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Diamond Pressing on the Wear Resistance and the State of Heat Treated Alloy Steel Surfaces

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Abstract: In manufacturing processes, surfaces and their properties are as important as the bulk properties of the materials. Surface treatment is an important aspect of all manufacturing processes. It has been used to impart certain physical and mechanical properties, such as appearance, corrosion, friction, wear and fatigue resistance. Widely used methods of finishing treatment that create necessary parts with the given roughness usually do not provide optimum quality of the surface. Therefore, methods of surface plastic deformation (SPD) are used. One of the most effective representative is the diamond pressing. In this paper the effect of diamond pressing process with a different pressing force (50, 100,150,200,250) N on the state of heat-treated alloy steel surfaces was studied and the results of the experiments are presented. Enhancements on the micro hardness of the heat treated alloy steel surfaces that have been processed by diamond pressing up to the following percentages compared to the ground surfaces: 32, 28, 31 and 43% for D2, O1, H13 and 3115 hardened alloy steel surfaces, respectively. In addition, it has been shown that there is an enhancement on the surface quality of heat-treated alloy steel surfaces. The best enhancement of the average surface roughness (Ra) was 16.6, 45, 36 and 50% for D2, O1, H13 and 3115, respectively, which are heat-treated. For the microstructure analysis, micrograph of the processed surfaces of D2 heat-treated alloy steel was given. It has been shown that the depth of plastic deformed layer about 200 µm. Experimental scheme for wear testing of steel shaft in the friction couple type "shaft-cuff" and results has been given in this paper. It has been shown that Diamond pressing process has a considerable effect on the wear resistance of D2 heat treated alloy steel and it is concluded that the DPP has an improvement on the wear resistance of D2 heat treated alloy steel shaft that have been processed by diamond pressing relative to the ground shaft

Key words: Diamond pressing, micro hardness, micro roughness, microstructure, wear resistance

INTRODUCTION

In manufacturing processes, surfaces and their properties are as important as the bulk properties of the materials. It is important that the surface produced should be free of defects such as cracks, have no harmful residual stresses and not to be subjected to undesirable metallurgical changes[1]. Surface treatment is an important aspect of all manufacturing processes. It has been used to impart certain physical and mechanical properties, such as appearance, corrosion, friction, wear and fatigue resistance. Several techniques are available for modifying surfaces, they include mechanical working (grinding, honing, lapping …etc) and coating of surfaces, heat treatment, deposition and plating[2].

Widely used methods of finishing treatment that create necessary parts with the given roughness usually do not provide optimum quality of the surface. Therefore, methods of surface plastic deformation (SPD) are used. One of the most effective representative is the diamond pressing.

Diamond pressing process is considered as one of the surface plastic deformation methods (shot peening, roller burnishing ... etc.) and it is one of the effective finishing treatment methods in terms of stabilization of surface layers' properties along the depth [3], a field of which application is yet narrow. In comparison with other finishing treatment methods, diamond pressing has considerable advantages related to the physical and mechanical properties of diamond. Diamond is the hardest substance known (7000-8000 HK where; HK: Knoop Hardness micro hardness test [2]), by utilizing this characteristics, diamond could be used in pressing the hardest surface. Diamond pressing tool consists of spherical diamond tip, both of natural and synthetic diamond could be used in diamond pressing tools, the spherical diamond could be polished to Ra = 0.25-0.63 µm [3].

Materials, Equipment and Experimental procedure: In this study four different types of alloy steel have been studied, according to the AISI their designation are D2, O1, H13 and 3115 Table 1.

Specimens as shown in Fig. 1 were turned using single point carbide cutting tool and ground using a cylindrical grinding machine.

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Table 1: Chemical composition of D2, O1, H13, and 3115 alloy steel

Type: (AISI)	C wt %	Si wt%	Mn wt %	Cr wt %	Mo wt %	V Wt %	W wt %	Ni wt %
D2	1.55	0.3	0.4	11.8	0.8	0.8	–	–
O1	0.95	–	1.1	0.6	–	0.1	0.6	–
H13	0.40	1.0	–	5.30	1.40	1.0	–	–
3115	0.15	0.25	0.90	0.80	0.10	–	–	1.20

