International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 6 Issue 8, August - 2022, Pages: 1-9

AN INVESTIGATION OF THE RELATIONSHIP BETWEEN THE COOLING MODES AND MECHANICAL PROPERTIES OF AISI 5120 ALLOY STEEL

Meshref A. A., Mostafa S. S., Deyaa M. A., Emad B. A., Osman A. O.

Department of Production Engineering & Design, Faculty of Engineering, Minia University, EGYPT.

Abstract: *In this work, three kinds of heat treatments namely full annealing, normalizing, and hardening are applied* to investigate the effect of cooling modes the on the mechanical properties of the *AISI 5120 alloy steel*. *Also, the fracture surface of the* specimens *after tensile testing has been studied. The results of this work reveal that the cooling in boiling water creates a 5120 steel alloy with high tensile properties and the high Vickers hardness number. Cooling in oil decreases the tensile properties and the Vickers hardness number for steel alloy 5120. This work indicates that, the tensile properties and the Vickers hardness number for steel alloy 5120 dependent on the cooling modes. The best cooling mode is the cooling in boiling water, as it posses the best combination of strength and ductility.*

Keywords: Heat treatments, cooling modes, mechanical properties, tensile testing, Vickers hardness number, AISI 5120 alloy steel.

1. INTRODUCTION

Heat-treating is the technique of heating and cooling of metals to attain the desired physical and mechanical characteristics through modification of their crystalline structure. The temperature, time duration, and cooling rate after heat-treating will have their dramatically impact on characteristics [1].

Heat-treating in general is classified into (i) Bulk heat-treating; (ii) Surface hardening heat- treating. Bulk heat-treating includes annealing, normalizing, hardening and tempering [2]. Annealing, normalizing, hardening and tempering are the most important heat treatments often used to change the structure and mechanical characteristics of engineering materials particularly steels and its alloys [3].

Full annealing consists of heating the steel above the A_{c3} temperature for hypoeutectoid steels and the A_{c1} temperature for hypereutectoid steels, and then the steel is cooled in the furnace at the rate of a few tens of degrees per hour [4]. In normalizing, the steel is heated to a temperature that is 55 ^{0}C above the upper critical line of the iron- iron carbide phase diagram, above A_{C3} temperature for hypoeutectoid steels and above A_{Cm} temperature for hypereutectoid steels, for a short period, and then the steel is allowed to cool in open air [1]. In hardening, the steel is heated above the upper critical temperature and then cooled rapidly in water or oil or forced air [5].
Broadly, the procedure of heat-treating process consists of three stages: 1) heating the metal; 2) holding the temperature for a period of time and 3) cooling the metal to room temperature [6]. To cool the metal, the metal can be directly in contact with a cooling mode composed of a gas, liquid, solid, or in combination of any of these. The rate at which the metal is cooled depends on the metal and the desired properties. The rate of cooling depends on the mode; therefore, the choice of a cooling mode has an significant effect on the desired properties [1]. Heat- treating of steel is a necessary technology to increase the strength, wear resistance, durability of core parts in automobile, aircraft, tool machine and shipbuilding [7].

High strength low alloy (HSLA) steel is one of the most vastly used steels in heat-treating industry. The advantages of high strength low alloy steel are extremely excellent in toughness and fatigue and are used for material of machine parts in manufacture industry. AISI 5120 steel alloy is general high strength low alloy steel and is used to available cold working process. AISI 5120 steel alloy is low carbon low alloy steel made with chromium alloy additives. Generally AISI 5120 steel alloy is commonly used as gears and shafts that work under severe cyclic load [7].

The goal of the present work is to discuss the effects of heat treatment cooling modes on the yield strength, ultimate tensile strength, percent elongation, modulus of resilience, modulus of toughness, and Vickers hardness number of the AISI 5120 alloy steel.

2. EXPERIMENTAL

2.1. MATERIALS

AISI 5120 alloy steel with carbon content of 0.2 % carbon is used in this work. Table 1 reports the chemical composition of the AISI 5120 alloy steel. AISI 5120 alloy steel is received as round bars.

