INFLUENCE THE QUENCHING AND TEMPERING ON THE MICROSTRUCTURE, MECHANICAL PROPERTIES AND SURFACE ROUGHNESS, OF MEDIUM CARBON STEEL

Sattar Hantosh A. Alfatlawi
alisattar_2011@yahoo.com

ABSTRACT

One of ways to improve properties of materials without changing the product shape to obtain the desired engineering applications is heating and cooling under effect of controlled sequence of heat treatment. The main aim of this study was to investigate the effect of heating and cooling on the surface roughness, microstructure and some selected properties such as the hardness and impact strength of Medium Carbon Steel which treated at different types of heat treatment processes. Heat treatment achieved in this work was respectively, heating, quenching and tempering. The specimens were heated to 850°C and left for 45 minutes inside the furnace as a holding time at that temperature, then quenching process was performed in four types of quenching media (still air, cold water (2°C), oil and polymer solution), respectively. Thereafter, the samples were tempered at 200°C, 400°C, and 600°C with one hour as a soaking time for each temperature, then were all cooled by still air. When the heat treatment process was completed, the surface roughness, hardness, impact strength and microstructure tests were performed. The results showed a change and clear improvement of surface roughness, mechanical properties and microstructure after quenching was achieved, as well as the change that took place due to the increasing toughness and ductility by reducing of brittleness of samples.

KEYWORDS : Heat treatments, Surface Roughness, Mechanical properties, Microstructure, Medium Carbon Steel .

تاثيرالاخماد والمراجعة على البنية المجهرية ، الخواص الميكانيكية ، خشونة السطح للحديد متوسط الكاربون

ستار حنتوش ابوسودة الفتلاوي

الخلاصة

احدى الطرق لتحسين خصائص المواد دون تغيير شكل المنتج للحصول على التطبيقات الهندسية المطلوبة هي التسخين والتبريد تحت تاثير خطوات متتالية مسيطر عليها من المعالجة الحرارية. وكان الهدف الرئيسي من هذه الدراسة هو بحث تأثير التسخين والتبريد على خشونة السطح و البنية المجهرية وبعض الخصائص المختارة مثل الصلادة ومقاومة الصدمة للصلب المتوسط الكربون والذي تمت معالجته في أنواع مختلفة من عمليات المعالجة الحرارية. المعالجة الحرارية التي تحققت في هذا العمل كانت على التوالي، التسخين، التبريد ثم الاخماد ثم المراجعة. تم تسخين العينات الى 850 درجة مئوية والبقاء 45 دقيقة عند تلك الدرجة كزمن مكوث داخل الفرن ثم تنفيذ عملية الاخماد في أربعة أنواع من وسائط التبريد (الهواء الساكن، الماء البارد(2 مئوي) ،الزيت ومحلول البوليمر على التوالي . بعد ذلك تم مراجعة العينات عند 200درجة مئوية، و 400 درجة مئوية، و 600 درجة مئوية مع ساعة واحدة كوقت نقع لكل درجة حرارة بعد ذلك جميعها تم تبريدها بالهواء الساكن. عندما تم الانتهاء من عملية المعالجة الحرارية تم فحص خشونة السطح، الصلادة، ومقاومة الصدمة، و اختبارالبنية المجهرية. وأظهرت النتائج تغييرو تحسنا واضحا في خشونة السطح و الخواص الميكانيكية والبنية المجهرية بعد الاخماد، بالاضافة الى التغيير الذي حصل بسبب المتانة والمطيلية المتزايدة عن طريق الحد من هشاشة العينات .

الكلمات الدالة: المعالجة الحرارية، خشونة السطح، الخواص الميكانيكية، البنية المجهرية، صلب متوسط الكاربون.