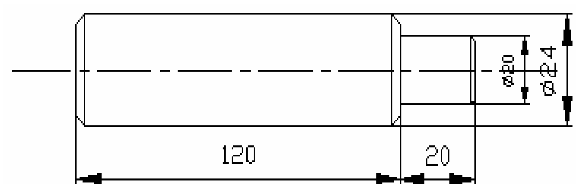

Fig. 1: Geometry of the work piece

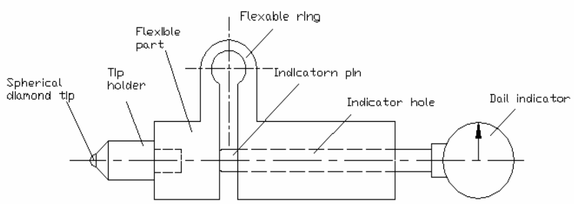

Fig. 2: The diamond pressing tool holder with spherical diamond tip(R=0.6mm)

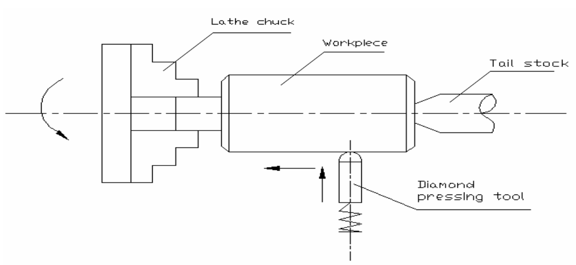

Fig. 3: Set up of the diamond pressing process

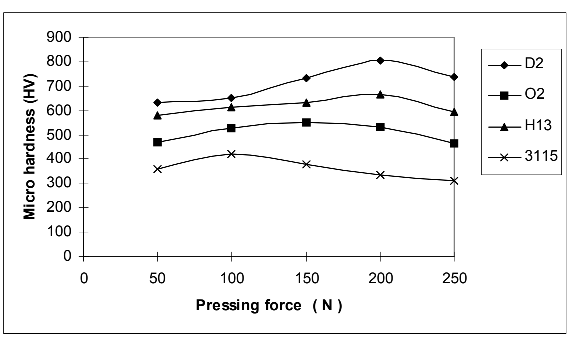

Fig. 4: Effect of diamond pressing force on the micro hardness of alloy steel (the initial micro hardness values of the D2, O1, H13 and 3115 alloy steel are: 611, 431, 505 and 294 HV, respectively)

By using DP tool with spherical diamond tip (R=0.6mm) with a special holder as shown in Fig. 2 and 3 the outside cylindrical surfaces of the specimens were pressed with the given parameters. Pressing force (P_p) = (50, 100,150, 200, 250) N, feed rate (f_p) = 0.04 mm rev^{-1}, Pressing speed (V_p) = 41.5m min^{-1}, Number of Passes (N_p) = 3. The work piece can be fixed in the lathe chuck while the diamond pressing tool is fixed on the tool holder. This holder contains a flexible part in order to ensure the necessary pressure applied on the work piece surfaces. While the work piece is rotating, the tool of diamond pressing operation moves (by sliding) upon the work piece surfaces by appropriate pressing feed rate.

RESULTS AND DISCUSSION

The effect of different pressing force (P_p) = (50, 100,150, 200, 250) N on the state of heat treated alloy steel surfaces was studied and the results of the experiments are presented and discussed.

Micro hardness: Hardness is one of the most important properties, which is commonly used to give a general indication of the strength and resistance to wear and scratching of a material. It can be defined as the ability of a material to resist permanent indentation when it is in contact with an indenter under load. For all specimens Vickers's microhardness was measured in both ground and pressed cylindrical surfaces using a Highwood HWDM-3 (TTS Unlimited Inc., Japan) instrument with (500g) load.

Figure 4 shows the effect of diamond pressing force on the micro hardness of alloy steels (the initial micro hardness values of the D2, O1, H13 and 3115 alloy steel are: 611, 431, 505 and 294 HV, respectively). It can be seen that there are an enhancements on the micro hardness of the heat treated alloy steel surfaces that have been processed by diamond pressing compared to the same surfaces that have been processed by grinding for the same specimen. In general, an increase in diamond pressing force up to about 100 N for 3115, 150 N for O1 and up to about 200 N for D2 and H13 alloy steels, leads to increase in micro hardness. With a further increase in diamond, pressing force micro hardness gradually decreases. This is because the pressure generated through the tool exceeds the yield point of the piece-part material. Also, from Fig. 4 it can be seen that, the best enhancement of the surface layer micro hardness was 32, 28, 31 and 43% for D2, O1, H13 and 3115 heat treated alloy steels, respectively

