The Effect of Heat Treatment on the Machinability, Tensile Strength, Hardness, Ductility and Microstructure of Carbon steel (GOST 50).

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Abstract

In this work, the heat treatments were performed by three types of processes: normalizing, quenching and tempering, where the samples were heated to 900°C and held for 1 hour inside the furnace at that temperature. The first group of hot samples was cooled by air to room temperature through the normalizing process, but the second group was rapidly cooled by two types of the quenching media: (cold water at 5°C and polymer solution). The samples after quenching processes were tempered by heating to 450°C for one hour as a soaking time at this temperature. The samples were then taken out of the furnace, and cooled by air. The machinability, tensile strength, hardness, ductility and microstructure tests of carbon steel (GOST 50) have been achieved after the completion the heat treatment processes. The results appeared improvement and change in these properties after the heat treatments due to the change of the hardness, ductility and toughness of samples.

Keywords: Machinability, Tensile strength, Ductility, Microstructure, Hardness, Normalizing, Quenching, Tempering, Carbon Steel (GOST 50).

الخلاصة

في هذا لبحث، المعاملات الحرارية انجزت بثلاثة انواع كانت التبريد بالهواء، الاخماد والمراجعة. حيث تم تسخين النماذج الى 900 درجة مئوية وساعة واحدة مكوث داخل الفرن عند تلك الدرجة، المجموعة الاولى من النماذج الساخنة تم تبريدها بالهواء الى درجة حرارة الغرفة، لكن المجموعة الثانية تم تبريدها بصوره مفاجئة بنوعين من وسائط الاخماد هما (الماء البارد عند 5 مئوي ومحلول البولمر) على التوالي. كذلك تم اجراء عملية المراجعة بعد الاخماد بتسخين النماذج الى 450 مئوي مع ساعة مكوث عند تلك الدرجة ومن ثم تبريدها بالهواء جميعا بعد اخراجها من الفرن. تم اجراء عملية الفحص لقابلية التشغيل، مقاومة الشد، البنية المجهرية، المطيلية والصلادة بعد اتمام المعاملات الحرارية للكاربون ستيل. وقد اظهرت النتائج تحسن وتغيير بتلك الخواص بعد اجراء المعاملات الحرارية بسبب التغيير بالصلادة والمطيلية والمتانة للنماذج.

الكلمات المفتاحية : قابلية التشغيل ، مقاومة الشد، الصلادة ، المطيلية، البنية المجهرية ، التطبيع ، الاخماد ، المراجعة ، الصلب الكاربوني (GOST 50).

1. Introduction

Carbon steel with a carbon contain of (0.05% -1.5%) is called plain carbon steel. This ratio has a direct effect on the strength, hardness, ductility, machinability, weldability, etc. of the carbon steel. In other words, if the ratio gradually decreases to 0.05% of carbon, that would lead to reduction of the hardness and strength. Conversely, it would also lead to increasing other properties such as machinability and ductility. Actually, the carbon steel which has a carbon with ranges from 0.3% to 0.5% is called medium carbon steel which is used in important applications such as shafting, crank hooks, axles, forging, gears, dies, wheels, etc. In addition to the carbon content, there are other reasons which change the mechanical properties above to be suitable to the desired application such as heat treatments that are performed by a sequence of controlled steps of heating and cooling to improve the properties of the medium carbon steel to suit the requirements or a particular application. (Singh , 2009) .

If the process of heat treatment is done, that extend to change of mechanical properties of medium carbon steel such as hardness that increases with quenching and decreases with the increase of the tempering temperature due to the martensite transformation into a new state of tempered martensite, so the ductility increases with the increase of the tempering temperature. If the temperature of tempering increases, the phase of martensite matrix converts into tempered martensite which makes the recovery of the residual stress, strength and ductility increasing. (Motagi and Ramesh Bhosle, 2012) . Tensile strength, elongation and yield strength of mild steel by normalizing process were best than the other heat treatment process, but the elongation of stainless steel by all heat treatment process is large.(Tanwer, 2014).

The effect of heat treatment on the surface roughness directly influenced especially with the quenching process. In other words, the rapid cooling leads to the increase of hardness and toughness of carbon steel after quenching with the possibility of a crack in the structure. Therefore, the surface roughness is sensitive with the hardness increasing of the quenching samples more than the non-quenching samples. (Jumbiao, 2016).