Received : 2017 - 7 - 17
Accepted : 2017 - 11 - 12

INTRODUCTION

Carbon element in steel plays a main role in changing the structure and properties of carbon steel, so the structure at transformations of steel depend on the carbon during phase transformation with heat treatments, as full-annealing, hardening, tempering and etc. So, other elements in steel, such as manganese, chromium, vanadium and tungsten have the ability to increase the hardness and effect on some properties of steel. Therefore, a balance must be made between hardness and ductility in the case of the use of carbon steel in engineering applications. The common applications of steel contain carbon from (0.4 - 0.6), such as axles, gears, couplings, etc. [Noor Mazni Ismail, 2017]. Generally, the carbon steel can be divided into three groups, low-carbon with the highest quality of carbon (0.3% C), the medium-carbon contains from (0.3–0.7% C) and high-carbon contains (0.7–1.7% C). The heat treatment of medium carbon steel can be quenched and then tempered to improve toughness, ductility, and strength. [Kadhim, 2016]. The aim of heat treatment is to make the alloy useful to new applications by changing or improving its structure, mechanical and physical properties by a series of controlled operations which is heated and cooled without reaching into melting state and without changing the profile of product. The heat treatment process can make the alloy harder, stronger, resistant to impact, resistance to wear, softer and more ductile. Changing the properties of steel can be obtained if the controlling of the temperature and the time during heat treatments is accurate [Vishal Singh, 2016]. It is known that increasing of hardness and strength of steel due to carbon content, carbon content and the microstructure affect the properties of carbon steel, but carbon alone has properties, such as strengthening and hardening, lowers ductility, machinability, weldability, corrosion resistance, thermal and electrical conductivity and magnetic permeability. The heat treatment consists of heating and cooling operations performed to material to obtain the required mechanical properties, such as impact strength, hardness, etc. Heating and quenching, the necessary heat treatment processes are used to improve the mechanical properties of carbon steel. Typically, annealing, quenching and tempering are the types of heat treatment used to soften and improve the steel grains size because of the microstructure of ferrite-pearlite, where a high tensile strength is required in steel. [U. K. Singh, 2009]. Three main processes of heat treatment are commonly termed annealing, quenching and tempering. These processes consist of heating the alloy and holding it at that temperature for a soaking time, then the material is cooled to room temperature to improve properties of alloy. When the ductility, hardness and strength of medium carbon steel are required, also there is a desire to change other properties such as its ability to contact heat and electricity, can use the previously processes of heat treatment. [Ashish Bhateja, 2012]. The grain size of steel after quenching with water media was refered to a mixture of martensite and lower bainite, while with oil some martensite was obtained with lower bainite, but the polymer quenched steels showed a mixture of a small amount of ferrite with fine tempered martensite. The effect of heat treatment by oil, water, polymer respectively on the mechanical properties clearly improved, the ductility with the polymer was better because the cooling rate of polymer was higher than oil (but lower than water media) and its uniformity compared to oil and water. Also, the toughness and impact strength values with polymer quenching were improved. [Chandan, 2017]. Usually in this process, the steel is heating then rapidly cooled by quenching it in a liquid to exact control on the final properties of the steel. [O. O. Daramola, et al, 2010]. Increasing of steel strength by some heat treatment technologies was developed in last years, exactly with rapid heat treatment. If the crystalline grain size decreased, the strength of steel was increased and this state was obtained from the rapidity of austenitizing. Then to gate a high strength, it was followed by rapid cooling or quenching, but decreasing of ductility occurred with rapid cooling. [J. Abou-Jahjah and J. Dobránszky, 2001]. It's known the effect of heat treatment is direct on the microstructure of materials which leads to change that the mechanical properties, In other words, the effect of heat treatment on the toughness, ductility, strength of material was directly related to the machinability of materials. So, the microstructure is an important factor for the cutting of materials in addition to other factors, such as chemical composition, cutting condition, rigidity of tool and holding of devices. [G. R.Nagpal 2011]. In this work, the mechanical properties of medium carbon steel, such as impact strength, hardness, also the surface roughness and the change of microstructure have been studied. Therefore, the medium carbon steel was heated to 850°C and quenched in four types of quenching media respectively: still air, cold water, oil, and polymer solution. Then, the samples were tempered at 200°C, 400°C, and 600°C at the holding time of one hour for each temperature and then cooled in still air. All tests were carried out for specimens after quenching and tempering for each one of quenching media.