Table 1: Chemical composition of AISI 5120 steel, wt. %

C	Si	Mn	S	P	Cr	Mo	Ni	Cu	w	Al	V

0.2	0.28	0.78	0.033	0.023	1.04	0.1	0.1	0.22	0.007	0.016	0.004

2. 2. HEAT-TREATING

Three kinds of heat-treating are employed in this work, namely full annealing, normalizing, and hardening. Heat-treatment specimens are positioned in electrical furnace. The heating temperature, holding time and cooling modes will be described in the heat-treating schedule in Table 2.

Table 2: Heat- treating schedule

Process	Details of Heat-treating
Full annealing	Specimens are fully annealed at 884 ^{0}C for 37 minute, cooled in furnace
Normalizing	Specimens are normalized at 884 ^{0}C for 37 minute, cooled in air
Hardening	Specimens are hardened at 884 ^{0}C for 37 minute, cooled in oil, hot water (70 ^{0}C), and boiling water (91 ^{0}C)

2.3. TENSILE TEST

For tension test, cylindrical short specimens of 9 mm diameter and 45 mm gauge length are used to determine the tensile properties (yield strength, ultimate tensile strength, and % elongation, modulus of resilience, and modulus of toughness) of the AISI 5120 alloy steel. Tension test is carried out at room temperature on Universal Testing Machine (UTM) at a cross-head speed of 4 mm/min.

2.4. VICKERS HARDNESS TEST

To evaluate the Vickers hardness number of the specimens, round specimens having a diameter of 10 mm and a length of 10 mm and of the AISI 5120 alloy steel are used. The test is performed on Vickers hardness tester with a force of 100 Kg for 20 second using a diamond pyramid indenter. Vickers hardness number is measured on one side of the specimens at room temperature.

2.5. FRACTURE SURFACE EXAMINATION

The specimens for fracture surface examination are sectioned after the finishing of the tension test. Fracture surfaces are examined by digital camera. The observation is focused on the fracture mode change from one cooling mode to another.

3. RESULTS AND DISCUSSION

3.1. TENSION TEST RESULTS

The effect of cooling modes on the yield strength (lower yield strength) of the steel alloy 5120 is indicated in Figure 1. These results denote that, the steel alloy 5120 cooled in boiling water exhibits the highest yield strength (653.78 MPa) followed by the steel alloy 5120 cooled in hot water (589.64 MPa), the steel alloy 5120 cooled in air (585.67 MPa), the steel alloy 5120 cooled in furnace (539.13 MPa) and lastly the steel alloy 5120 cooled in oil (530.73 MPa). These observations could be related to the change in the structure of the steel alloy 5120. Based on these data, it may be concluded that the steel alloy 5120 cooled in boiling water has the higher withstand to deform which led to failure. Whereas, the steel alloy 5120 cooled in oil has the lower withstand to deform.

International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 6 Issue 8, August - 2022, Pages: 1-9

