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Improving Mechanical Properties, Microstructure And Wear Resistance Of Dual-Phase Medium Carbon Steel

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Abstract

A combination of heating and cooling processes used to a metal or alloy in its solid state to achieve desired conditions or qualities is known as heat treatment. Annealing is metal heat treatment type, it means heating the metal to a pre-determined temperature, holding it at that temperature for a set time, then cooling slowly to room temperature. It is changing metal mechanical properties by increasing its strength and ductility. In the presented work, the mechanical properties and wear resistance for samples that made from dual-phase (DP) medium carbon steel studying through heat treatment for this samples. Complete annealing following by cooling were implemented on the DP medium carbon steel samples. Slowly and rapid cooling's with different media (air, ice water, salt 10% ice water, motor oil, and cooling by left the samples in turned off oven for a whole day) applied for that samples for recognizing changing in their properties. Tensile and hardness testing for samples shown improvement in mechanical properties and microstructure of samples that cooled in 10% salty ice water. Increasing in hardness, tensile stress, and wear resistance also observed.

Keywords: Heat treatments, Microstructure, Mechanical properties, Wear resistance, DP medium carbon steel.

1. Introduction

A hard, tough metal made of iron alloyed with small amounts of carbon and other metals such as nickel, chromium, manganese, and others to increase hardness, corrosion resistance, and other properties. 2. a steely substance. Carbon steels classified into low carbon steel with a carbon content of not more than 0.25% and is characterized by strength, ease of forming and operation used in the manufacture of plates and wires. Second type is medium carbon steel with a carbon content of (0.20% - 0.6%) characterized high strength and the possibility of hardening, it is used in the manufacture of shafts, axles, and gears. High carbon steel with a carbon (0.60% - 1.0%) is the third steel type, it has very high strength and used in the manufacture of springs, wrenches, iron saws, dies, pistons and drills [1-2].

Steel has risen in prominence because it is one of the engineering materials that can be heat treated to take advantage of changes in mechanical characteristics caused by changes in the internal structure. The heat treatment of steel is managed to change the fine structures to suit engineering applications to acquire the necessary mechanical properties. To attain the desired qualities, it must be fixed at this temperature for a given duration of heating and then cooling in the right medium [3-14].

Steel's structural composition consists primarily of two phases, ferrite, and martensite, and is referred to as two-phase (DP) steel. Ferrite is a soft mineral with good ductility, whereas martensite is a hard mineral with strong strength [15-16]. Due to improvements in strength and wear resistance, medium and high carbon two-phase steels have recently gained popularity. They can be employed in mining operations when there is no need for welding [17-18].

Martensite microstructures are known for their high strength and hardness, which is why they're so common in steels. Carbon addition has been found to be an effective approach for strengthening martensite microstructures when controlled properly. As a result, researchers are always studying iron and steel to find new ways to improve martensitic steels' strength, toughness, and ductility [19-24].

A lot of research have been carried out in order to improve the microstructure of biphasic steels through diversification of heat treatments [25-26]. Studies by Modi et al. [27] indicate that the microstructure of steel with 0.2% C changed because ofthe change in heat treatments. The primary microstructures included martensite, ferrite, pearlite, or austenite. As the heat treatments severely affected the final morphology. Few studies have been conducted on the effect of heat treatment on the final two-stage microstructure and mechanical properties. The study by Modi [28] on two phase steels of 0.19%C indicates that samples that have undergone annealing process yielded higher ductility but lower strength than the investigation by Khotinov et al. [29].

Water, salt solutions, and oil have all been investigated as cooling possibilities [30-32]. Liang & Peng [33], Meng et al. [34], and Gao et al. [35] have all reported on this. Some research suggests that water quenching increases hardness and tensile strength in two-phase medium carbon steels [36]. Oil's usefulness as a cooling medium for two-stage steel manufacture was the subject of further investigations [37-41].

Several prior investigations employing different quenching media and tests of hardness, tensile strength, shock, and torsion for carbon steel and their effect on the microstructure and mechanical properties were undertaken [42-43].

However, some prior investigations of quenching media and their effect on medium carbon biphasic steels failed to account for the role of these media in microstructure evolution. Annealing process for carbon steel adds ductility and improved wear resistance [44]**.**

In the presented paper an annealing process was implemented on samples of dual-phase medium carbon steel to study its effect at mechanical properties, microstructure, and wear resistance of the samples. First section explains in detail the physical meaning of dual-phase medium carbon steel, annealing process and its types, and the main mechanical properties of the steel. with the comparison between different quenching media. The characteristics of the material (carbon steel) that used in this work, specifications of annealing process, microstructures, and tests of the samples after heat treatment appeared in second section. Third and final section discussed the tests results and microstructures get from microscope images and conclusion of the work respectively.

