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# Evaluation of Quenching and Tempering on Cutting Force and Surface Finishing of Steel Machining

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**Abstract.** In this paper, quenching and tempering effects on the machining conditions of medium carbon steel were investigated. The samples were quenched in a saltwater and polymer solution after heated to austenitizing temperature at 870°C, then, the tempering process of the samples were conducted to reduce internal stresses and hardness. In the tempering process the samples were heated again to 400°C with a soaking time was one hour, so cooled in still air. So the samples were machined by lathe machine with selected cutting conditions. The results appeared the effect of heat treatments on hardness, surface finishing, cutting force and microstructure that were evaluated before and after heat treatment with various cutting conditions.

**Key words:** Quenching, Tempering, Cutting force, surface finishing, Medium Carbon Steel.

## 1. Introduction

The wear resistance and hardness AISI 1045 steel are required in manufacturing processes, especially with parts that have contact and friction applications such as gears. To investigate that aim, can be using the heat treatment processes was achieved, there are changes of microstructure and mechanical properties especially the hardness property [1]. Microstructure, hardness, yield strength and tensile strength of low carbon steel were tested after quenching by different types of water (cold, salt, boiled), all properties were improved after heat treatment processes were conducted. Medium carbon steel alloy was heat treated by various heat treatment processes to improve some mechanical properties such as hardness and impact strength, also has been improved a microstructure by change the size of the grains [2,3]. The best surface roughness of steel achieved by quenching and tempering processes due to increasing of ductility after reduced the brittleness. The effect of heat treatment was clear on other properties, such as impact strength and hardness, especially, with cold water were obtained [4].

Alloys of carbon steel properties altered by heat treatment and compare with three types of carbon steel (low, medium and high), the impact strength of low and medium carbon steel is increased with oil and water quenching, but the high carbon steel has different behaviour with quenching and no clear improvements were evaluated [5]. Selected mechanical properties of medium carbon steel such as



tensile strength, hardness, ductility and other, those related to cutting conditions and the machinability of that metal directly were achieved by heat treatment. In other words, the Strong and sturdy metal can be obtained by hardening process and softer and ductile metal is conducted with tempering to improve grain size. The heat treatment was changed of physical and mechanical properties of metal [6,7].

The surface roughness of AISI 4140 steel were decreased due to the effect of heat treatment more than 90% with different parameters of machining, in other words, the surface of the metal was improved with heat treatment. with lower cutting speed, the surface roughness were decreased and the improvement of surface was obtained, also at low rates of machining conditions the roughness were reduced, especially after the heat treatment [8].The best surface roughness of heat treated samples after machinability, so, the improvement of machinability with low cutting speed after heat treatment, but obtained the built up edge (BUE) for cutting tool can be appear. Hardness did not effect on cutting force and machinability, but with decreasing of hardness lead to roughness of surface [9,10]. Some parameters such as the geometry of tool, material type of workpiece and machining conditions, these have an important and direct effect on the quality of machining. They can change the tool life and material removal rate, which lead to poor machining if not good selected. The cutting conditions such as feed, speed and depth of cut have an effect on the finishing and cutting force [11,12,13].

To improve surface roughness can be used mall feed and depth of cut (DOC) at high cutting speed with wet machining, but at increasing of the feed the power consumption was decreased. The depth of cut with dry and wet machining has a clear effect on cutting force. On the contrary, the speed and feed have less effect on cutting force. In other words, the cutting speed and feed have less effect on material removal rates, but the depth of cut has effected more than them [14,15]. Generally, the feed and depth of cut have a clear effect on cutting force more than the cutting speed, the cutting force was increased with increasing depth of cut and feed, but it was decreased at high speed of cut, So, the cutting forces were increased with increasing of (DOC) for all materials. On the contrary, the cutting force was high at increasing in feed, depth of cut and cutting speed [16,17,18]. The cutting force was high with dry machining, but less with wet machining, it decreased with the tempering process for medium carbon steel. Also, after the annealing and hardening processes the surface machining was fine with dry machining because the chips shape was changed into discontinuous [19].