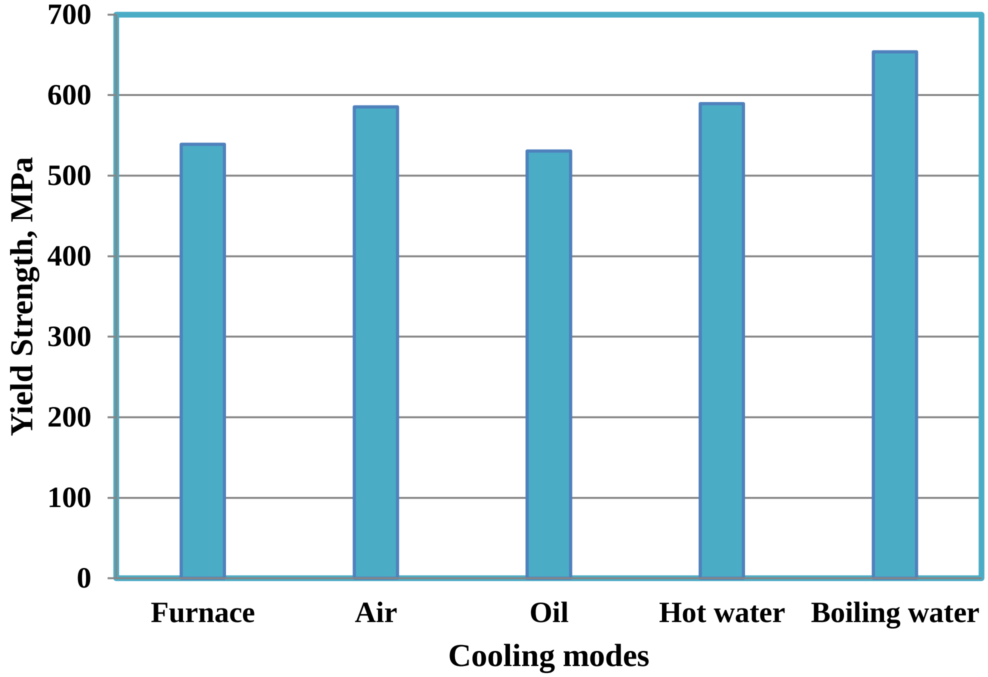

Figure 1 Influence of cooling modes on the yield strength (lower yield strength) of the steel alloy 5120

The effect of cooling modes on the ultimate tensile strength of the steel alloy 5120 is presented in Figure 2. It is clear that the steel alloy 5120 cooled in boiling water exhibits the highest value of the ultimate tensile strength (813.37 MPa) followed by the steel alloy 5120 cooled in air (734 MPa), the steel alloy 5120 cooled in hot water (733.87 MPa), the steel alloy 5120 cooled in furnace (730.3 MPa) and lastly the steel alloy 5120 cooled in oil (654.77 MPa). This means that the steel alloy 5120 cooled in boiling water enable to withstand the fracture under the tensile loads compared to the steel alloy 5120 cooled in hot water, oil, air and furnace.

The ductility (% elongation) of the steel alloy 5120 is plotted as a function of cooling modes as shown in Figure 3. The obtained results as shown in Figure 3 reveal that the cooling modes showed pronounced effects on the ductility (% elongation) at all used cooling modes. The highest ductility is obtained in the steel alloy 5120 cooled in boiling water (35.6 %), then the steel alloy 5120 cooled in furnace (33.33 %), then steel alloy 5120 cooled in hot water (32.22 %), then steel alloy 5120 cooled in air (31.11 %) and lastly the steel alloy 5120 cooled in oil (26.67 %). Based on Figure 3, it may be concludes that the steel alloy 5120 cooled in boiling water exhibits the highest formability followed by the steel alloy 5120 cooled in furnace, hot water, air and oil.

International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 6 Issue 8, August - 2022, Pages: 1-9