2. Materials and Methodology

Characteristics of samples that prepared from dual-phase medium carbon steel, methodology that used through this paper for heat treatment process, and tests done on the samples after treatment process will be explained in the following points.

2.1 Materials:

Cylindrical samples with dimensions 20- and 15-mm diameter and length respectively, its chemical composition shown as in table 1 [45] will used in the current work. Chemical consents analyzed by spectroscopy of the Saudi Standards, Metrology and Quality Organization.

Table 1. Chemical composition of dual-phase medium carbon steel (wt.%):

Materials	Fe	C	Mn	Si	Cr	Cu	Ni	Al	P	V	S	As	Zn
(wt%)	98.2	0.33	0.71	0.29	0.24	0.06	0.03	0.03	0.02	0.02	0.001	0.01	0.0005

2.2 Heat Treatments:

Annealing process implemented on the steel samples by heating them at electric oven (BARNSTEAD 48000/F 48020 (Furnace)). Heating temperatures (860˚C) and time (45 min.) automatically controlled with high quality and accurate system (degree of accuracy = ±1). After heating the samples, a rapidly cooling process for the samples done through air, ice water, salt 10% ice water, and motor oil while slowly cooling process done by turned off the oven and remained the samples in the oven for a whole day. Soaking time for cooling process for all using media was 90 minutes, as shown in Table 2.

2.3 Material Testes

After heat treatment for the steel samples some testes done on them to know their mechanical properties, microstructure, and wearing rate. This test will explain as following.

2.3.1 Microstructure Test

sectioning, mounting, course grinding, fine grinding, polishing, and etching are the main steps that were implemented on the DP medium carbon steel samples after heat treatment and before microscopic examination for investigating their microstructure. Grinding and polishing done by 320, 400, 600, 1200, and 1500 sandpapers. 98% methyl alcohol and 2% nitric acid solutions used in etching step for steel samples to show the contrast of the surface layers and the surface composition. Optical microscope metallograph with polarized light and magnification power used for microstructure test. Three different locations on samples surfaces used to get clear microstructure images.

2.3.2 Micro Hardness Test

Micro hardness test used for determining the hardness gradient of samples along a cross section. In our work a microhardness device ((Microhardness, Turky METKON) with 100g/10s load was used. 5 readings for each sample with different treatment were founded, the mean of these readings gave the exact hardness of DP medium carbon steel material.

2.3.3 Tensile Test:

The final test for the steel samples was tensile test which done by Instron blue hill3 machine. The test applied on specimen prepared from the dual-phase medium carbon steel treating material in standard shape and dimensions specified by the American Society for Testing Materials (ASTM). Tensile test was used at a rate of 20mm/mim.

3 Results and discussion

3.1. Microstructures

The figure1 (a) shows a micrograph of the untreated sample by light microscopy featuring a matrix of ferrite and perlite islands which agree with survey data [46]. Figure 1 (b, c, d, e) shows the microstructures of samples treated by heating them at a temperature of 860°C for 45 minutes and then quenching them in air, ice water, salty ice water, and oil for cooling them, they are all composed of a matrix of ferrite interlocked by martensite. Martensite is clear in the 10% ice water brine quenching medium when compared with that in samples quenched with ice water, air and oil. The grain boundaries were distinct and defined.

The two-sided microstructure is gradually and balanced across the cooling media because the soaking time lasted for 90 minutes, which indicates that choosing the appropriate duration of soaking leads to an increase in the distribution of martensite and promotes the transition of martensite morphology from polygonal to fibrous.

Saldana-Garza et al. were indicated that, the microstructure of the DP ferrite-martensite structure after the use of varying quenchants. Manas & Chakraborti [47] reported an additional amount of austenite retained in the DP ferrite martensite structure. The austenite phase did not support, Muhammed et al. [48] and this indicates in our work which made sufficient soaking duration was a strategy to eliminate the phenomenon of austenite retained in DP steels. The figure 1 (c) show the microstructure of the sample after being heated to 860 °C for 45 minutes and lifted inside oven for a whole day for cooling which know as complete annealing process. The microstructure shows that the grains are large compared to the samples that were subjected to different quenching which supported by Aaditya Srivastava et al. [49].