Tensile strength and hardness with high value can be obtained by quenching process as in the case of normalization process but with less value of ductility and impact strength. So the hardness and tensile strength of medium carbon steel have been increased by plastic deformation. (Fadare, 2011). The heat treatment done of rolled medium carbon steel is heating to 830 °C and rapidly cooling by water, then reheating to 745°C and tempering at 480 °C. The results showed the improvement of tensile strength, impact strength and ductility. (Daramola, 2010).

The increasing of tensile strength and hardness was investigated with quenching by cold water also decreasing the elongation, impact strength and wear rate in this process.(Kadhim, 2016). It's known that the heat treatments have directly effect on the microstructure of materials which lead to the change of mechanical properties, In other words, the effect of heat treatment on the toughness, ductility, strength of material are 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. (Nagpal, 2011) .

Heating and cooling under specific conditions to alter and improve the mechanical properties of carbon steel (GOST 50) such as tensile strength, ductility and hardness, in addition to the surface roughness and microstructure to obtain suitable purpose or application have been studied in the present work. All tests carried out for specimens before and after heat treatment according to the type of the examination.

2. Details of Experimental

Carbon steel (GOST 50) was selected as raw material in this study for all samples. Table (1) refers to the chemical composition of the carbon steel. The analysis of the chemical composition was carried out at 22°C and 27% of humidity in the State Company for Inspection and Engineering Rehabilitation (SIER) according to (GOST) Russian Steel Standards. All samples were machined by milling and lathe machines. Tensile test samples were machined by milling machine according to ASTM E 8M-04 and tested by Computer Control Electronic Universal Testing Machine, model: WDW-200. But the samples of the surface roughness were machined by the lathe machine. These samples have been produced for the roughness test device (Surface Roughness Tester, model: 210, TA620 Stand& column) before and after heat treatment processed. Hardness tests before and after heat treatment processes were achieved by the hardness testing device (Digital Display Microhardness, Tester Model HVS-1000).

Untreated samples were tested after machining directly, but the treated samples were heated to 900°C and left for one hour inside the furnace (Digital Muffle Furnace, Model: DMF-12) as a soaking time, then coolied by three types of cooling media (air, polymer and cold water at 5°C). The cooling by still air is named normalizing process but the cooling by polymer solution and cold water is termed quenching process. Tempering process was performed for samples after quenching by polymer and cold water, they were reheated to 450°C for one hour as a hold time. Ten cooled to room temperature by still air. The microstructure was tested by an optical microscope after the surfaces of samples were performed by grinding, polishing, and etching before and after heat treatment. Various grades of aluminum oxide emery were used for the grinding and the alumina paste was used for the polishing process. Etching process of nital solution (98% methylated with 2% Nitric acids) was carried out for a clearly visible the crystal structure of samples.

3. Results And Discussion

3.1 Mechanical Properties

The results showed a clear improvement of tensile strength, hardness and machinability with water and polymer solution quenching but with reducing of ductility (elongation and reduction) see figure 1, the rate of three readings was taken for all tests to final results. The highest value of the tensile strength with water quenching was 875 N/mm², polymer solution quenching was 822 N/mm², the results values of normalizing, polymer tempering, water tempering, unheated samples were 425.3, 386.3, 369 and 353 N/mm², respectively. This leads to the fact that the water quenching gives the best result of the tensile strength.

Figure 2 refers to the hardness for untreated and heat treated samples. It is observed that the best value of hardness was 461HV with the quenching by cold water. The quenching by polymer achieved the second value of hardness (450HV), but the results reduced for other values of hardness for normalizing, water tempering, polymer tempering and unheated samples, the values were 210, 186.3, 179.7 and 178 HV respectively. Also the result of the hardness with quenching by cold water was the best result compared to other processes.

Figures 3 and 4 showed the results of the ductility (elongation and reduction) for all processes. They observed a convergence between the results with a slight improvement for results of tempering after quenching by cold water and polymer solution, where the elongation for tempering after water and polymer quenching were 21.3% and 22%, and the reduction were 87.7% and 83.2% respectively. However, the lowest results of the ductility were with the quenching by cold water and polymer solution due to the increased hardness and tensile strength with those processes.

Figure 5 shows the results values of the surface roughness for untreated and heat treated samples. It is observed that the best value of surface roughness with the quenching by polymer solution and cold water, they were 0.105 µm and 1.91 µm respectively, due to the toughness of the structure after quenching has given best smoothness to the surface. The remaining cases, such as normalizing and tempering, showed a slight improvement in the surface roughness.