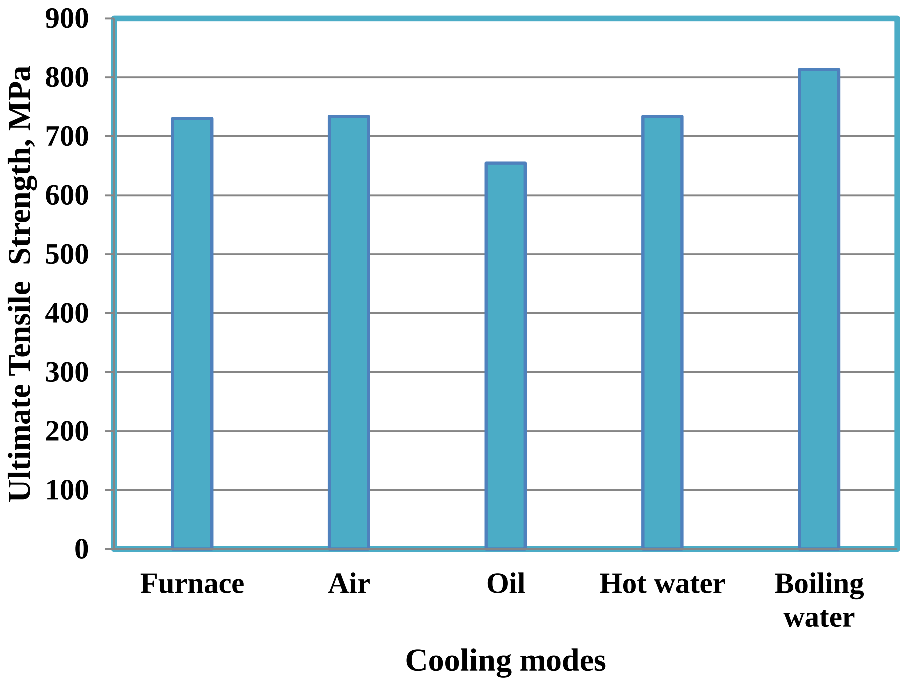

Figure 2 Influence of cooling modes on the ultimate tensile strength of the steel alloy 5120

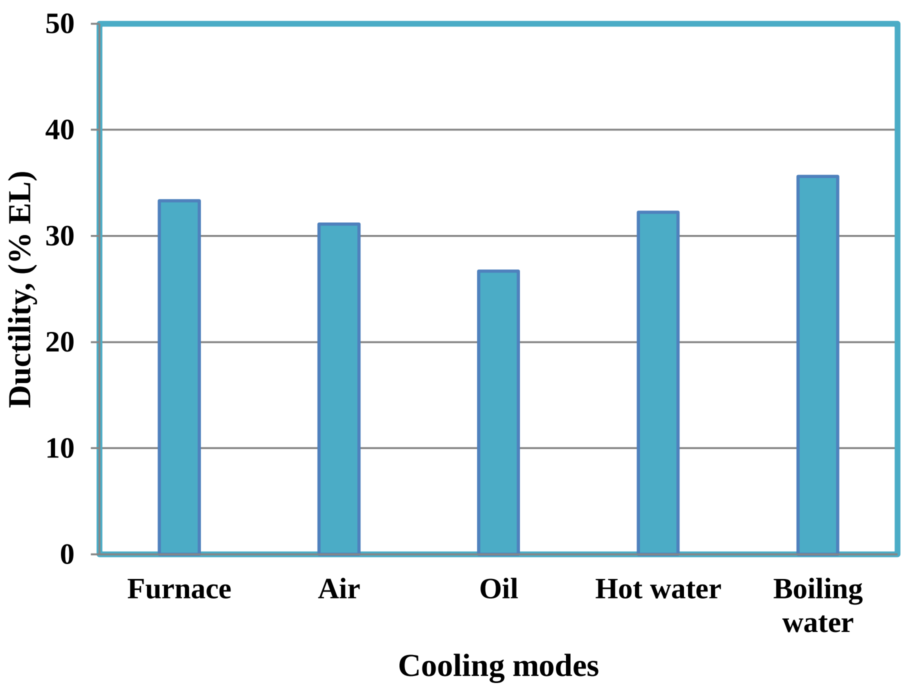

Figure 3 Influence of cooling modes on the ductility (% elongation) of the steel alloy 5120

Figure 4 shows the variation of the modulus of resilience of the steel alloy 5120 against the cooling modes. As it is evident in Figure 4, the steel alloy 5120 which cooled in boiling water has high modulus of resilience value (1.2 MJ/m^3) followed by the steel alloy 5120 cooled in hot water (1.032 MJ/m^3) but when the steel alloy 5120 cooled in oil and furnace, the modulus of resilience value will be low (0.823 $MJ/m^3$and 0.809 MJ/m^3) respectively. The high modulus of resilience values for the steel alloy 5120 cooled in boiling

International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 6 Issue 8, August - 2022, Pages: 1-9

water and hot water modes may be due to the high yield strength values since the modulus of resilience is proportional to the yield strength.

