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THE EXPERIMENTAL STUDY ON THE MACHINING CONDITIONS OF HEAT TREATED MEDIUM CARBON STEEL USING CERAMIC CUTTING TOOL

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ABSTRACT

The current study shows the effect of various heat treatments on the cutting force and surface finishing of machining for medium carbon steel (0.522C) with different cutting conditions have been investigated. In this research, samples have been divided into two groups. Samples of the first group were heated to austenitizing temperature and quenched in a polymer solution (Polyethylene glycol M. W.400), followed by tempering. Tempering process is to reduce brittleness and relieve residual stresses. In this treatment, the samples were heated again to 450°C, held for one hour at that temperature (soaking stage), then cooled in still air. Samples of the second group were heated to austenitizing temperature and cooled by air (normalizing process). The cutting force and other properties were evaluated before and after heat treatment. The results showed a direct effect of heat treatments on cutting force and machinability. In other words, a correlation between the machinability and the heat treatment of specimens was established.

KEYWORDS: Cutting Force Heat Treatments, Surface Finishing, Medium Carbon Steel & Polyethylene Glycol M. W 400

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Original Article

INTRODUCTION

To achieve useful engineering applications, medium carbon steel is heat treated to make balance between its mechanical properties such as; hardness, strength, ductility, etc. That means, a harder and stronger metal is achieved with hardening. But, with softening processes, a softer and more ductile metal is obtained with improved toughness and refined grain size. That is, heat treatment of metals is done to change their physical and mechanical properties. The effect of heat treatment on the microstructure of metal is related to the machinability or the cutting parameters of that metal directly. Heat treatment has the ability to convert the mechanical properties such as toughness, ductility or strength of a material into other useful properties ([1], [2]).

The heat treated samples have better surface roughness than the non-heat treated after machining. Also, surface roughness improved with low cutting speed for samples after heat treatment. No effect of hardness on cutting force and machinability but arise the built up edge (BUE) at lower speed. While, decreasing the hardness leads to increase the surface roughness ([3], [4]).

There are some factors such as tool geometry, work piece and cutting conditions, which affect the performance measures and quality of machining. They can alter the material removal rate, tool wear and lead to poor surface finishing if not properly selected for that work. The feed and depth of cut (DOC) have an effect on the cutting force and surface roughness, but no significant influence on cutting speed ([5], [6], [7]).

Wet machining and high speed with decreased feed can be used to obtain an improvement of surface roughness. During wet cutting, cutting depth reduced to half. So, the power consumption decreases even if the feed is increased. Apparently, with wet and dry cutting the depth of cut has an effect on cutting force while the feed and cutting speed have less effect. Accordingly, the depth of cut has an important influence on materials removal rate, while cutting speed and feed rate have slightly less important influence respectively ([8], [9])

It was shown that the effect of depth of cut and feed rate on cutting force is larger than the effect of cutting speed with all results. On the other hand, with increasing feed and depth of cut, the cutting force increased but at high speed the cutting force decreased. For different materials, the increase of depth of cut led to increase the cutting force. On the contrary, the cutting force which was high with feed, and less with the depth of cut, also increased with increasing cutting speed using special cutting tool of turning ([10], [11], [12]).

It is known that the cutting force with wet cutting is less than that in dry cutting. It decreases after hardening and tempering processes of medium carbon steel. Consequently, annealed and hardened samples have fine surface finish after dry machining due to the chips is altered from continuous into discontinuous. Tempering and annealing processes give further easy cutting and fast deformation of chips, this leads to fine surface finish too [13].

Previous studies mentioned a big difference in results of cutting forces between quenching and normalizing processes due to rapid cooling with quenching in oil or water. In this study, quenching in polymer solution (Polyethylene glycol M. W.400) is used. Cooling rate, using this solution, is fast at the beginning and somewhat slows at the end. It is expected that the hardness results of normalizing and quenching are converged, leading toa direct effect on the machining operation, which is the main aim of this study.