Surface roughness: Surface roughness is a term used to describe the surface irregularities, which is responsible to a great extent for the appearance of a surface and its suitability for an intended application of

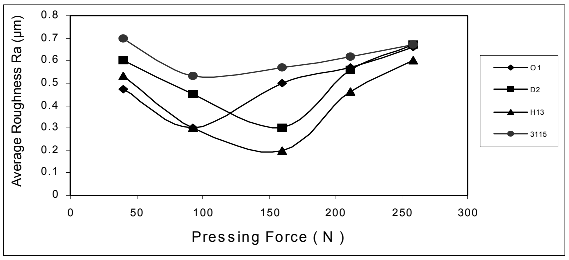

Fig. 5: Average surface roughness (µm) Vs. diamond pressing force (N). (The initial Ra values of the D2, O1, H13 and 3115 alloy steel are: 0.36, 0.66, 0.44 and 0.53 µm, respectively)

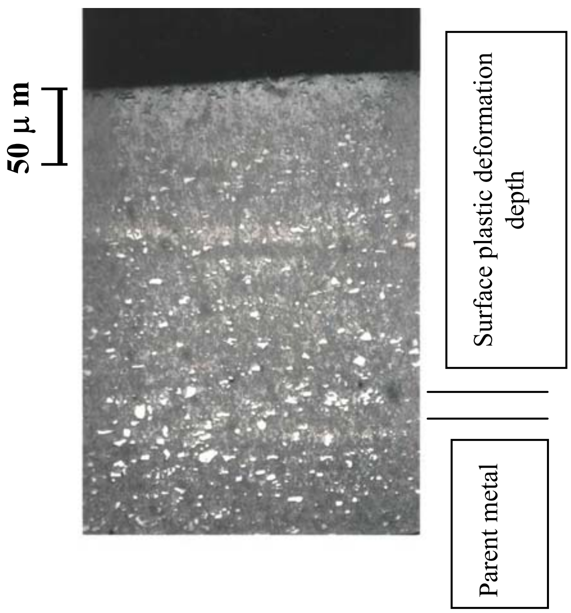

Fig. 6: A micrograph of the surface deformation of the D2 heat-treated alloy steel

the component. Surface roughness of a machined surface has an important effect on the functional properties and performance of machine parts Average surface roughness (Ra) test were performed using a MITUTOYO roughness tester. Tests were carried out in two positions at the specimens cylindrical ground and pressed surfaces, the average roughness (Ra) were measured at five different locations from which the (Ra) for each position was obtained.

Figure 5 shows the effect of diamond pressing force on the mean roughness (The initial Ra values of the D2, O1, H13 and 3115 alloy steel are:0.36, 0.66, 0.44 and 0.53 µm, respectively).. It can be seen that there are an enhancements on the surface roughness of the heat treated alloy steels that have been processed by diamond pressing, an increase in diamond pressing force up to about 100 N for 3115 and O1 and up to about 150 N for D2 and H13 alloy steels, leads to decrease in average surface roughness. With a further increase in diamond pressing force average surface roughness gradually increases. This is because of the increasing impact of the work piece surface in the contact area with the tool tip. Also, from Fig. 4 it can be seen that, the best enhancement of the average surface roughness (Ra) was 45% and 50 % for O1and 3115 heat treated alloy steels, respectively at pressing force 100 N, 16.6% for D2 and was 36% for H13 heat treated alloy steel at pressing force 150 N.

In general, the obtained enhancements of surface quality (Ra) can be explained in terms of the elimination of surface irregularities that occurred by the spherical diamond tip which slides along the cylindrical surfaces with pressing force.