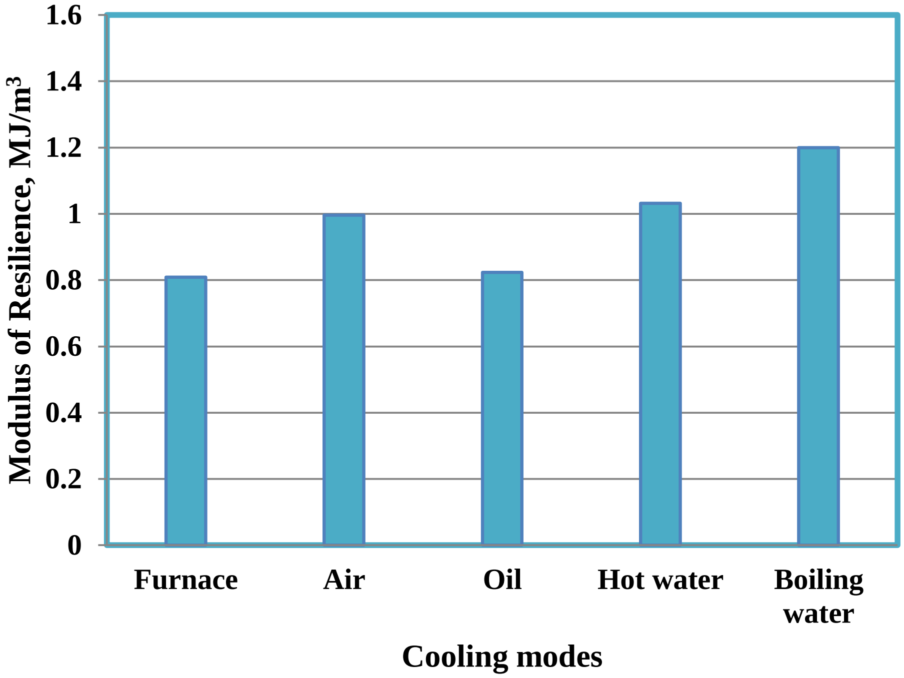

Figure 4 Influence of cooling modes on the modulus of resilience of the steel alloy 5120

Figure 5 shows the effect of different cooling modes on the modulus of toughness of the steel alloy 5120. Toughness measure the energy required to fracture. As indicated in Figure 5 the highest modulus of toughness is obtained in the steel alloy 5120 cooled in boiling water (261.15 MJ/m^3) followed by the steel alloy 5120 cooled in hot water (213.22 MJ/m^3), the steel alloy 5120 cooled in furnace (211 MJ/m^3), the steel alloy 5120 cooled in air (205.27 MJ/m^3) and lastly the steel alloy 5120 cooled in oil (158 MJ/m^3).

International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 6 Issue 8, August - 2022, Pages: 1-9