## 2. Work objective

Most of the previous studies were achieved the quenching by all types of water or oils, a few were dealing with the polymer solution. The quenching by oil and water were obtained by raping cooling of the metal that causes cracks in the structure. The present study, quenching was conducted by salt water and polymer solution (Polyethylene glycol M.W.400), so the tempering processes after quenching were achieved, then, compare between the results of them. It is known that cooling by polymer solution is rapidly at the beginning and slow at cooling end, which lead to uniform microstructure. So that can be taken the best results that suitable for machining, and therefore reducing the cutting forces that have an effect on a life of cutting tools by reducing the wear tools and surface finishing of metals, that main objective of this study.

### 3. Methodology

In this work, the heat treatment processes were achieved to some samples and left the others as untreated. The heat treatment processes were heated the samples and hold at heating temperature at soaking time, so quenched by two media (salt water and polymer solution), then tempering process investigated. The machining was conducted by lathe machine at the same selected cutting condition before and after machining. The test procedures before and after heat treatment were evaluated for hardness, microstructure, surface roughness and cutting forces.

#### 3.1. Heat treatment

The samples of medium carbon steel were heated till 870°C and left at this temperature for 45 minutes at a soaking time. The first group of samples was cooled by salt water, while the second group was cooled by the polymer solution to room temperature. The tempering process was performed in two groups at 400°C and a soaking time 45 minutes, then were cooled in outside of the furnace with air.

#### 3.2. Machining Processes

Machining processes were conducted for treated and untreated samples by lathe machine with specific parameters of cutting conditions. The parameters such as a fixed cutting speed at (120rpm), DOC (0.25, 0.50, 0.75mm), feed (0.04, 0.1, 0.18mm/rev.) respectively, were performed, all these parameters have been chosen according the type tests. The machining processes were dry and the tool of cutting was HSS were chosen for this study.