EXPERIMENTAL PROCEDURE

The samples were made of medium carbon steel in this study. The samples were machined before and after heat treatment by a lathe machine with ceramic cutting tool using dry machining. The specific cutting parameters as cutting speed, depth of cut (DOC) and feed have been chosen according to type of test. Hardness test was conducted using (Digital Display Micro hardness Tester Model HVS-1000). Surface roughness measurements were achieved utilizing a testing device (Surface Roughness Tester, model: 210, TA620 Stand& column). Microstructure examination of the surface was obtained by a camera mounted on an optical microscope at magnification of60x. The cutting force was calculated by a device type (IEICOS Multi component Digital Force Indicator- model 652).

The process of heat treatment for the first group was heating the samples to the austenitizing temperature (850°C), and then directly followed by cooling in a polymer solution to room temperature, then heating to (450°C) with holding time of one hour inside the furnace. After that, cooling followed by still air to achieve the tempering process. The second group was heated to austenitizing temperature (850°C), and then cooled by still air as a normalizing process. The samples were held for 1 hour inside the furnace for the two groups during quenching and normalizing processes.

RESULTS AND DISCUSSIONS

The microstructure of medium carbon steel after heating above the critical temperatureA3 (800°C) is converted directly into austenite. However, with longer time of heating above this temperature, the hardness decreases due to larger grain size (Crystalline growth) accompanied by decrease in grain boundaries. When the carbon steel is quenched after heating above (A3), the hardness is increased with lowering strength due to the deformation of the ferrite. Naturally, ferrite absorbs (0.025% C), but in the quenched state, it is forced to absorb more than this ratio. It has now an unstable and deformed (BCC) crystal structure with low strength and difficult to operate. So, it is tempered to get soft granules, higher toughness and less brittle structure.

The microstructure of the base metal is revealed in figure (1, A). It shows an untreated sample structure which contains ferrite (bright regions) and pear lite (dark regions). The amount of pear lite is larger than that of ferrite. The hardness for this structure was 167HV as shown in table (1). Figure (1, B) shows the microstructure with ferrite and lamellar pearlite after heat treatment, when samples were heated to 850°C, then air cooled as normalizing process, with hardness 209HV. In figure (1, C), the samples were quenched from the austenizing temperature to room temperature rapidly in a polymer solution to obtain martensite structure. This structure has hardness up to274HV. Figure (1, D) shows the microstructure after tempering, and the hardness was 191HV.

The structure after normalizing process is much tougher than in any other heat treatment. The ferrite structure has fine grains and closer spaces of pear lite were formed due to the effect of cooling rate that is slower than cooling in a polymer solution. That led to improve the roughness (lower values) as shown in figure (3). Because the cooling was not fast enough, the carbon atoms would reform as ferrite from austenite and the refined grain structure; the toughness and machine ability improved with an increase in cutting force as feed and DOC increased compared to untreated samples illustrated in figure (2).

Usually, during quenching in polymer solution the atoms of carbon are diffusion due to formation of pear lite and the grains are smaller than that in normalizing. That leads to increase of grains boundary which increase hardness and therefore increase cutting force, figure (4), compared to normalizing. However, the roughness values were close to that of the normalized samples as seen in figure (4), because even though cooling was fast at the beginning it slowed at the end. That means the time of cooling with polymer solution was close to that of normalizing, which led to somewhat similar behavior of the two processes that reduced the brittleness and kept some toughness.

After quenching in polymer solution the metal must be tempered to improve toughness and reduce hardness. The result structure shows that the martensite changes to small deposits of spherical pear lite in the ferrite regions. Thus, lead to the toughness is improved due to the changes of martensite. Figure (5) shows the effect of tempering after quenching on machinability, hardness and surface roughness. There was a noticeable improvement in roughness and reduce in cutting force with the in feed and DOC, due to brittleness decrease and increase in toughness with tempering. Obviously, the tempering process removes the deformation of ferrite after quenching. In other words, convert the grains into uniformity and more stable structure.