3.1 Microstructure

Figure 6 refers the microstructure of the untreated sample which observed a structure contains two phases: ferrite (white regions) and pearlite (dark regions). It is also observed that the amount of pearlite is larger than the amount of ferrite. Figure 7 showed the microstructure after normalizing process. The structure also contained two phases: ferrite and lamellar pearlite but the grains of ferrite were smaller than that of the untreated sample. Generally, the air cooling is faster than the cooling of furnace, but slower than the rapid cooling by water. This is evident in the form of granules due to the effect of the cooling rate on them, fine grains of ferrite and closer space of pearlite.

Figure 8 shows the samples which were rapidly quenched by cooling water at (5°C) from austenizing temperature to room temperature, the martensite as a needle shape (dark colour) and some of retained austenite (white colour). Martensite has more hardness and strength but has low toughness and ductility. Quenching behavior of polymer somewhat looks like quenching by water but with uniformity of the needle shape because the cooling rate of polymer was fast at the beginning of the cooling same the cooling of water, so that kept some heat with cooling continued. That process leads to reduce of cracking with that process but with rabidly of cooling as the case of cooling by water this could happen that clear in figure 9.

To improve the toughness and durability of carbon steel after quenching, it must be tempered to temperature under A1 (critical temperature) to control on the microstructure and properties of steel. Figure 10 showed the structure by tempering at 450°C after cooling by water. It is clear the reforming and more reduction grains of ferrite and closer spacey of lamellar pearlite thus, the toughness is increase due to fine grains by tempering at 450 . The ductility is improved in this stage of tempering but the hardness and the internal stresses were reduced. Figure 11 shows the tempering after quenching by polymer, the grains of structure were more uniform shapes, in other word, the grains were reforming with more uniform than previous tempering of water.

4. Conclusions

From the results of this study, the following points can be concluded;

- The results showed that the clear improvement of tensile strength and hardness with highest values by quenching of cold water and polymer solution, but with lowest value of ductility.
- Tempering after quenching by water and polymer achieved the highest ductility (elongation and reduction %) comparing with other processes.
- The best result of surface roughness was with quenching by polymer solution due to the toughness of the structure after quenching and the nature of the cooling rate of the polymer which prevents cracks after quenching.
- The result of surface roughness with cooling by water was good but less than polymer cooling due to rapidly cooling rate with water.
- The microstructure results showed improvement with quenching processes. The quenching behavior of polymer referred to uniformity of a needle shape due to the cooling rate which was fast at the beginning, then it was slower than the water quenching afterwards.

Table 1: Chemical Composition of Carbon Steel (GOST 50)

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Fe
Weight%	0.522	0.247	0.693	0.015	0.002	0.011	0.002	0.005	0.043	0.014	Bal.