EXPERIMENTAL DETAILS

Samples preparation

The present study was achieved by taking the medium carbon steel as a basic material for all samples tests. All samples were prepared and tested in the laboratories of the Materials Engineering College / University of Babylon. Table 1, shows the result of chemical composition according to (GOST) Russian Steel Standards, which was carried out at 22°C and 27% of humidity in the State Company for Inspection and Engineering Rehabilitation (SIER).The medium carbon steel was used to produce 20 samples for impact strength in this work. They were machined by a milling machine with a dimension 55 mm x 10 mm x 10 mm and then notched with angle 45° and 2 mm depth according standard dimension for Charpy impact test (see figures 1, 2 and 3). Also, these samples were used to examine impact strength previously, they were machined again for surface roughness test by a lathe machine with specific cutting conditions as cutting speed, depth of cut and feed, were 12 m/min, 0.2 mm and 0.03 mm/rev, respectively (see figure 4). These samples were used for surface roughness measurements by a testing device, (Surface Roughness Tester, model: 210, TA620 Stand& column) before and after heat treatment process (see figure 5) . **The** microstructure test of the samples before and after heat treatment was performed by grounding, polishing, and etching medium carbon steel samples. Aluminum oxide emery papers (220, 320, 600, 800) were used for grinding, and the alumina phase was used for polishing process. The etching process in Nital solution (98% methylated with 2% Nitric acid) was carried out for a clearly visible crystal structure of samples. Then, microscopic test of surface was conducted by an optical microscope with a camera and photographed with magnifications 20x, 40x, 60x and 80x as shown in figure 6. The samples of microstructure examination before and after heat treatment were used again to test the hardness after completing of microstructure examination, the hardness test achieved by the hardness testing device type (Digital Display Microhardness Tester Model HVS-1000) as shown in Figure 7.

Heat Treatment Processes

Only 18 samples were heat treated, and two samples untreated were left to observe the basic tests. The carried out heat treatment process was respectively as following; heating, quenching, and tempering. All samples were heated to 850°C and held for 1 hour inside the furnace as a holding time. Then, the samples were cooled in various media as a quenching process respectively in still air, cold water (2°C), oil, and polymer solution. The tempering process was done at 200°C, 400°C, and 600°C with a holding time of one hour for each temperature, and samples were then cooled in still air. Type of furnace (Digital Muffle Furnace, Model: DMF-12) which used in this work.

RESULTS AND DISCUSSION

Microstructure

Figure 8 refers to the microstructure of the base metal. It is observed that the structure contains two phases: ferrite and pearlite for untreated samples. Usually, pearlite is formed after break down the eutectoid from austenite by diffusion the atoms of carbon with cooling process. The structure seems as full-annealing, the grains of ferrite are large and the space of lamellar pearlite is wide. It is also noted, the amount of pearlite (dark regions) is larger than the amount of ferrite (white regions), (Jon. L. Dossett, 2006). Figure 9 shows the microstructure of medium carbon steel after heat treatment when samples were heated to temperature 850°C and then air cooled. The structure also contains two phases: ferrite and lamellar pearlite, but the grains of ferrite are smaller than the annealing process. The space of lamellar pearlite is closer than the annealing process. Fine grains of ferrite and closer space of pearlite are due to the effect of cooling rate. It is known that the air has a higher cooling rate than furnace cooling but slower than rapid cooling by water. When the samples were quenched from the austenizing temperature to room temperature rapidly by water cooling (2°C), this leads to rapid quenching of medium carbon steel from austenizing temperature exposing the structure to shear stresses, blocking the atoms of carbon to diffusion and creating the BCT (body center tetragonal) of martensite structure. Martensite in this case has more hardness that reached to 437.6 HV, but with the toughness was 37.6 J, the roughness also improved with quenching by cold water was 0.193 µm. Figure 10 shows the martensite as a needle shape (dark colure) and some of retained austenite (white colure). To improve the toughness and durability of steel after quenching, the steel must be tempered to temperature under A1 to control the microstructure and properties for steel. Figure 11 appears the microstructure after water tempering at 200 °C for one hour. It is clear that this martensite has more uniform structure with reduced the amount of retained austenite (white colure) and at this temperature, the internal stresses were reduced with improvement in the impact strength values from 37.6 J to 63.7 J, but the hardness values reduced to 380.8 HV, see table 3. Figure 12 shows the microstructure of steel after water tempering at 400°C. It observed that the martensite changes to a small precipitate of spherical pearlite in the fine matrix of ferrite. In this structure, the toughness and the ductility improved due to the changes in the structure of martensite. Figure 13 shows the structure that tempered at 600°C, it is clear that grains of ferrite reformed with quantity, and these grains are larger than previous tempering at 200°C and 400°C. The ductility was improved in this stage of tempering, but the hardness was reduced from 437.6 HV with quenching to 261.6 HV at 600°C of tempering. Figures 14-21 depict the effect of quenching by polymer and oil respectively, where the behavior of steel was somewhat similar to behavior of water quenching, but with uniformity of a needle shape due to the cooling rate of polymer and oil. Also, the remain figures of tempering at 200, 400 and 600°C show the clear behavior of steel due to effect of tempering after quenching by polymer and oil which was fast at the beginning of cooling similar to cooling by water, but kept some heat as cooling continued and led to reduce the cracking with that process, but with rapid cooling as the case of cooling by water maybe some cracks may occur. In other word, the shape of grains reformed with more uniformity than previous tempering of water. This process leads to improve the ductility better than with tempering of water in this stage of tempering, but the hardness is less than it was when tempering after quenching by cold water where it was 237 HV and 176.5 HV at 600°C with tempering after oil and polymer quenching respectively, see table 3.