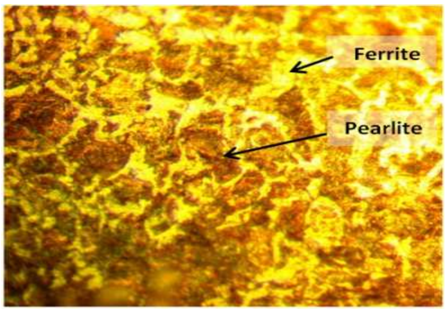
Generally, the results of roughness are improved with all heat treatments. On the other hand, the cutting force with quenching and normalizing processes is higher as hardness, feed and (DOC) increased, specially, at low cutting speed. Meanwhile, with increasing cutting speed, the cutting force decreased as showed in figure (6). The roughness values increased with increasing all parameters, figure (7), but it continued being less than that of the untreated samples. The best results of cutting force and roughness were with tempering process because the refined grains and removal of the deformation of ferrite.

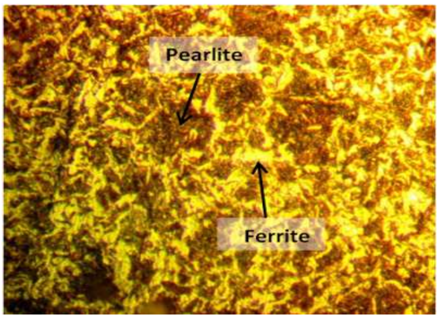
CONCLUSIONS

- The results obtained from this study can lead to the following conclusions;
- Normalizing has highest toughness compared to quenching and tempering processes , but has roughness values close to quenching because almost the same cooling time.
- Built up edge (B. U. E) is less with the quenched samples in wet cutting and discontinuity of the chips leads to decrease the cutting force and roughness despite the high hardness, but still not less than tempering and normalizing processes.
- The best results of cutting force and roughness were for the tempered samples due to improvement of the microstructure of medium carbon steel.
- The roughness is less with hardened material at low cutting speed, but the ductile tempered material needs high speed for less roughness.
- The improvement of surface roughness was obtained in heat-treated samples more than those of the untreated samples at all cutting conditions.

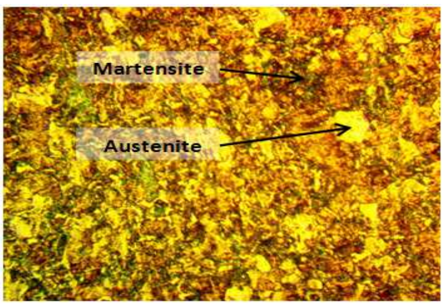
Table 1: Results of Hardness Tests before and after the Heat Treatment

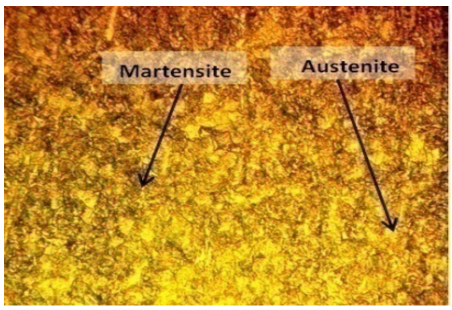
Property	Unheated	Normalizing	Polymer Quenching	Tempering
Hardness (HV)	167	209	274	191





(a) Untreated 6OX **(b) Normalizing 60X**





(c) Quenching 60X **(d) Tempering 60X**

Figure 1: Optical Microscope Images for Medium Carbon Steel after Each Heat Treatment