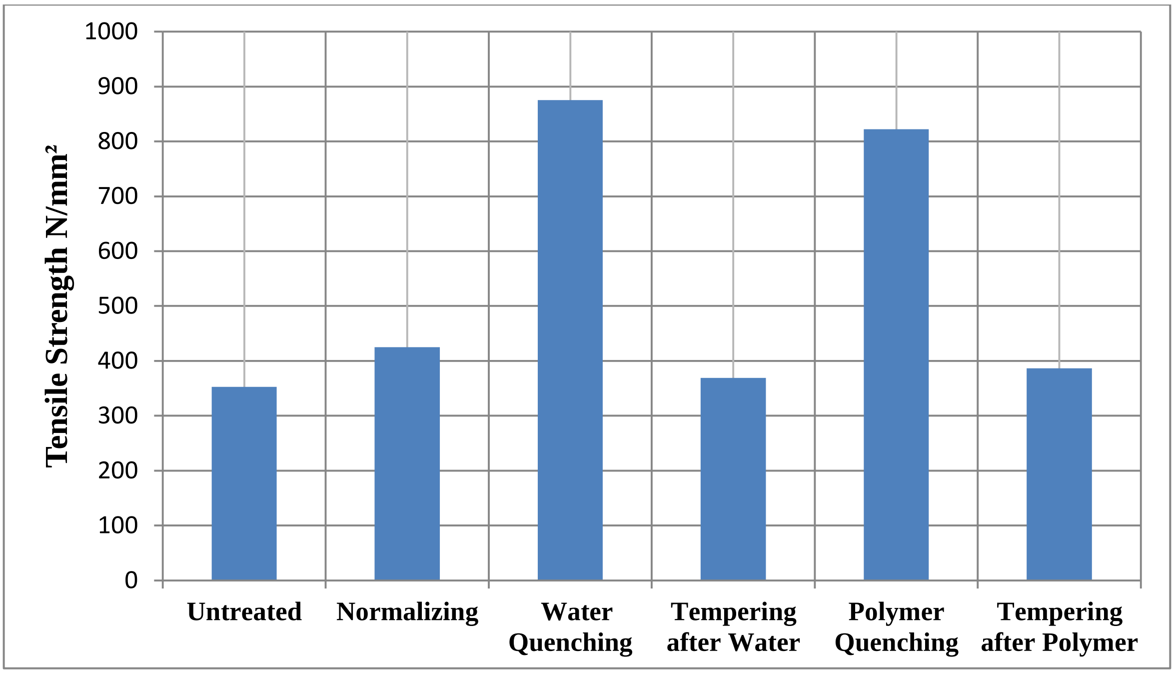

Figure 1; Tensile strength for untreated and heat treated samples

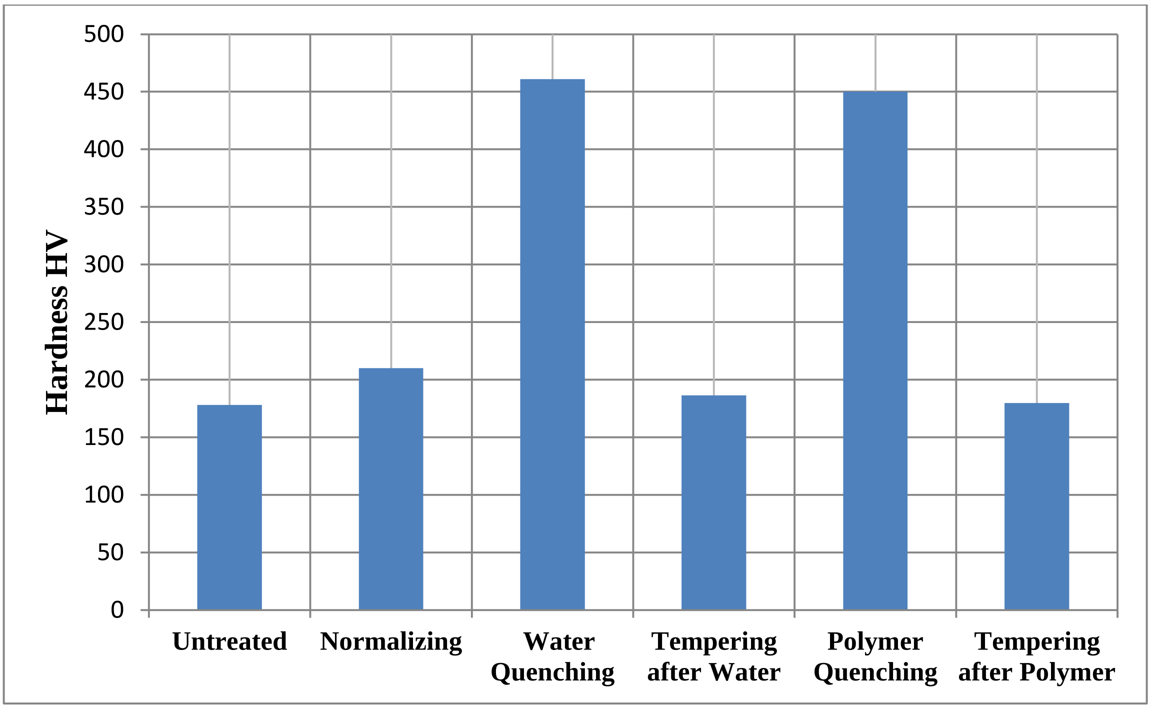

Figure 2; Hardness for untreated and heat treated samples