Mechanical Properties and Surface Roughness

The rate was taken for three readings of hardness, surface roughness and impact strength testing for final results, these shown in the tables 2 and 3. The results exhibited a clear improvement in the mechanical properties and surface roughness after heat treatment. Mechanical properties test was carried out to check the impact strength and hardness of samples before and after heat treatment as follows; a high hardness occurred with rapid quenching by media such as water to create hard martensite but if the quenching was not fast enough, the carbon atom would reform as ferrite from austenite. Fundamentally, the microstructure was hard with reduced ductility but increased hardness and tensile strength. Also the samples cannot be used with any application if the rapid quenching was performed due to their high brittleness. In this case, quenching must be followed by a tempering process to reduce the brittleness and increase the ductility or toughness of samples. Table 2 refers to the effect of heating and quenching in different media on the hardness and impact strength, where it shows clearly increasing of hardness and reducing of impact strength. Higher value of hardness was with water quenching and less value with air, on the other hand, the highest increase was in impact strength with air and less value with water due to the faster cooling rate of water than air. But, the result was close between oil and polymer quenching because the cooling rate with polymer and oil was fast at the beginning of cooling but kept some heat as cooling continued which led to reduce the cracking that was happened with rabid cooling as the case of cooling by water. Table 3 appears the effect of tempering on the hardness and impact strength as well surface roughness, there was a clear improvement of the impact strength that was accompanied with improved ductility and tensile strength with tempering at 600 °C. Really, it is possible to control the increase and reduction of hardness or impact strength according to the application, in other words, the higher resistance to deform action or to compressive load is with high hardness, while the higher impact strength is with increasing of ductility and reducing of hardness. It is obvious from the above that the quenching improved the hardness, while tempering improved the toughness and ductility. Tables 2 and 3 show clear change in surface roughness before and after heat treatment, also the results are close between the base alloy and samples cooled by air after heated to 850 °C. But, a clear improvement was observed in the roughness of surface with cold water, polymer solution and oil quenching, respectively (see table 2). Also, tempering of samples after quenching revealed that the surface quality was less than state of quenching (table 3). The decrease in surface roughness after quenching and tempering in various media cold be attribute to the interaction between these media and the hard external surface of heat treated steel. Thus the reduction of roughness was high with water quenching but it was less with air, this might be due to more surface oxidation effect on steel during quenching by air.

CONCLUSIONS

From the results of this investigation, it can be concluded the following points:

• Cold water was the better media of quenching due to the rapid of cooling but in this case, the microstructure may contain cracks.

• Best results for surface roughness, microstructure, hardness and impact strength can be obtained with cold water for quenching and tempering processes, the percentage improvement was as follows; the hardness improvement were 2.458 %, impact strength 1.164 %, surface roughness 13.14 % with quenching process. But, the result at tempering process of impact strength was 5.52 %, at 600°C with decreasing of hardness and surface roughness.

• Good application has been obtained when improved toughness of medium carbon steel after the increase of tempering temperature.

•Polymer is better than oil but less than cold water for quenching and tempering process.

• By using tempering process, brittleness can be reduced by increasing the ductility.

• The surface roughness revealed more improvement after quenching by water and close with polymer and oil but with increase of tempering temperature, the surface quality is somewhat reduced.