Micro structure: Microstructure examination of a finished surface is an important analysis to be carried out. It is very useful, since it can provide important information about the material properties and reliability. It can show the surface cracks or other machining damage, improper machining cause transformation of the microstructure. So, microstructure examination is important in this investigation to show the effect of the DP on the surface microstructure as well as the plastic deformation depth. For microstructure analysis of low, medium and high carbon steel, A cylindrical part (test piece) with 25mm diameter and 15mm length was cut off from each specimen. The flat surfaces of the test pieces were ground by different grades of emery papers. After polishing the test pieces using a rotary polishing machine with the aid of diamond paste of 7 □m until achieving a surface like a mirror, the polished surfaces were etched by NITAL (97%CH_3CH_2OH, 3%HNO_3) etching solution for 15 sec. Finally, photographs of the microstructure with magnification of 200X were taken at the plastically deformed surface area and at the parent metal surface using a Nikon Epiphot 200 metallurgical microscope equipped with a digital camera. This Surface plastic deformation takes place in the surface layer of the carbon steel that occurred by the process of slipping the crystal structure of the surface layer and this can be seen in the deference of the microstructure of the deformed surface layer and the parent metal surface

For the microstructure analysis of D2 heat treated alloy steel, Fig. 6 shows a micrograph of the D2 surface that have been processed by diamond pressing (pressing force =200 N, feed rate = 0.4mm rev^{-1}, pressing speed = 41.5 m min^{-1} and number of passes (Np) = 3.), from this figure it was found that there is a difference between the structure of the deformed layer and the parent metal. Furthermore, the depth of the deformed layer (surface plastic deformation layer) was about 200µm.

Wear resistance: The wear resistance of D2 heat treated alloy steel was studied and the experimental scheme for wear testing of steel shaft in the friction couple type “shaft-cuff” and experimental results have

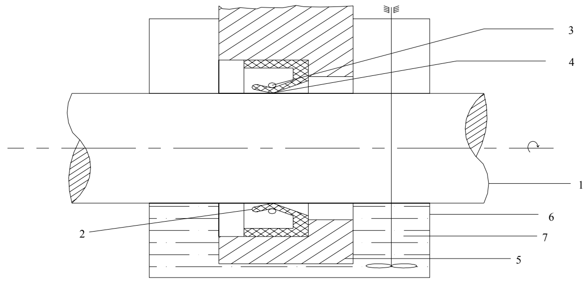

Fig. 7: Experimental scheme for wear testing of steel shaft in the friction couple type" shaft-cuff" (1- shaft, 2- cuff, 3- spring, 4- conjugate, 5- case, 6- Cartier, 7- Lubrication with 0.6 % abrasive particles {natural sand size 15-60 microns})

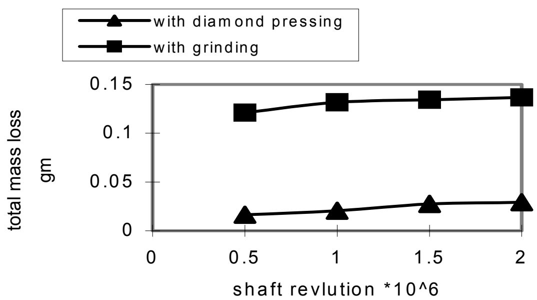

Fig. 8: Experimental abrasive wear results of D2 heat-treated alloy steel shaft (friction speed V==0.339m sec^{-1})

been given. Figure 7 and 8 show the experimental scheme using D2 heat-treated alloy steel shaft and the experimental results.

From Fig. 8 it can be seen that the loss of mass during all the testing process of the steel shaft that have been processed by diamond pressing (pressing force =200 N, feed rate = 0.4mm rev^{-1}, pressing speed = 41.5 m min^{-1} and number of passes (Np) = 3), less than the loss of mass of the ground shaft.

CONCLUSION

1. Diamond pressing process has a considerable effect, on the surface layer micro hardness of the heat treated alloy steels and the improvements on micro hardness of the heat treated alloy steel surfaces that have been processed by diamond pressing were up to the following percentages relative to the ground surfaces: 32, 28, 31 and 48% for D2, O1, H13 and 3115 hardened alloy steel surfaces, respectively.
2. For certain Diamond pressing parameters, it is concluded that the diamond pressing process has an improvement on (Ra) for all types of heat treated alloy steel surfaces.
3. Micro graphs of the processed surfaces of D2 heat-treated alloy steel show generally, that the depth of plastic deformed surface is about 200 µm.
4. Diamond pressing process has a considerable effect on the wear resistance of D2 heat treated alloy steel, it is concluded that the diamond pressing process has an improvement on the wear resistance of D2 heat treated alloy steel shaft that have been processed by diamond pressing relative to the ground shaft.

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