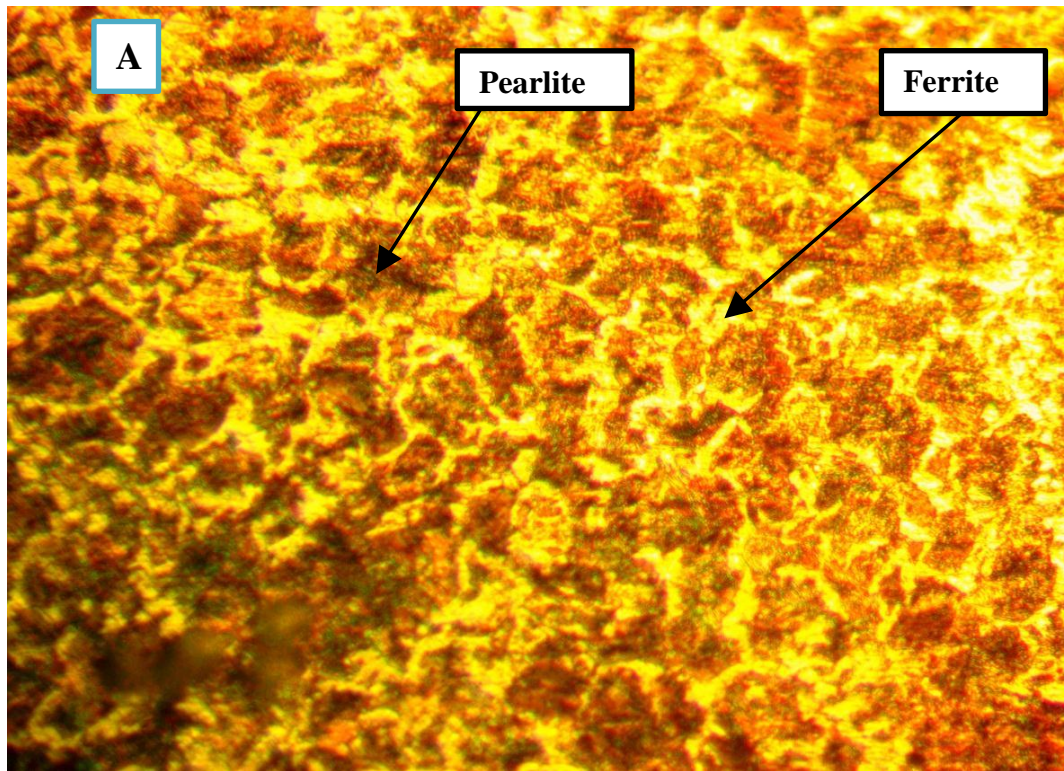
#### 3.3. Test Procedures

The tests were performed to four parameters as a fellow; microstructure was tested for surface of untreated samples, samples after quenching by salt water and polymer solution and tempering processes, the optical microscope images were obtained at magnifications of 40X by camera of optical microscope. Hardness was evaluated for samples before and after heat treatment by the tester (model HVS-1000). The surface roughness and cutting force were evaluated by devices (model: 210, TA620 Stand& column and IEICOS Multicomponent Digital Force Indicator- model 652) respectively. The examination of surface roughness and cutting force were investigated through the machining processes.

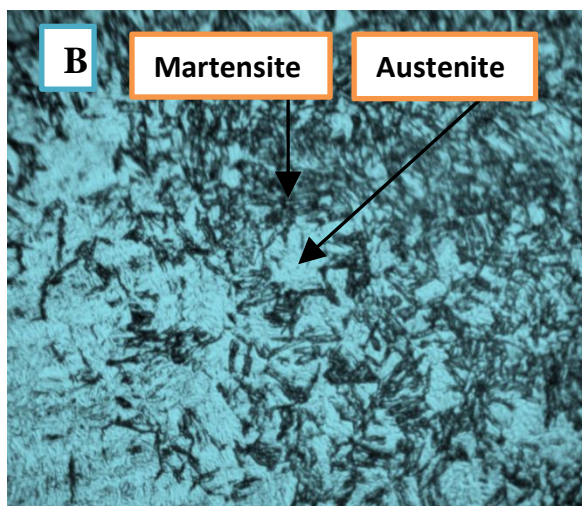
## 4- Results discussion

Microstructure of medium carbon steel for untreated and treated samples was observed in figure 1, two phases appeared in figure 1(A), dark colour (pearlite) more than the white colour (ferrite) for untreated samples. Figure1 (B, D), referred to the microstructure of quenching processes after heated to 870°C and cooled by salt water and polymer solution, respectively, in this case the structure has two phases, the needle shape refers to martensite (dark) and the other phase was austenite (white), with this process the structure has higher hardness (high brittleness) showed in table 1. In this case can be improved the toughness by heating to 400°C and cooled by air as tempering process. Figure 1 (C, E) showed the structure with uniform and soft granules of matensite (dark ) and reduced of ferrite (white) in the tempering process after quenching by salt water and polymer solution, that lead to increasing of toughness by reducing of brittleness and internal stresses.