(a) (b)

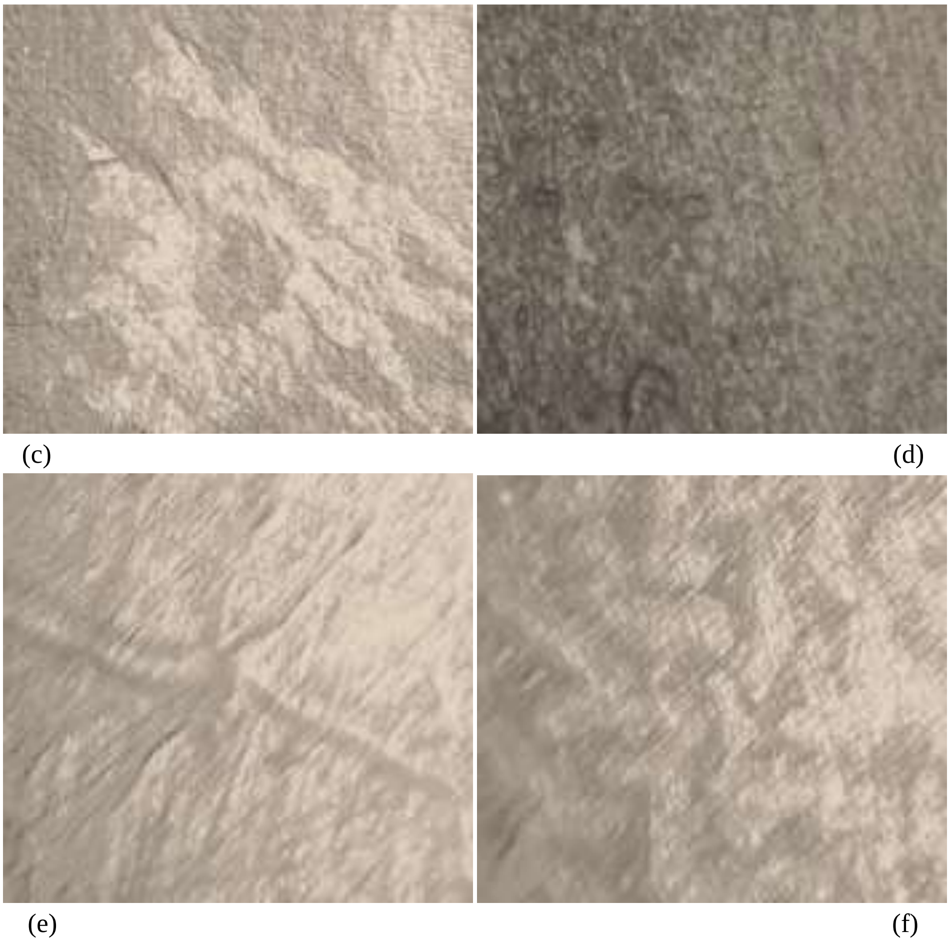

Figure 1: Microstructure of samples before and after cooling media. (a) Before cooling, (b) Cooling with air, (c) Full annealing, (d) Cooling with ice water, (e) Cooling with 10% salty ice water, (f) Cooling with oil

3.2. Mechanical properties

Table (2) shows the microhardness values of the DP medium carbon steel samples before heat treatment, while table 3 and figure 2 show the microhardness of the samples after annealing process according to different cooling media. The difference in hardness values is due to the microstructure responsible for the hardness of (DP) steel and its distribution. Microstructure of the material samples determines the level of hardness in the structure. It is noted that, the untreated sample has a lower hardness compared to the treated samples. It was quenched in oil is considered to have low hardness values because the microstructure of the sample is characterized by a low distribution of martensite, Muhammed et al. [50]. Also the samples that were completely annealed in the furnace are considered to have low hardness values because the microstructure of the samples is characterized by the large size of the grains, which means that the annealing reduced the stress and this agrees with the results of Aaditya Srivastava et al. [51]. Samples quenched in the medium of cold water and brine ice water by 10% increased the hardness value and this corresponds to High distribution of martensite. The highest values in hardness and tensile strength are samples that have been quenched in 10% salt water. This is because this cooling medium creates a martensite phase in high proportions that make the mechanical properties better [52].