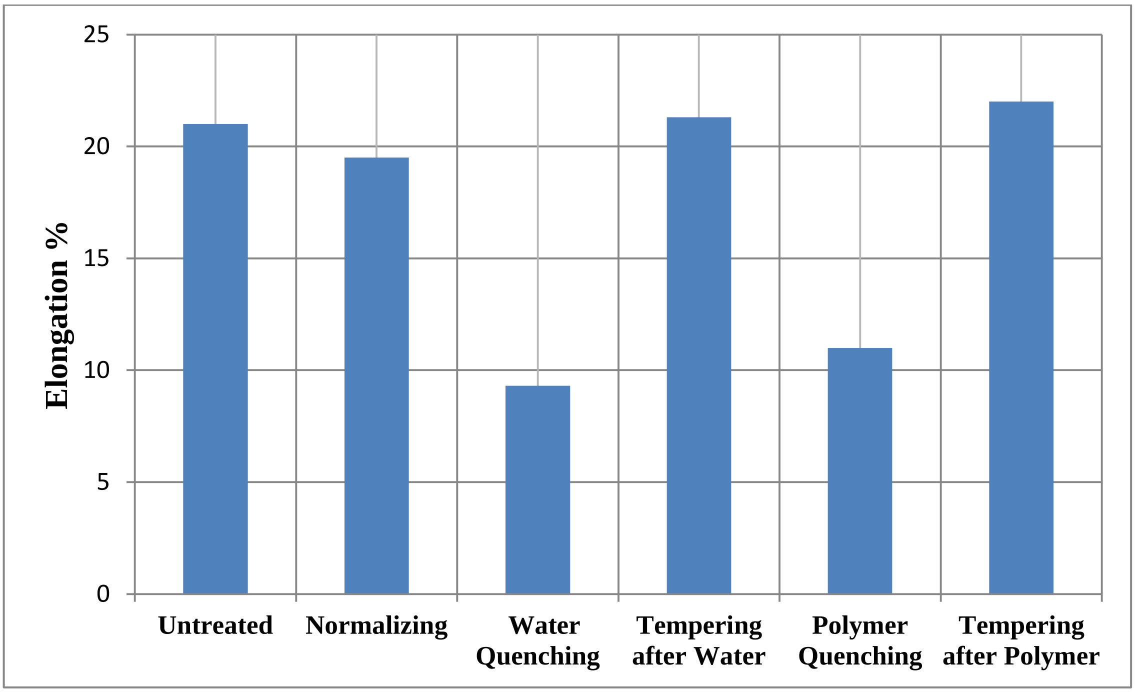

Figure 3; Elongation for untreated and heat treated samples

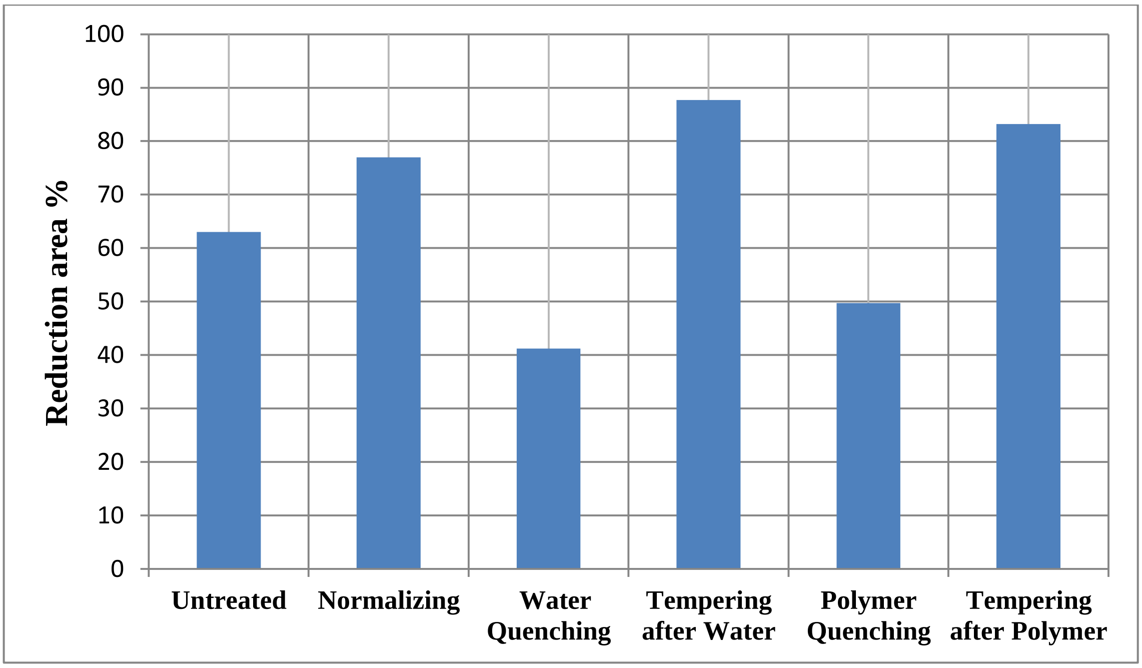

Figure 4; Reduction area for untreated and heat treated samples

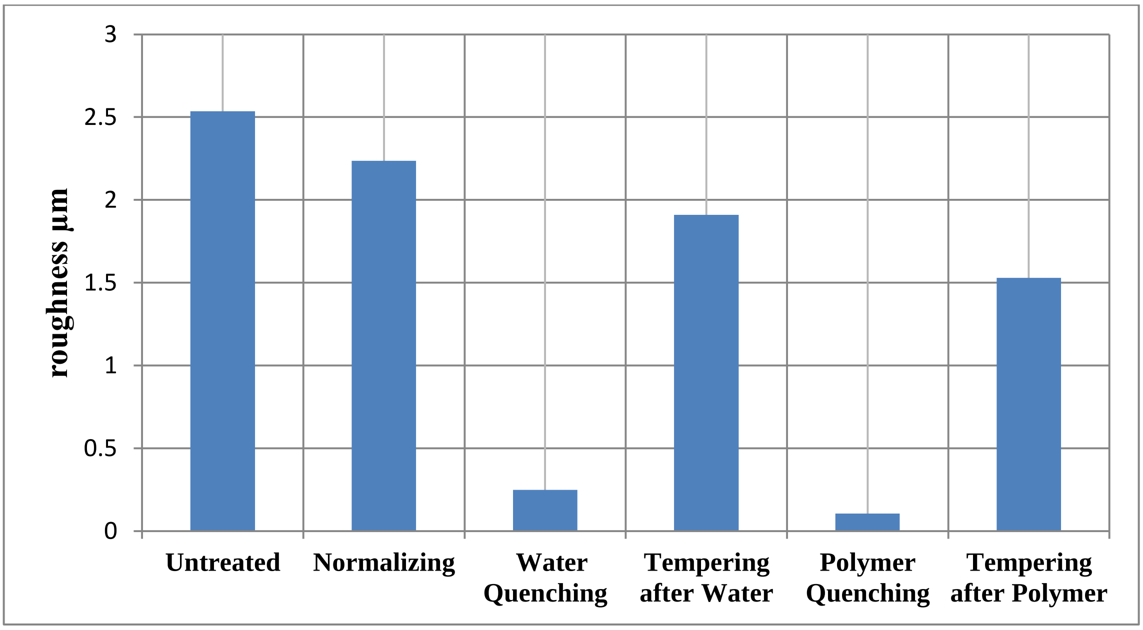