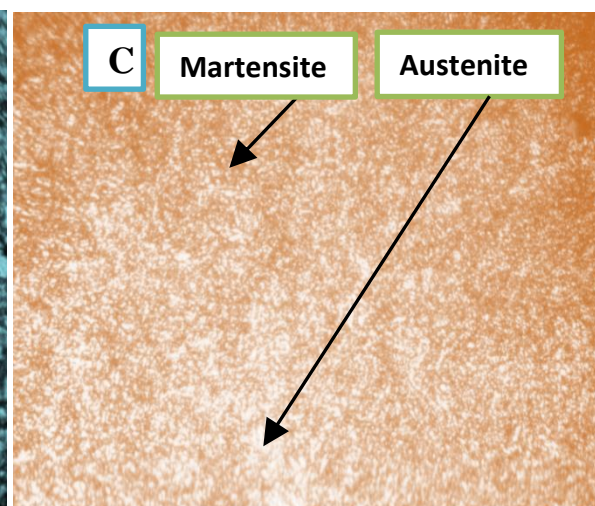




(A): Untreated 40X



(B) Water Quenching 40X



(E) Water Tempering 40X

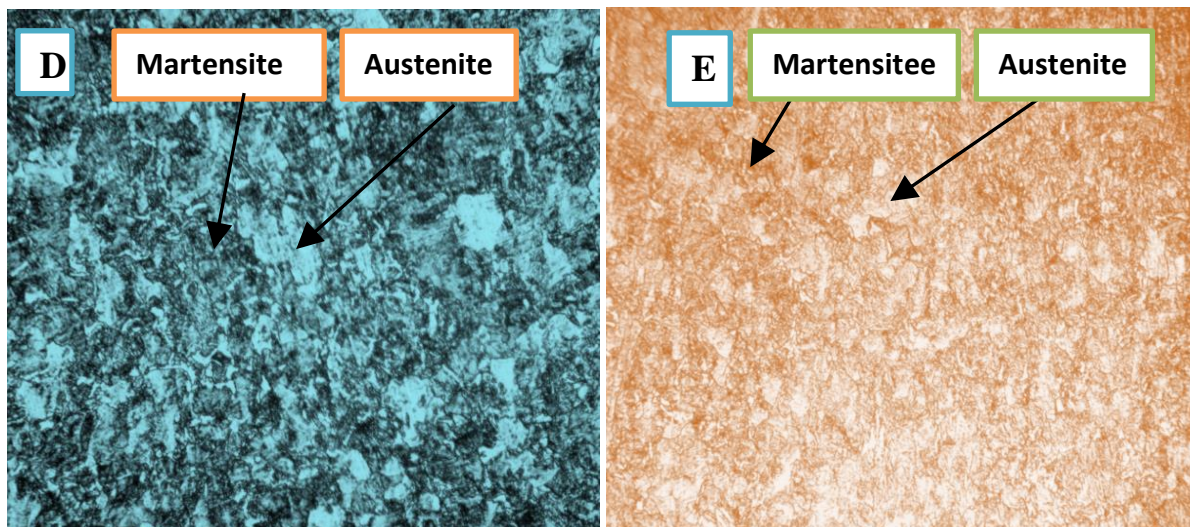
**(D) Polymer Quenching 40X****(E) Polymer Tempering 40X****Figure (1):** Microstructure of medium carbon steel before and after heat treatment.

Table 1 is observed the relation between the roughness of surfaces and parameters of machining such as speed, DOC, feed, speed was fixed at 120 rpm, it is also noted changes in value of depth of cut (0.25, 0.50, 0.75 mm) and feed (0.04, 0.1, 0.18 mm/rev). Best value of surface roughness ( $0.51 \mu\text{m}$ ) evaluated with DOC (0.25mm) and feed (0.04 mm/rev) at 120 rpm speed and dry machining, in other word, can be obtained good machinability with the tempering process (PT) after quenching by polymer at previous cutting conditions because the uniform and refine of structure grains. Also the values of roughness alter with change of cutting parameters for water quenching (WQ) and tempering (WT) after water quenching. Generally, there are the effects of heat treatment on surface finishing of medium carbon steel, tempering process after quenching was better than the quenching process for machinability, especially, after quenching by polymer solution (PQ) as showed in table 1.