Table 2. The hardness values of the sample as received:

The Microhardness values of the sample as received					Average
1	2	3	4	5	
255	232	248	238	231	240.8

Table 3. The Microhardness values of the sample after heat-treated:

The Microhardness values of the samples according to the different types of quenching media							
Quenching type	Sample Code	1	2	3	4	5	Average
Air	002	456	452	466	460	455	457.8
Full annealing in the oven	003	275	287	277	282	275	279.2
Ice water	004	488	492	463	489	478	482
Salty ice water 10%	005	558	560	578	553	571	564
Oil	006	266	252	245	274	265	260.4

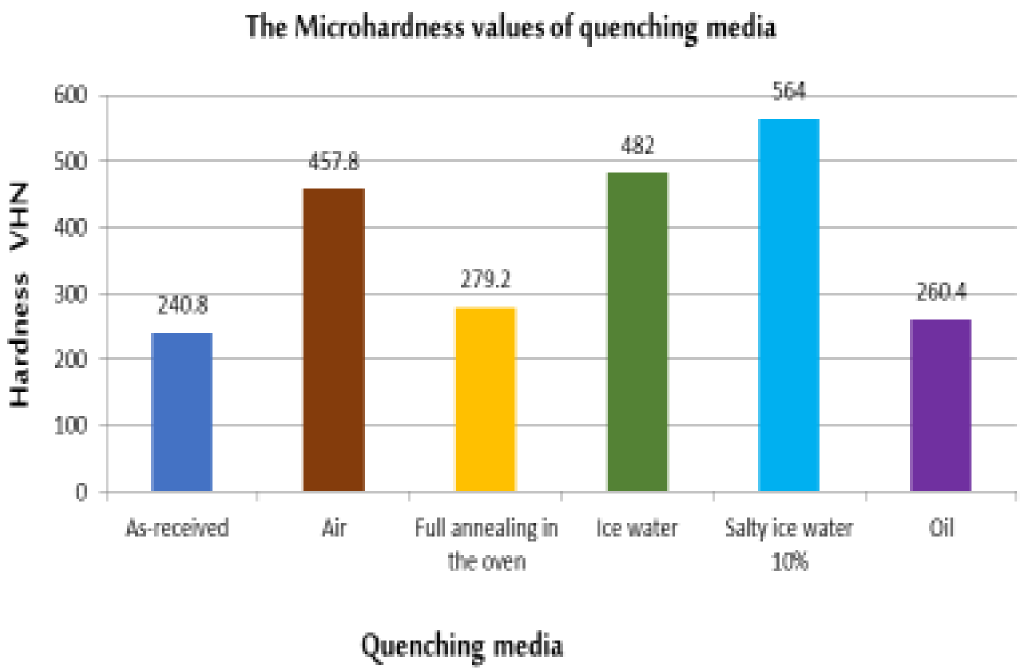

Figure 2. Relation between quenching media and average microhardness values.

Table (4) and figure (3) show the results of tensile test, the tensile strength increased after heat treatments compared to the sample before treatment (as received sample), due to change in microstructure, Doomra Akash et al. [53]. Where we obtained the tensile strength of the samples that were placed in cold pure and salty water higher than the sample before treatment and cooled in the laboratory temperature in air and oil and annealed in the furnace, Minh Quang Chau [54].

Table 4. Tensile strength of sample before treatment (as-received) and after cooling in different media

Quenching type	Sample code	σ_{uts} N/mm^2
As-received	001	477
Air	002	637

Full annealing in the oven	003	509
Ice water	004	653
Salty ice water 10%	005	785
Oil	006	484