Table 1: Chemical Composition of Medium Carbon Steel (wt %)

Materials	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Fe
Used	0.522	0.247	0.693	0.015	0.002	0.011	0.002	0.005	0.043	0.014	Bal.
Standard 50 (GOST)	0.47-0.55	0.17-0.37	0.5-0.8								

Table 2; Results of hardness, impact strength and surface roughness tests after quenching in different media

Type of test	Results of as-received alloy	Results after quenching			
		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

Table 3; Results of hardness, impact strength and surface roughness tests after tempering in various media at different temperatures

Type of tests	Results after tempering								
	Oil			Cold water			Polymer		
	200 °C	400°C	600°C	200°C	400°C	600°C	200°C	400°C	600°C
Hardness (HV)	266.7	240.9	237	380.8	319	261.6	280	254.8	176.5
Impact (J)	90	120	145	63.7	88	178.3	86	144	150
Roughness µm	1.323	2.133	2.301	0.920	1.411	2.033	1.291	2.174	2.281

Fig. 1; Impact strength samples before heat treatment

Fig. 2; Impact sample after heat treatment

Fig.3; Sample after impact strength test

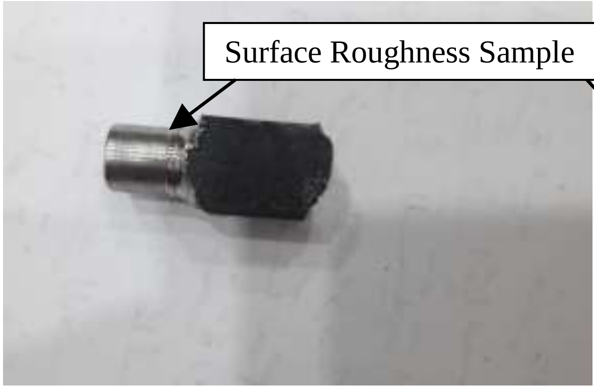

Fig. 4; Sample of surface roughness test

Fig. 5; Device of surface roughness test

Fig. 6; Optical Microscope

Fig. 7; Microhardness Tester

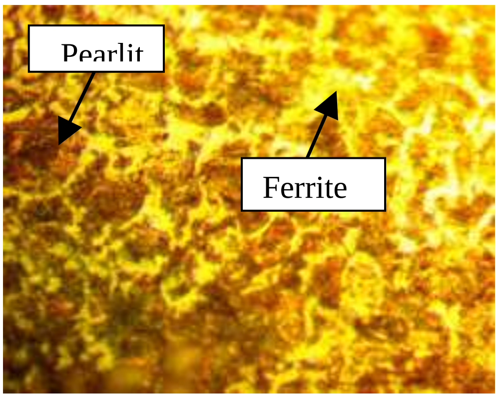

Fig.8; Microstructure of non-heat treated (80x)

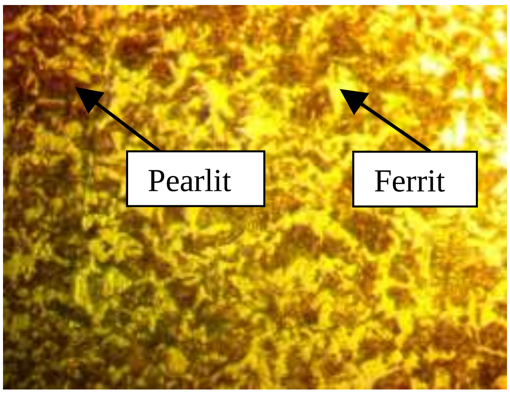

Fig.9; Microstructure with air cooling (80x)

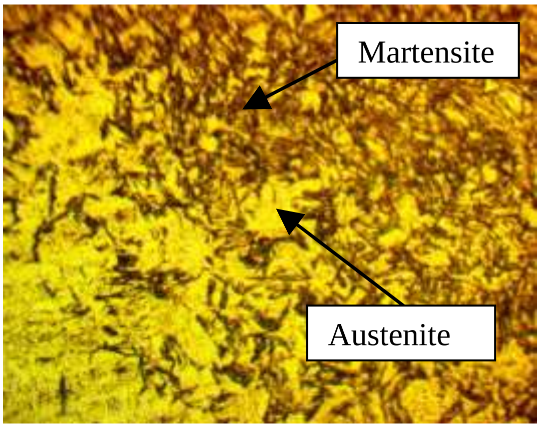

Fig.10; Water quenching with (80x)

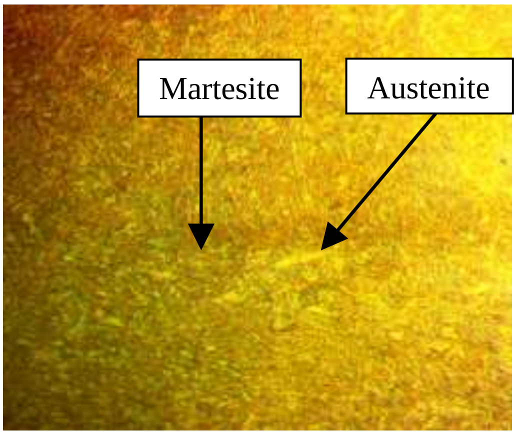

Fig.11; Water Tempering at 200°C with (80x)