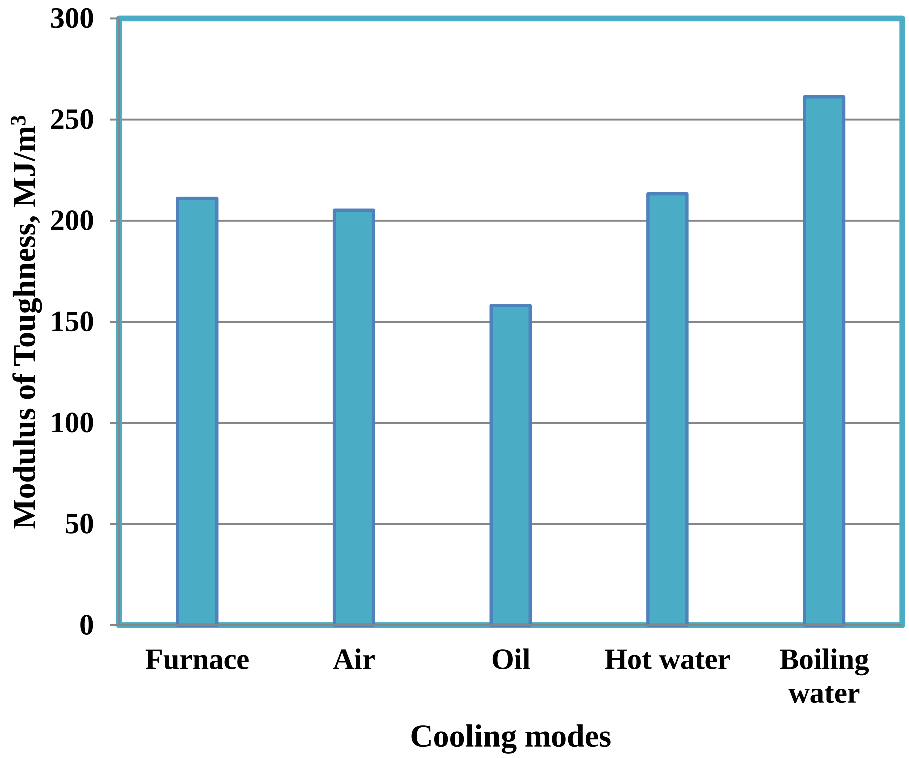

Figure 5 Influence of cooling modes on the modulus of toughness of the steel alloy 5120

3.2. HARDNESS TEST RESULTS

The Vickers test is suitable for testing materials with a wide range of hardness number, including heat-treated steels, and gives essentially the same hardness number regardless of the load [8]. Figure 6 illustrates the Vickers hardness number (HV) obtained by the steel alloy 5120 cooled in furnace, air, oil, hot water and boiling water. It is clear that, the steel alloy 5120 which cooled in boiling water has a high Vickers hardness number followed by the steel alloy 5120 cooled in hot water, then the steel alloy 5120 cooled in air, then the steel alloy 5120 cooled in furnace and lastly the steel alloy 5120 cooled in oil. This means that, the steel alloy 5120 cooled in boiling water has a surface with high resistance to indentation, while the steel alloy 5120 cooled in oil has a surface with low resistance to indentation. In other words, the steel alloy 5120 cooled in boiling water has a surface with high resistance to plastic deformation, while the steel alloy 5120 cooled in oil has a surface with low resistance to plastic deformation.

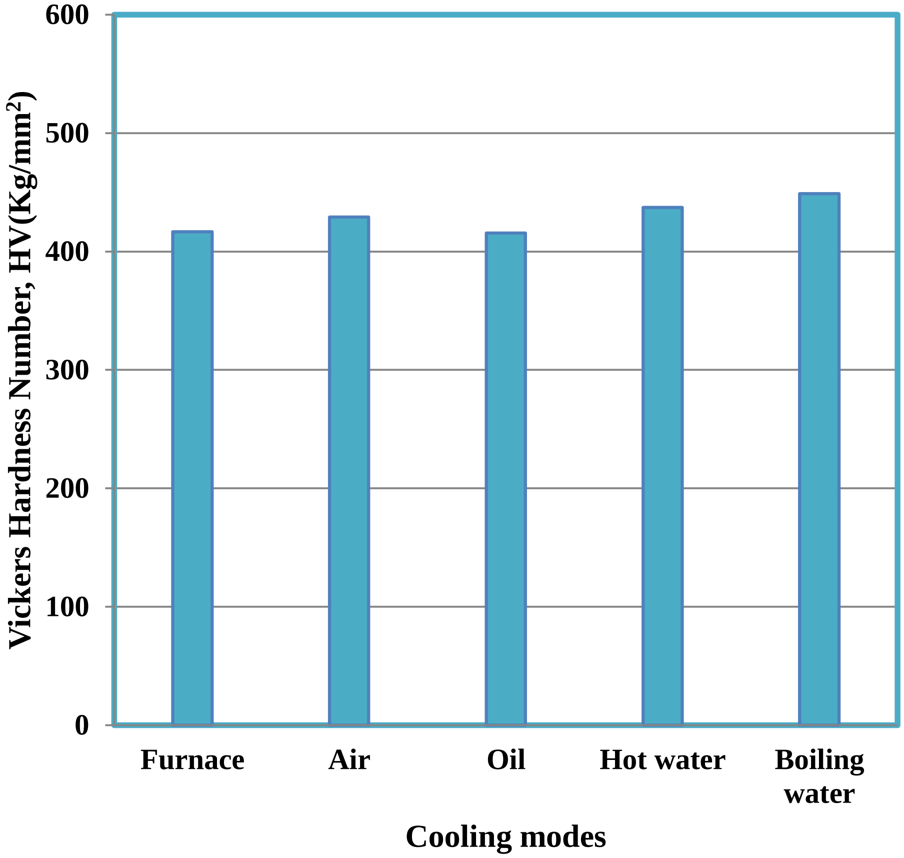

Figure 6 Influence of cooling modes on the Vickers hardness number of the steel alloy 5120