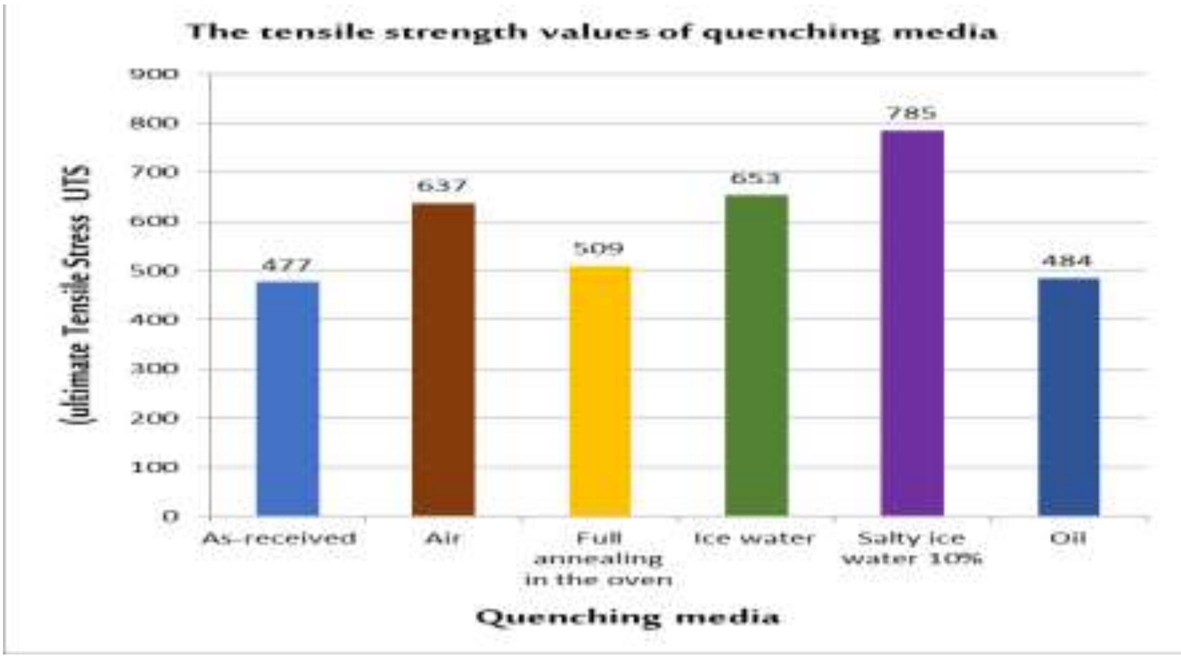

Figure 3. Relationship between quenching media and tensile strength values.

Conclusions

Results obtained from hardness and tensile tests which applied on DP medium carbon steel before heat treatment and after cooling processing can be concluded as following: • Low hardness of medium carbon steel due to its ductile structure.

• The process of heat treatment (quenching) led to a change in the microstructure compared to the sample without heat treatment where the microstructure formed after treatment in a matrix of ferrite interlocked with a varying percentage of martensite.

• The improvement of the hardness values of medium carbon steel and the maximum tensile strength depends on the choice of cooling medium and the soaking time. The hardness and maximum tensile stress improved after heat treatment and their highest value was in the case of cold brine quenching because this cooling medium creates martensitic phase in high proportions that makes Mechanical properties are better.

• Wear resistance of dual-phase medium carbon steel improved after annealing process as hardness and tensile strength.

• Heating was chosen to the appropriate temperature while giving the treated pieces the time needed to reach the correct thermal impregnation so that the entire structure would turn to the new state for 45 minutes, then choose a fast and complete cooling rate and soaking time for 90 minutes and this time is sufficient to not allow transformation before the martensitic transition temperature is reached.

References

[1] D. T. Llewellyn, “Steels : Metallurgy and Applications”, Oxford: Butterworth-Heinemann, (1992).

[2] S. K. Mandal “Steel Metallurgy : Properties, Specifications and Applications ", McGraw-Hill Education (India) Private Limited, (2015).

[3] A. Calik, "effect of cooling rate on hardness and microstructures of AISI 1040 and AISI 1060 Steels", Int. J. of Phys. Sci. 4 , (2009), pp. 514-518.

[4] Francois Njock Bayock ; Paul Kah , Belinga Mvola and Pavel Layus, " Effect of Heat Input and Undermatched Filler Wire on the Microstructure and Mechanical Properties of Dissimilar S700MC/S960QC High-Strength Steels ", Metals, (2019), 9, pp. 883-903.

[5] P.P. Ikubanni; O.O. Agboola; A.A. Adediran; A.A. Adeleke; B.T. Ogunsemi; T.S. Olabamiji; D.C. Uguru-Okorie; C.O. Osueke, “Experimental data on mechanical properties evaluation of medium carbon steel quenched in different waste media", Data in Brief, Volume 20, (2018), pp. 1224-1228.

[6] S. M. Mahbobur Rahman, Kazi Ehsanul Karim, MD. Hasan Shahriar Simanto, "Effect of Heat Treatment on Low Carbon Steel: An Experimental Investigation", Applied Mechanics and Materials, vol. 860. (2016), pp. 7-12.

[7] Raji, N.A. & Oluwole, O.O. “Effect of Soaking Time on the Mechanical Properties of Annealed Cold-Drawn Low Carbon Steel”, Materials Science and Applications 3. (2012), pp.513-518.