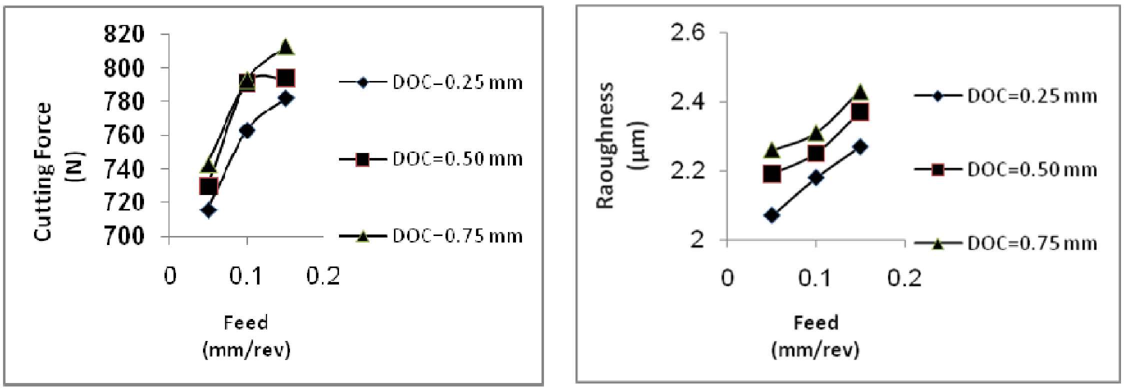


Figure 2: Cutting Force and Roughness Vs Feed for Untreated State at 100rpmspeed

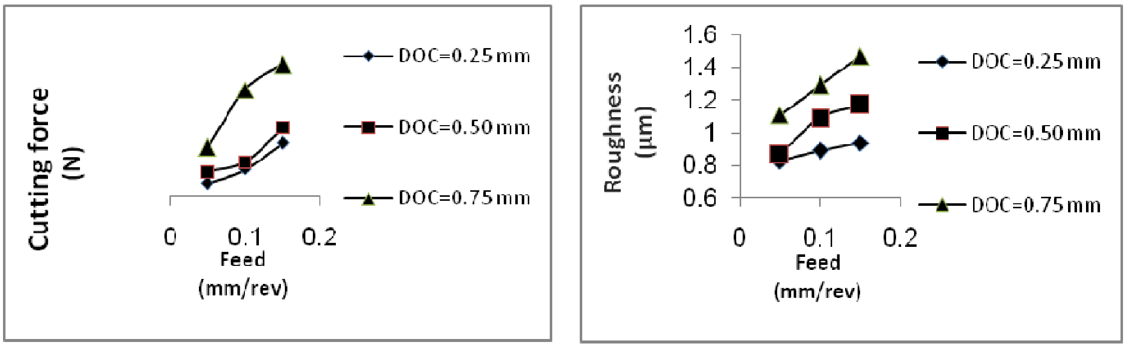


Figure 3: Cutting Force and Roughness Vs Feed for Normalized State at 100rpm Speed