3.3. FRACTURE SURFACE INSPECTION

Fracture may be known as the mechanical segregation of a solid owing to the application of stress [9]. Two types of fracture modes are possible for engineering materials: ductile and brittle fracture. Sorting is based on the ability of a material to experience plastic deformation. In ductile materials there is substantial plastic deformation with high energy absorption before fracture. On the other hand, there is usually little or no plastic deformation with low energy absorption accompanying a brittle fracture [10]. Figure 7 shows the appearance of the fracture surface of tested tensile specimens for the steel alloy 5120 cooled in furnace, air, oil, hot water and boiling water. From Figure 7 it can be seen that the fracture surface of the specimens cooled in furnace, air, oil, hot water and boiling water have a cup-and-cone ductile fracture.

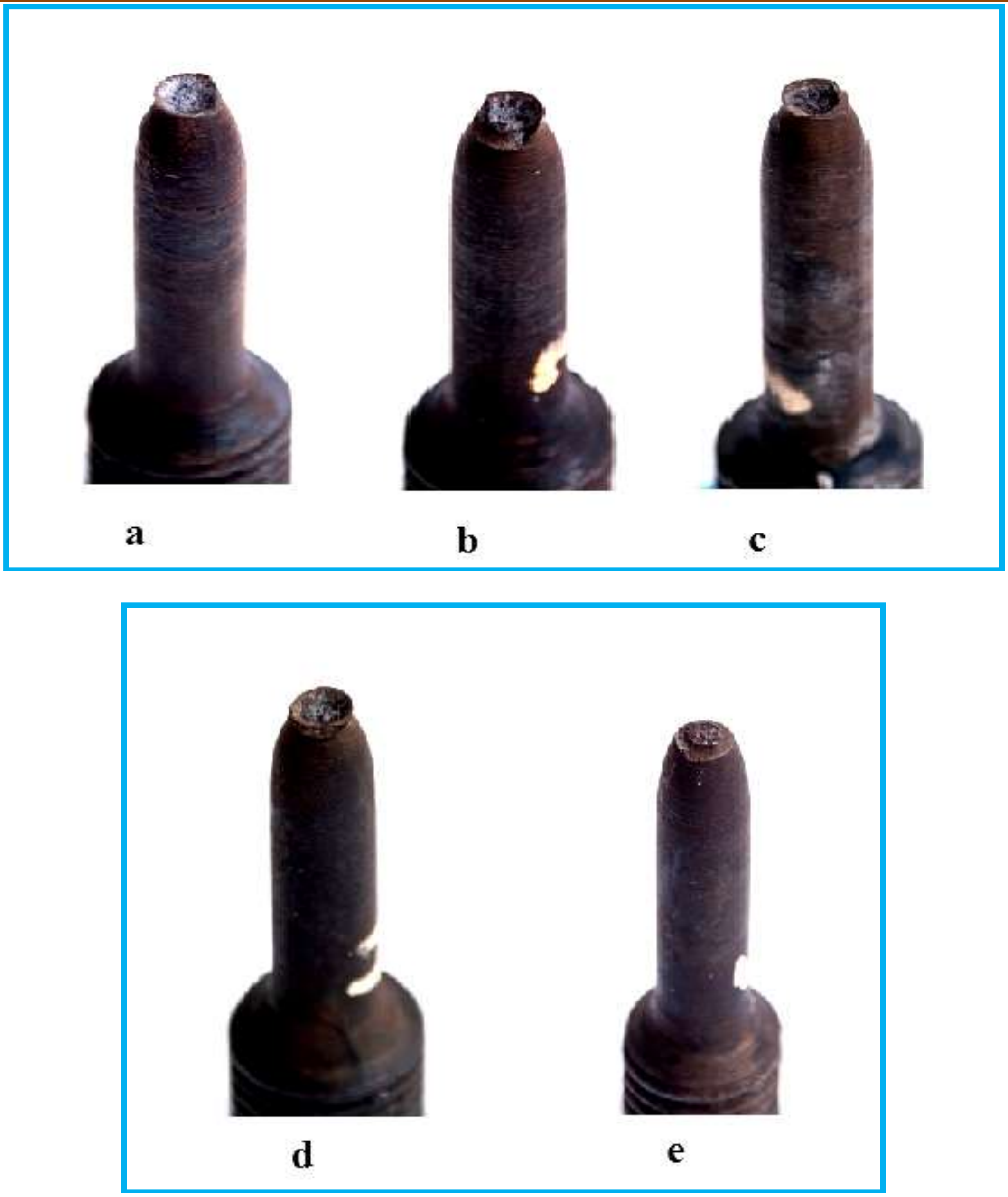

Figure 7 Fracture surfaces of tensile specimens for the steel alloy 5120; a) cooled in furnace; b) cooled in air; c) cooled in oil; d) cooled in hot water; e) cooled in boiling water.

4. CONCLUSIONS

Under the conditions of this work, it can be concluded that:

1. Cooling in boiling water gives the highest values of yield strength, ultimate tensile strength, ductility, modulus of toughness, modulus of resilience, and Vickers hardness number for steel alloy 5120.

2. Steel alloy 5120 can be heat-treated by hardening and cooling in boiling water to produce high strength with high ductility.
3. Cooling in oil gives the lowest values of yield strength, ultimate tensile strength, ductility, modulus of toughness, and Vickers hardness number for steel alloy 5120.

REFERENCES