[8] G.R. Speich, V.A. Demarest, and R.L. Miller, "Formation of Austenite During Intercritical Annealing of Dual-Phase Steels", Metall. Trans. A, 12A, (1981), pp. 1419–1428. [9] H. Yu and Y. Kangb, "Research on the Mechanism of Aging of Dual Phase Steel Produced by Continuous Annealing", Adv. Mater. Res., 97-101, (2010), pp. 556–559.

[10] Emerald Group Publishing Limited, "Practical Heat Treating, 2nd edition", Anti-Corrosion Methods and Materials, Vol. 53 No, (2006).

[11] Chidiebere, Maduabuchi A.; Oguzie, Emeka E.; Liu, Li; Li, Ying; Alshawabkeh, Akram N.; Wang, Fuhui, The effect of microstructure and elemental content on corrosion and corrosion inhibition of mild steel in a 0.5 M H2SO4 environment", RSC Advances; (2015), Vol. 5 Issue 114, pp.93907-93916.

[12] Information Resources Management Association, " Materials Science and Engineering : Concepts, Methodologies, Tools, and Applications", Hershey, PA : Engineering Science Reference, (2017).

[13] Frihat; Mohamed H., "Effect of Heat Treatment Parameters on the Mechanical and Microstructure Properties of Low-Alloy Steel", Journal of Surface Engineered Materials and Advanced Technology, 5, (2015), pp.214-227.

[14] Hannula, Jaakko1; Porter, David A.1; Kaijalainen, Antti1; Kömi, Jukka " Evaluation of Mechanical Properties and Microstructures of Molybdenum and Niobium Microalloyed Thermomechanically Rolled High-Strength Press Hardening Steel", The Journal of The Minerals, Metals & Materials Society (TMS); (2019), Vol. 71 Issue 7, pp.2405-2412.

[15] D. Das and P.P. Chattopadhyay, "Influence of Martensite Morphology on the Work Hardening of High Strength Ferrite-Martensite Dual Phase", Steel, J. Mater. Sci. 44, (2009), pp. 2957–2965.

[16] Neha Shukla, Suvajeet Das, Sumanta Maji, Subhro Roy Chowdhury, and Bijay Kumar Show, " Effect of Pre-intercritical Annealing Treatments on the Microstructure and Mechanical Properties of 0.33% Carbon Dual-Phase Steel", JMEPEG, 24, (2015), pp.4958–4965.

[17] R. Tyagi, S.K. Nath, and S. Ray, "Effect of Martensite Content on Friction and Oxidative Wear Behavior of 0.42% Carbon Dual-Phase Steel", Metall. Mater. Transactions A, (2002), 33, pp. 3479–3488.

[18] R. Tyagi, S.K. Nath, and S. Ray, 'Development of Wear Resistant Medium Carbon Dual Phase Steels and Their Mechanical Properties", Mater. Sci. Technol., (2004), 20, pp 645–652.

[19] Li, D., Dong, H., Wu, K., Isayev, O, Hress, O, Yershov, S. " Effects of cooling after rolling and heat treatment on microstructures and mechanical properties of Mo–Ti microalloyed medium carbon steel ", (Materials Science and Engineering A, 773, 31, (2020), pp. 430080.

[20] G.W. Yang, X.J. Sun, Q.L. Yong, Z.D. Li, X.X. Li, "Austenite grain refinement and isothermal growth behavior in a low carbon vanadium microalloyed steel", J. Iron Steel Res. Int., 21 (2014), pp. 757-764.

[21] J.Y. Yoo, W.Y. Choo, T.W. Park, Y.W. Kim, "Microstructures and Age Hardening Characteristics of Direct Quenched Cu Bearing HSLA Steel", ISIJ International,Volume 35, Issue 8, (1995), pp. 1034-1040

[22] C. Ouchi, "Development of Steel Plates by Intensive Use of TMCP and Direct Quenching Processes", ISIJ Int., V.41, Issue 6, (2001), pp. 542-553,

[23] S.K. Dhua, S.K. Sen, " Effect of direct quenching on the microstructure and mechanical properties of the lean-chemistry HSLA-100 steel plates", Materials Science & Engineering A, Volume 528, Issue 21, (2011), pp. 6356-6365.

[24] I.A. El-Sesy and Z.M. El-Baradie, "Influence Carbon and/or Iron Carbide on the Structure and Properties of Dual-Phase Steels", Mater. Lett., 57, (2002), pp. 580–585.

[25] A. Fallahi, "Microstructure-Properties Correlation of Dual Phase Steels Produced by Controlled Rolling Process", J. Mater. Sci. Technol., 18(5), (2002), pp. 451–454.