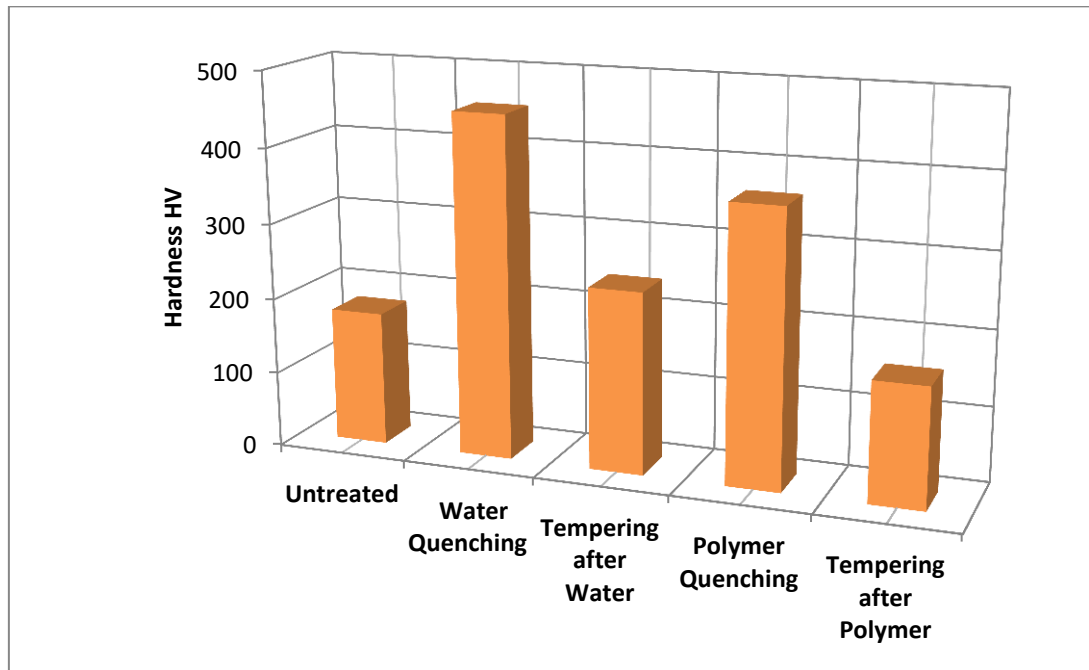
Table 1; Roughness results

<u>DOC</u> (mm)	Feed (mm/rev)	<i>Untr.</i> <i>Ra. (μm)</i>	WQ Ra. (μm)	<i>WT</i> <i>Ra (μm)</i>	PQ Ra. (μm)	<i>PT</i> <i>Ra. (μm)</i>
0.25	0.04	2.01	0.98	0.78	0.88	0.51
0.25	0.1	2.12	1.14	0.97	1.06	0.72
0.25	0.18	2.25	1.21	1.23	1.9	1.02
0.50	0.04	2.16	1.15	0.93	1.5	0.63
0.50	0.1	2.21	1.28	1.06	1.14	0.83
0.50	0.18	2.30	1.32	1.38	1.21	1.15
0.75	0.04	2.23	1.21	1.13	1.11	0.83
0.75	0.1	2.30	1.42	1.25	1.29	1.11
0.75	0.18	2.39	1.61	1.41	1.48	1.21

Figure2 showed the results of hardness tests before and after the heat treatment, the higher value (453HV) was with quenching by salt water due to the martensite grains, but the less value of hardness was (159HV) with the tempering process after quenching by polymer solution due to soft and uniform of structure grain and removing the internal stresses. Others values of hardness were as following;

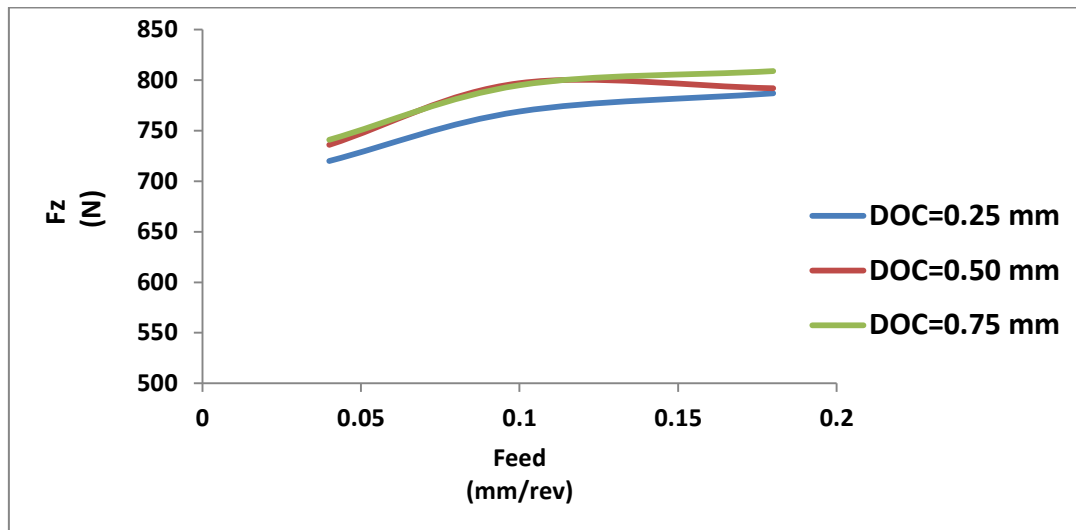


(178HV) of untreated samples and (241HV) for tempering after quenching by salt water. Generally, after quenching process can be increased the number of grain boundary due to reduced number of grains and decreased the space between the grains that leads to increase the hardness.



