahani, Sachin Vishwakarma and Sandeep Kumar. "A review on effect of heat treatment on mechanical properties of various steels", International Conference on Latest Innovation in Engineering Science and Management, Buddha Institute of Technology, GIDA, Gorakhpur(UP), ISBN: 978-93-87793-80-4, pp.826-834, 2019.

U Achutha Kini, Kini, Shankara Sathya, Shama Suhas Yeshwant and Srinivas Shenoy Heckadka. "Mechanical characterization of heat treated EN 9 Steel", International Conference on Engineering and Information Technology, Kuala Lampur, Malaysia, ISBN: 9788193137314, 2017.

Velaphi Jeffrey Matjeke, Goodness Mukwevho, AM Maleka and JW van der Merwe. "Effect of heat treatment on strength and ductility of 52CrMoV4 spring steel", IOP Conf. Series: Materials Science and Engineering, South Africa, 430 (2018) 012044 doi:10.1088/1757-899X/430/1/012044.

Wanhui Huang Liping Lei and Gang Fang. "Optimizing heat treatment to improve the microstructure and mechanical properties of 5CeNiMoV steel", Metals, 2023. doi.org/10.3390/met13071263.

Yiran Wang, Ruian Wang Wenzhen Yu and Yimin Gao. "Effect of heat treatment parameters on the modification of Nano residual austenite of low carbon medium-chromium steel", Nano materials MDPI, 13, 2829, 2023.

Zeyd D. Kadhim. "Effect of quenching media on mechanical properties for medium carbon steel", Journal of Engineering Research and Application, Vol. 6, Issue 8, pp..26-34, 2016.