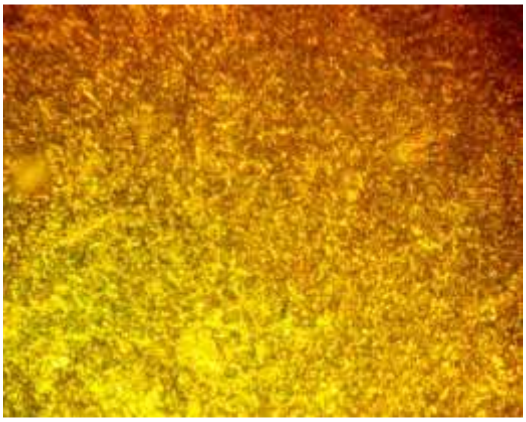
Fig.12; Water tempering at 400°C with (80x)

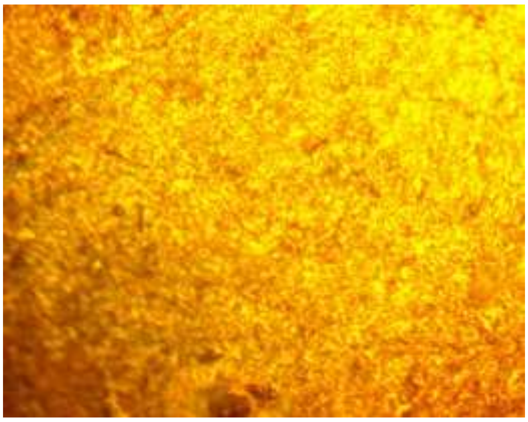
Fig.13; Water tempering at 600°C with (80x)

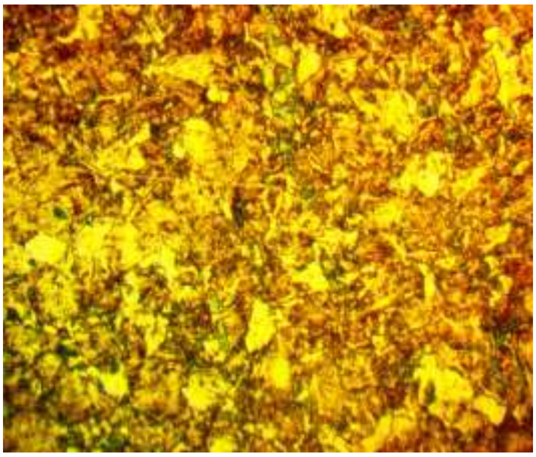
Fig.14; Polymer Quenching with (80x)

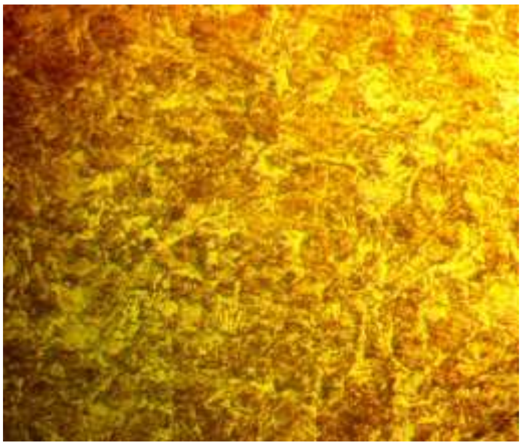
Fig.15; Polymer tempering at 200°C with (80x)

Fig.16; Polymer tempering at 400°C

Fig.17; Polymer tempering at 600°C

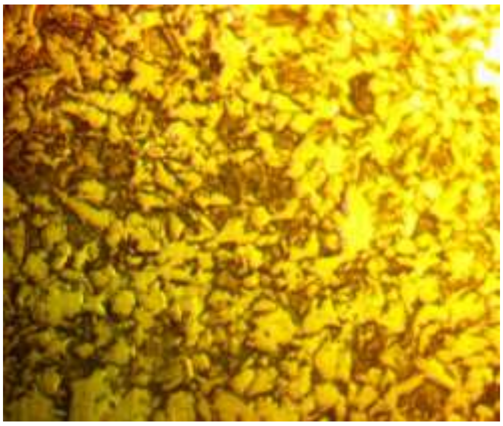

Fig.18; Oil quenching at (80x)