[26] J. Lis, A.K. Lis, and C. Kolan, "Processing and Properties of C-Mn Steel with Dual-Phase Microstructure", J. Mater. Process. Technol., 162-163, (2005), pp. 350–354.

[27] O.P. Modi, P. Pandit, D.P. Mondal, B.K. Prasad, A.H. Yegneswaran, and A. Chrsanthou, "High-Stress Abrasive Wear Response of 0.2% Carbon Dual Phase Steel", Mater. Sci. Eng. A, 458, (2007), pp.303–311.

[28] A.P. Modi, "Effects of Microstructure and Experimental Parameters on High Stress Abrasive Wear Behaviour of a 0.19 wt % C Dual-Phase Steel", Tribol. Int., , 40, (2007), pp.490– 497.
[29] V.A. Khotinov, S.V. Oshchukov, and V.M. Farber, "Structure and Mechanical Properties of Medium-Carbon Steels after Heating in the Intercritical Temperature Range", Met. Sci. Heat Treat., 53, (2012), pp.11–12.
[30] M.O.H. Amuda, T.A. Olaniyan, L.A. Osoba, E.T. Akinlabi, "Mechanical properties of bitumen quenched dual phase steel", Sains Malays, 46, 5, (2017), pp.743-753.
[31] Mishra, Alok1; Mondal, Chandan2; Maity, Joydeep, " Effect of Combined Cyclic Heat Treatment on AISI 1080 Steel: Part II-Mechanical Property Evaluation ", Steel Research International, Vol. 88 Issue 4, (2017).
[32] Bilal Mohammed; Timur; Ayad, " 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, Vol 41, Iss 3, (2018), pp.43-46 .
[33] X. Liang, J. Li, Y.H. Peng, "Effect of water quench process on mechanical properties of cold rolled dual phase steel micro alloyed with niobium", Mater. Lett., 62, 2, (2008), pp.327- 329.
[34] Q. Meng, J. Li, J. Wang, Z. Zhang, L. Zhang, "Effect of water quenching process on microstructure and tensile properties of low alloy cold rolled dual phase steel", Mater. Des., 30, 7, (2009), pp. 2379-2385.
[35] L. Gao, Y.M. Zhou, J.L. Liu, X.D. Shen, Z.M. Ren, "Effect of water quenching process on the microstructure and magnetic property of cold rolled dual phase Steel", J. Magn. Magn. Mater., 322, 8, (2010), pp.929-933.
[36] S.A.Grishin, Y.N. Churyukin, "Evaluation of the cooling capacity of quenching media based on water", Met. Sci. Heat Treat., 28, 10, (1986), pp.744-745.
[37] A.S. Adekunle, J.K. Odusote, A.B. Rabiu, "Effects of using vegetable oils as quenching media for pure commercial aluminium", Proceedings of ICCEM of Nigerian Society of Engineers, (2012), pp.321-325.
[38] D. Scott MacKenzie, "Selection of oil quenchants for heat treating processes", Int. Heat Treat. Surf. Eng., 8, 1, (2014), pp.8-14.
[39] D.H. Herring, "Oil Quenching", The Herring Group, Inc. Elmhurst, Illinois., (2010), pp. 1- 24.
[40] M. B Adeyemi, S. B. Adedayo, "Vegetable oils as quenchants for hardening medium carbon steel", J. Appl. Sci.Technol., 14, 1-2, (2009), pp.74-78.
[41] Tajudeen Ajiboye; Adam Olalekan Abdulsalam, " Mechanical Characteristics of Heat-Treated Medium Carbon Steel Quenched using Blending Different Types of Vegetable Oils ", International Journal of Engineering Materials and Manufacture, Vol 4, Iss 4, (2019).
[42] Çalik ; Adnan, "Effect of cooling rate on hardness and microstructure of AISI 1020, AISI 1040 and AISI 1060 Steels", International Journal of Physical Sciences Vol. 4 (9), ,(2009) pp. 514- 518.
[43] Dodo, M. R.; Ause, T.; Adamu, M. A.; Ibrahim, Y. M," effect of post-weld heat treatment on the microstructure and mechanical properties of arc welded medium carbon steel", Nigerian Journal of Technology; 2016, Vol. 35 Issue 2, pp.337-343.
[44] Hung-Hua Sheu1,* , Ting-Yi Hong1 , Tzu-Te Lin2 , Ming-Der Ger1*, 2018, The Effect of Heat Treatment on the Corrosion Resistance, Mechanical Properties and Wear Resistance of Cr−C Coatings and Cr−C/Al2O3 Composite Coatings Electrodeposited on Low Carbon Steel, International Journal of ELECTROCHEMICAL SCIENCE, Vol.13, pp. 9399 – 9415, doi: 10.20964/2018.10.39
[45] S. K. Mandal, " Steel Metallurgy : Properties, Specifications and Applications", McGraw Hill Education, (2015).
[46] Mirosław Szala, Michał Szafran, Wojciech Macek, Stanislav Marchenko, Tadeusz Hejwowski, "Abrasion Resistance of S235, S355, C45, AISI 304 and Hardox 500 Steels with Usage of Garnet, Corundum and Carborundum Abrasives", Advances in Scien Research Journal, Volume 13, Issue 4, (2019), pp. 151–161.
[47] .A. Bag, K.K. Ray, E.S. Dwarakadasa, "Tensile behaviour of intercritically treated high martensite dual phase steel", Metall. Mater. Trans A, 30, (1999), pp.1193-1202. [48].E.I. Saldana-Garza, B.P. Wynne, R. Cerda-Rojas, R.D. Mercado-Solis, "Effect of different quench media on the microstructure and mechanical properties of large-scale low alloy steel forgings", Key Eng. Mater., 716, (2017), pp.270-280.
[49] M.K. Manas, P.C. Chakraborti, "Tensile properties of intercritically annealed 14 mm thick Nb – bearing micro alloyed steel", Trans. Indian Inst. Met., 57, 2, (2004), pp.149-156. [50] Muhammed O. H. Amuda, Taiwo F. Lawal, Tirimisiyu A. Olaniyan, Ganiyu A. Oladapo, "A Quenching media affect on the mechanical properties of medium carbon dual phase steel", Journal of Chemical Technology and Metallurgy, 55, 4, (2020), pp.895-909. [51] Aaditya Srivastava, Ansh Jain, Shubham Rajput, Nitin Johri, "A review on effect of heat treatment on the properties of mild steel", Materials Today: Proceedings 37, , Part 2: (2020), pp.2266-2268.
[52] Ali Baqer, "An investigation study using mixture proportion of polyethylene glycol-water as quenching medium and their effects on low carbon steel heat treatment process", International Journal of Energy & Environment, Volume 9, Issue 2, (2018), pp.205-210.