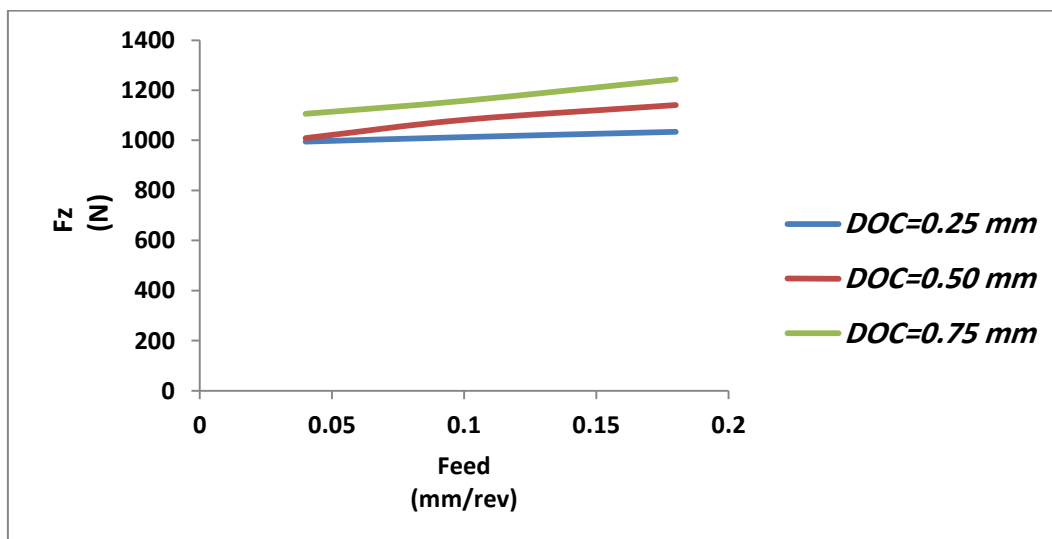
**Figure (2):** Results of hardness tests before and after the heat treatment.

Figures (3,4,5,6,7) appeared effects of heat treatments on cutting force ( $F_z$ ) at dry machining with fixed speed at (120rpm) and various feeds (0.04, 0.1, 0.18 mm/rev) and DOC (0.25, 0.50, 0.75mm) respectively. Figure 3 referred to cutting force at previous cutting parameters for untreated samples, which observed the higher value of cutting force was reached to (809N) with the DOC (0.75mm) and feed (0.18mm/rev), but the less value was (720N) at (0.25mm) of DOC and feed (0.04mm/rev) with dry machining.