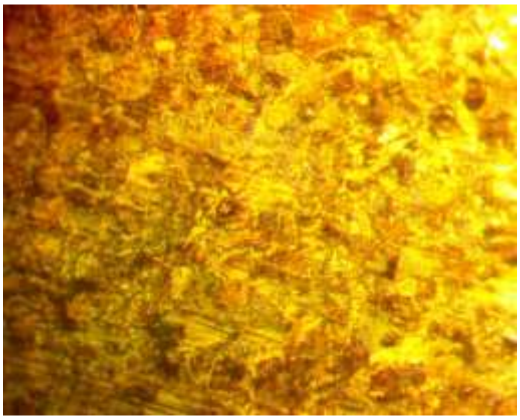

Fig.19; Oil tempering at 200°C with (80x)

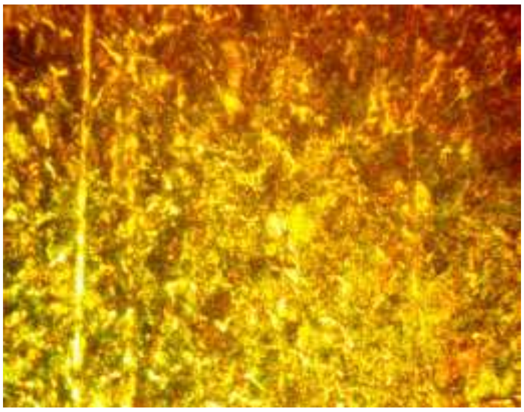

Fig.20; Oil tempering at 400°C with (80x)

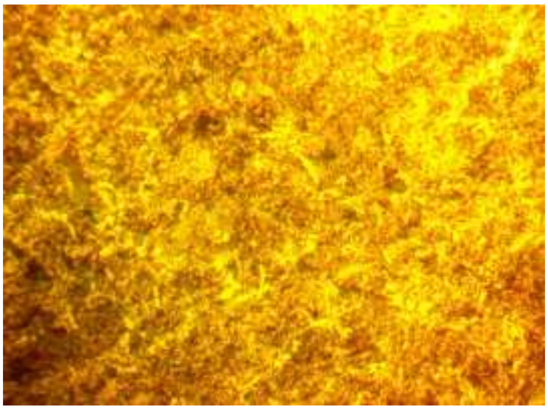

Fig.21; Oil tempering at 600°C with (80x)

REFERENCES

Ashish Bhateja, Aditya Varma, Ashish Kashyap, Bhupinder Singh, ”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, pp. 253-259, 2012.

Chandan B. R. and Ramesha C M, "Evaluation of Mechanical Properties of Medium Carbon Low Alloy Forged Steels Quenched in Water, Oil and Polymer", Material Sci Eng., Volume 6, Issue 2, pp. 2- 5, India, 2017.

G. R. Nagpal, "Machine tool engineering", Eighth Edition, Khanna Publishers, (www. KhannaPublishers.in), Delhi, 2011.

J. Abou-Jahjah and J. Dobránszky, Mechanical Properties Improvement of Low Carbon Steel by Combined Heat Treatments, First International Industrial Engineering Conference, 2001, Jordan.

Jon. L. Dossett and H. E. Boyer, "Practical Heat Treating" Second Edition, ASM International (www.asminternational.org), USA, 2006.

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 Publishing, Materials Science and Engineering, Malaysia, 2016.

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, Nigeria, 2010.

U.K. Singh and Manish Dwivedi, "Manufacturing Processes" second edition, New Age International (P) Ltd, rights@newagepublishers.com, pages (25-30) New Delhi, 2009.

Vishal Singh, Amresh Mishra, Km. Sonam, Rupma Gautam, Aamir Alam Azmi, "Effect of Various Heat Treatment Processes on Mechanical Properties of Mild Steel and Cast Iron" , IJRMET Vol. 6, Issue 2, India, 2016.

Zeyad, D. Kadhim, "Effect of Quenching Media on Mechanical Properties for Medium Carbon Steel", Int. Journal of Engineering Research and Application, Vol. 6, Issue 8, (Part -5), pp.26-34, Iraq, 2016.