Figure 5; Roughness for untreated and heat treated samples

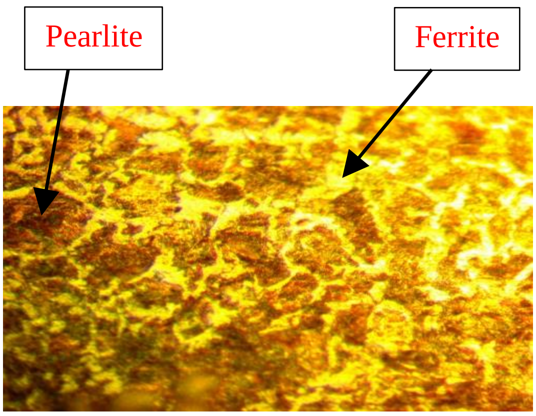

Fig.6; microstructure of untreated (80x)

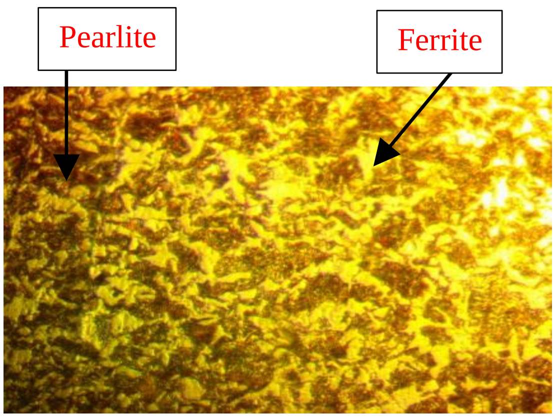

Fig.7; Microstructure of normalizing (80x)