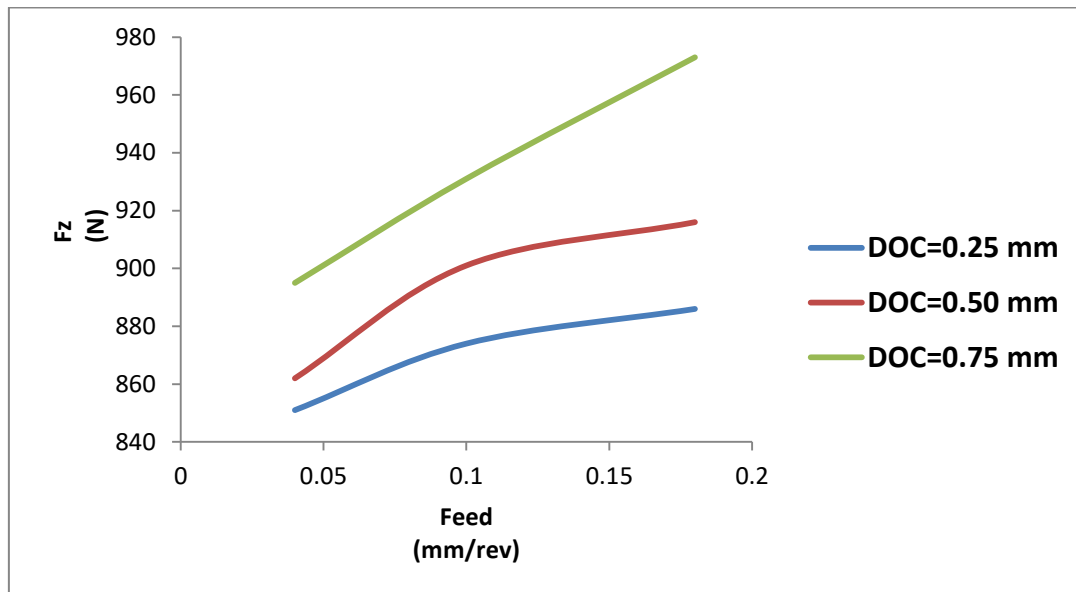
**Figure (3):** Cutting force ( $F_z$ ) vs. feed for untreated samples

Figure 4 showed the highest value of the cutting force ( $F_z$ ) recorded in this work, was (1244N) with the quenching of water due to highest the hardness and brittleness, that at a depth of cut (0.75mm) and feed (0.18mm/rev) and dry machining. But the less value of cutting force was (955N) at DOC (0.25mm) and feed (0.04mm/rev) in the same conditions of the process. Usually, the high hardness lead to increase the cutting force, for this reason, followed by the tempering process to reduce the hardness and to remove the internal stresses and improved the toughness; therefore reduce the cutting force, which observed in figure 5. Highest value of cutting force with tempering process after quenching by water was (973N) also at the DOC (0.75mm) and feed (0.18mm/rev) at fixed cutting speed (120rpm) and dry machining as showed in figure 5, although still highly by compare with tempering after quenching by polymer.



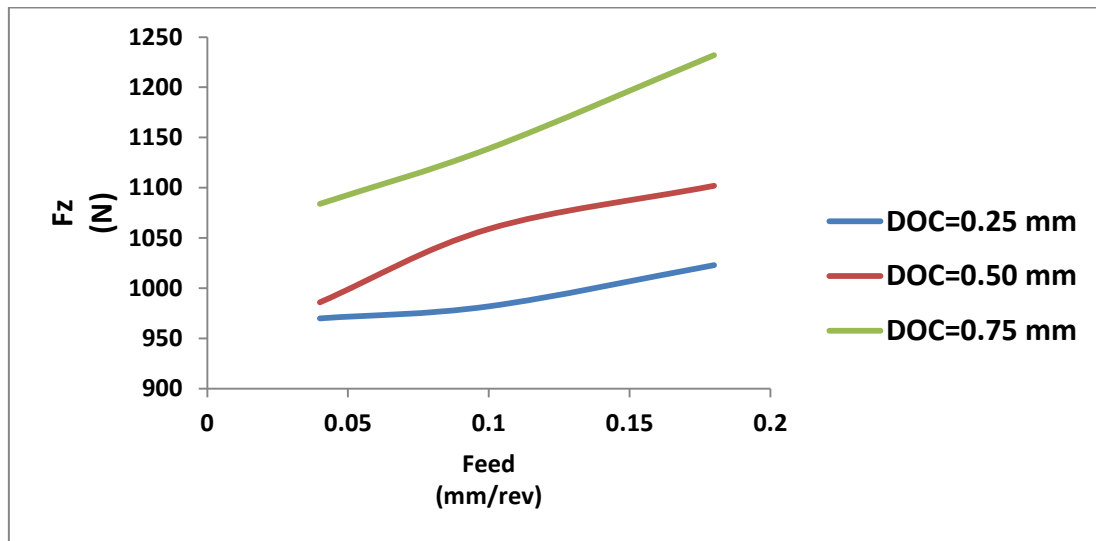
**Figure (4):** Cutting force ( $F_z$ ) vs. feed for water quenching process