1. Tripathy I., Effect of Microstructure on Sliding Wear Behavior of Modified 9Cr-1Mo steel, M. Sc. Thesis, National Institute of Technology, Rourkela, pp.19 – 27, (2011).

2. Meshref A. A., Mazen A. A., El-Giushi M. A., Effect of Heat Treatment Temperatures on the Mechanical Properties of AISI 4140 Alloy Steel, Metall, Vol. 73, pp. 386-390, (2019).

3. Wichan C., Loeshpahn S. and Dumrongrit P., The Effects of Heat Treatment on Microstructure and Mechanical Properties of AISI 4140 for Base Cutter Cane Harvester, Advanced Materials Research, Vol. 774-776, pp. 1059-1067, (2013).

4. Raghavan V., Physical Metallurgy principles and Practice, New Delhi, 2nd Edition, pp. 109 – 110, (2006).

5. Meshref A. A., Comparative Study on Fracture Toughness of Steel after Different Thermal Treatments", M. Sc. Thesis, Minia University, Egypt, p.37, (2014).

6. Noor Mazni Ismail, Nurul Aida Amir Khatif, Mohamad Aliff Kamil Awang Kecik, Mohd Ali Hanafiah Shaharudin, The effect of heat treatment on the hardness and impact properties of medium carbon steel, IOP Conf. Series: Materials Science and Engineering, 114, pp. 1-9, (2016).

7. K.O. Lee, J.M. Kim, M.H. Chin, S.S. Kang, A study on the mechanical properties for developing a computer simulation model for heat treatment process, Journal of Materials Processing Technology, Vol. 182, pp. 65–72, (2007).

8. Serope Kalpakjian , Steven R. Schmid , Manufacturing Engineering and Technology , Sixth Edition , Prentice Hall , New York , p. 70, (2009).

9. ASM International, ASM Handbook Volume 8: Mechanical Testing and Evaluation, American Society for Metals, Metals Park, Ohio, p. 1270, (2000).

10. Callister W.D., Materials Science and Engineering an Introduction ", Wiley, 6th Edition, pp. 235- 238, (2003).