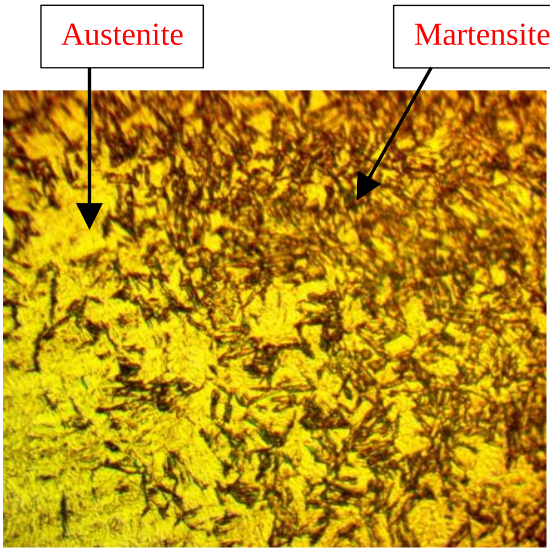

Fig.8; Water quenching (80x)

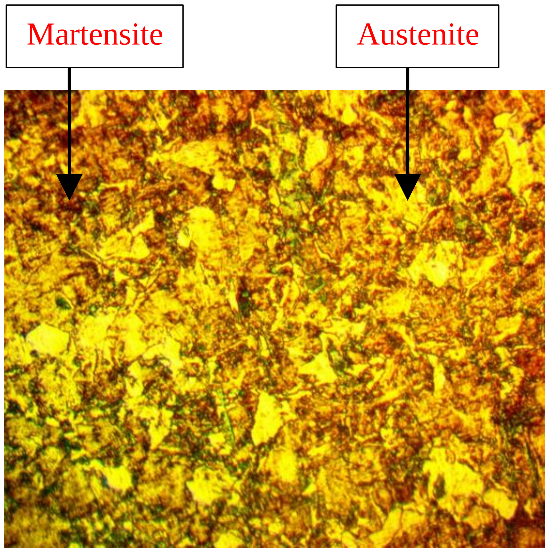

Fig.9; Polymer quenching (80x)

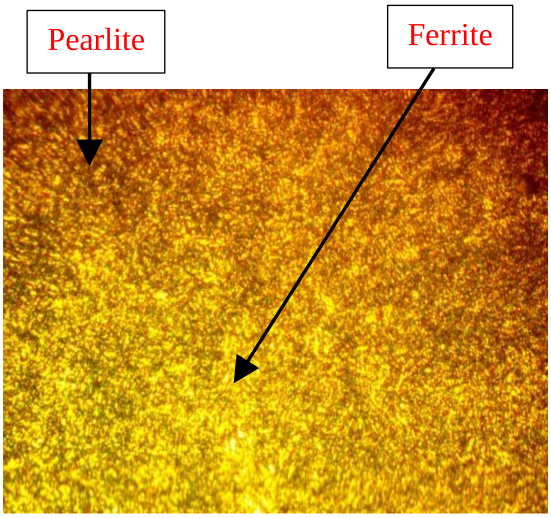

Fig.10; Water tempering (80x)

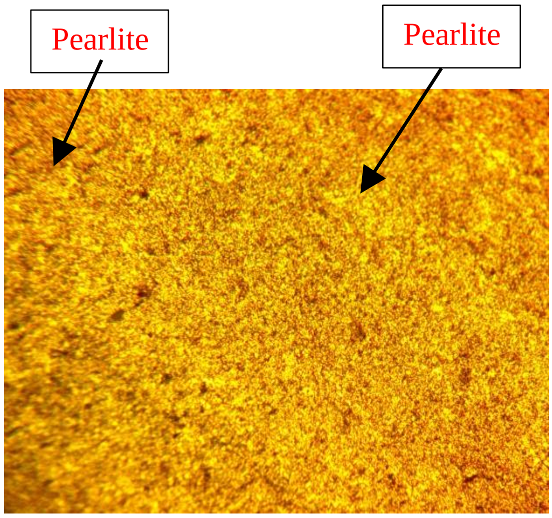

Fig.11; Polymer tempering (80x)

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