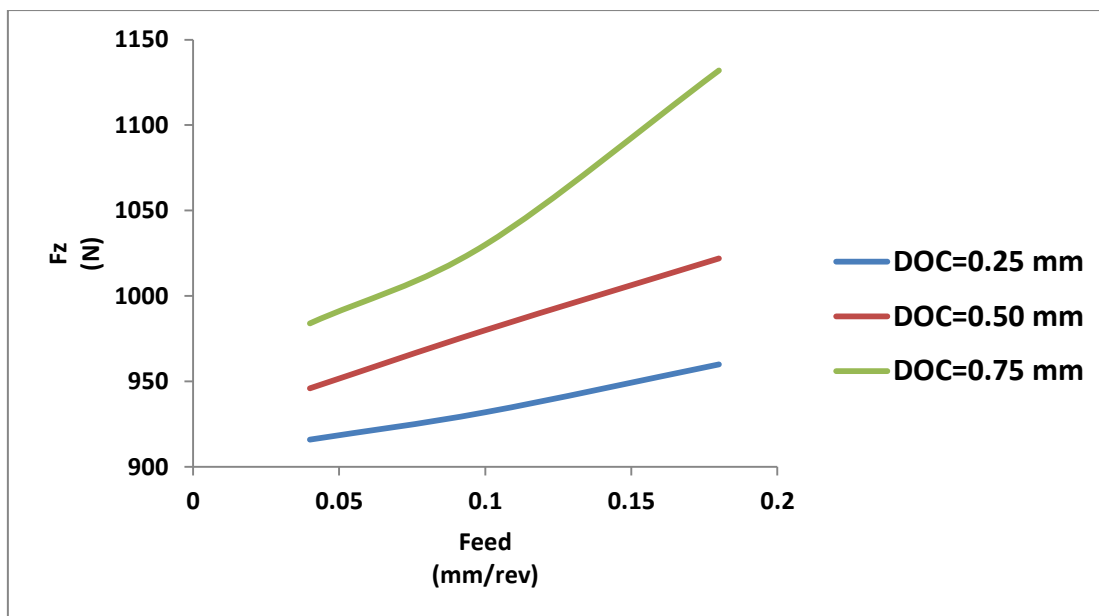


**Figure (5):** Cutting force ( $F_z$ ) vs. feed for tempering after water quenching

Figure 6 referred to results of cutting force after quenching by polymer solution, can be observed a clear change in highest and lowest value of cutting force, which were (1132N), (916N) respectively. But the results of the tempering process after quenching by polymer were much less than the results of tempering after water quenching, For highest and lowest values were (642N), (517N) respectively as shown in figure7. The huge different from values due to the rate of cooling, in other word, the cooling by polymer solution was uniform, but the cooling with water which rapid, that lead to brittle structure with internal micro cracks. That means the structural behaviour with cooling by polymer similar behaviour of the structure with normalizing process, which lead to soft structure grains with good toughness due to remove the deformation of ferrite with stable structure, also was reduced the brittleness. Generally, the best results of machinability with tempering after quenching by polymer, because the stable structure with refined grains and removing of internal deformation or stress in the structure were evaluated.



**Figure (6):** Cutting force ( $F_z$ ) vs. feed for polymer quenching process



**Figure (7):** Cutting force ( $F_z$ ) vs. feed for tempering after polymer quenching process

## 5- CONCLUSIONS

From the previous results can be concluded the following;

- 1- The improvement of machinability was obtained with heat-treated samples more than the untreated samples at all cutting conditions.
- 2- There are effects of heat treatment on roughness for all processes, the best results with tempering after quenching by polymer with less feed and DOC.

3- The highest value of hardness and brittleness was with quenching by water, but the machinability was poor.

4-The cutting force increases gradually at the increasing of feed and depth of cut with the cutting speed is fixed for all processes.

5- The microstructure after improvement by tempering was achieved best results of cutting force and roughness.

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