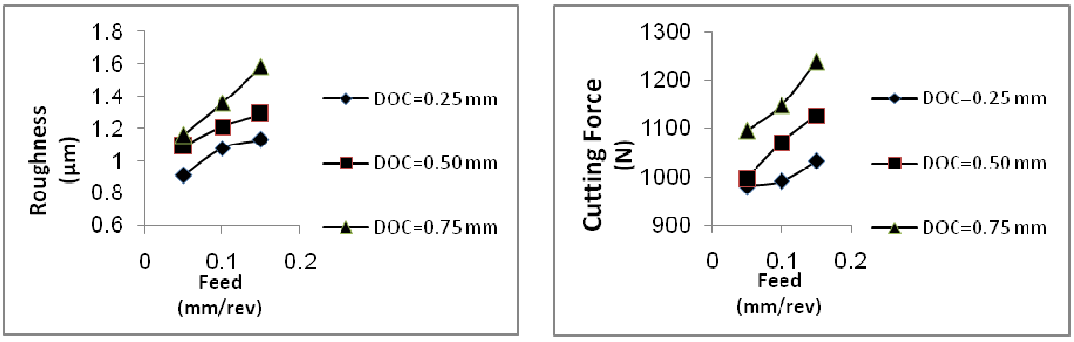


Figure 4: Cutting Force and Roughness Vs Feed for Quenched State at 100rpm Speed

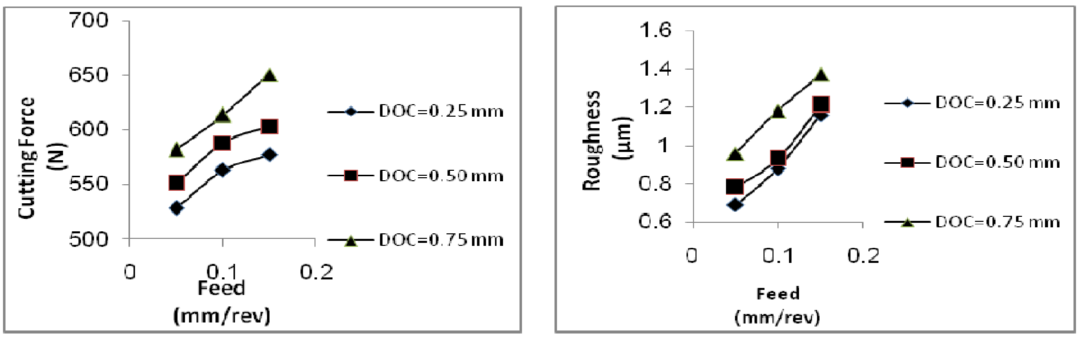


Figure 5: Cutting Force and Roughness Vs Feed for Tempered State at 100rpm Speed

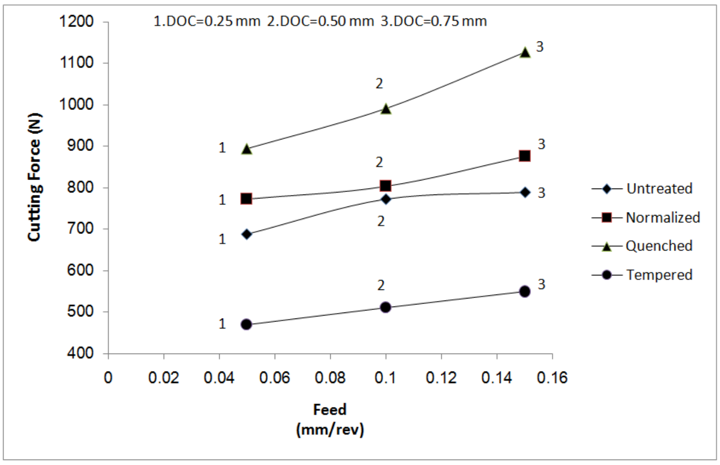


Figure 6: Cutting Force and Roughness Vs Feed for Quenched State at 100rpm Speed

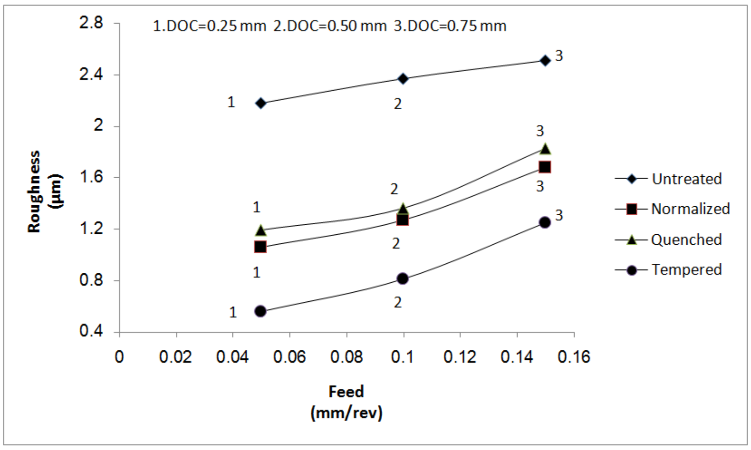


Figure 7: Roughness Vs Feed for Each Heat Treatment at 150rpm Speed

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