[53] Doomra Akash, Singh Beant, Sandhu Sandeep Singh, " Influence of Input Parameters and Post-weld Heat Treatment on the Metallurgical and Mechanical Properties of Electron Beam Welded Thick AISI 409 Ferritic Stainless Steel", Metallography, Microstructure, and Analysis: Application and Innovation for Metals, Alloys, and Engineered Materials. 10(2), (2021), pp.219-235.
[54] Minh Quang Chau, " Effect Of Different Quenching Media On Mechanical Properties Of Aisi 1018 Low Carbon Steel", Journal of Mechanical Engineering Research and Developments, Vol 42, Iss 3, (2019), pp. 81-83.
[55] Abdelhameed, M., et al. "Microstructure And Mechanical Characteristics Of Titanium Alloy TC21 After Heat Treatment." International Journal of Mechanical Engineering (IJME) 10.1 (2021) 49-56
[56] Jalil, Mohammad Abdul, et al. "Analysis of physio-mechanical properties of jute-PALF Union fabrics." International Journal of Mechanical Engineering (IJME) 4.3 (2015): 23-28.
[57] Singh, Raja Ramanna, et al. "Comparison of mechanical properties of medium carbon steel with dual phase steel." International Journal of Mechanical Engineering (IJME) 4.4 (2015): 1-8.
[58] Viswakarma, P. R. A. D. Y. U. M. N. A., Sanjay Soni, and P. M. Mishra. "An effect of reinforcement and heat treatment on AA7075 metal matrix composite–a review." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) 8.6 (2018): 275-288.
[59] Bhagyalaxmi, Sathyashankara Sharma, And Vijaya Kini. "Effect Of Heat Treatment And Mechanical Characterization Of AISI 4140 Steel." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) 8.6 (2018) 603-610
[60] Somayaji, ANANTHA KRISHNA, and N. A. R. A. S. I. M. H. A. Marakala. "Effect of T6 Heat Treatment on Hardness Wear and Fatigue Behaviour of Nickel Coated Carbon Fiber Reinforced Al-7079 MMC." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) 9.2 (2019): 253-264.