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Research Article

The Effect of Annealing Temperature and Roller Burnishing on the Microhardness and Surface Quality of AISI 3115 Alloy Steel

Ubeidulla F. Al-Qawabeha
Department of Mechanical Engineering, Faculty of Engineering, Tafila Technical University, Tafila, Jordon

Abstract: This study presents the effect of annealing and roller burnishing processes on the surface properties of AISI 3115 alloy steel. This steel was heat-treated at a temperature range of (700-850)°C, then left to cool inside the furnace. After that the steel was burnished with different forces, feeds and burnishing speeds. The microhardness, average surface roughness and microstructure were investigated. The experimental results of annealing revealed that hardness increases as the annealing temperature increase, where the burnishing results revealed that microhardness increases with increasing the applied force and feed. However, increasing the spindle speed increases the microhardness to certain limit. After that, any increase in spindle speed results in a decrease in the microhardness. The effect of burnishing process on the surface roughness was also studied. The results showed that surface roughness decreases with increasing of force and with feed up to certain limit and inversely with increasing of spindle speed.

Keywords: Burnishing process, heat treatment, microhardness, microstructure, surface roughness

INTRODUCTION

Some metal working process such as conventional machining methods (e.g., turning and milling) cannot provide the optimal quality of the surface. The resulted surfaces have inherent irregularities and defects like tool marks and scratches that cause energy dissipation (friction) and surface damage (wear). However, surfaces and their properties are as important as the bulk properties. Therefore, the surface should be free of defects and undesirable residual stresses. Surface treatment is used to improve some mechanical properties such as appearance, hardness, wear and fatigue resistance. There are many finishing processes used to produce surfaces with high quality. These processes could be classified into chip removal processes, such as grinding and chipless processes, such as burnishing.

Burnishing is an important cold-forming process; the principle of the burnishing process is based on an indenting tool (ball or roller) rolling against the workpiece's surface. Plastic flow of the original asperities occurs when the yield point of the workpiece's material is exceeded. In this way, asperities are flattened. Compressive stresses are also induced in the surface layer, giving several improvements to mechanical properties. Besides producing a good surface finish, the burnishing process has additional advantages over other machining processes, such as increasing hardness, improving corrosion resistance and increasing fatigue resistance as a result of producing compressive residual stress (Akkurt, 2011).

A literature survey shows that many works has been conducted on the burnishing processes. The studies showed that the burnishing processes improve the surface properties of the machined parts. The influence of burnishing process on surface roughness, hardness and microstructure of some non-ferrous metals was studied by Hassan and Al-Bsharat (1996). Hassan *et al*. (1998) optimized the effect of the burnishing force and number of tool passes, on surface roughness using response surface method. Hassan and Al-Dhifi (1999) used ball-burnishing tool to improve the wear resistance of brass components. They found that the burnishing process can be used to improve the wear resistance of the brass components. Luca *et al*. (2005) investigated the influences of certain burnishing parameters on roughness of hardened steel specimens. El-Axir and Ibrahim (2005) introduced a new burnishing tool. They used the center rest of a lathe as ball burnishing tool. The result of their investigation showed that the surface characteristics were improved with this burnishing tool. El-Tayeb *et al.* (2007) studied the effects of roller burnishing contact width and burnishing orientation on the surface quality and tribological behavior of aluminum 6061. El-Axir *et al.* (2008) constructed a new ball burnishing tool design to improve the out-of-roundness and microhardness of inner surfaces by internal ball burnishing process. El-Tayeb *et al.* (2008) studied the influence of roller burnishing process on hardness and roughness of cylindrical thermoset and thermoplastic polymers surfaces. They found that there is a good possibility of using the roller burnishing process as finishing process on the surfaces of polymers components and the effect of this process is more pronounced on thermoplastic than on thermoset. Al-qawabah (2011) studied the effect of roller burnishing on the surface roughness and hardness of Zn - 5% Al alloyed by copper at varied percentages. He found that there is an inverse relation between the depth of hardening and the copper content. The optimum surfaces occurs in Zamac5Z10% Cu alloy.

In present work, the effects of different annealing temperatures, on some mechanical properties and structures of commercial AISI 3115 alloy steel have been studied. After that, the annealed specimens burnished under different burnishing conditions. In particular, the effect of the burnishing force, feed and burnishing speed on the surface hardness and roughness have been studied.

MATERIALS EXPERIMENTAL PROCEDURE

Materials: AISI 3115 alloy steel was used as experimental work material. This material was selected because of the importance in industry. The chemical composition in weight percentage and the initial hardness are shown in Table 1.

Experimental procedure:

Specimens preparation: The steel specimens were received as bars of 20 mm diameter. The bars were sawn to four groups of specimens for 3115 AISI alloy steel with an approximate length of 240 mm.

Heat treatment process: In this experiment, the specimens of the alloy steel were annealed using different annealing temperatures according to the elements present in the alloy steel. Effects of the alloying elements on the lower critical temperature line (A_1) and upper critical temperature line (A_3) of $Fe-Fe_3C$ equilibrium phase diagram were calculated. For this study, the A_1 temperatures of AISI 3115 alloy steel were calculated to be 700°C. Each specimen of AISI 3115 alloy steel was heated to different temperatures, as shown in Fig. 1, with constant holding time of 35 min according to their diameters (20 mm), then it left to cool inside the furnace at a cooling rate of (100-150) °C/h.

Turning of specimens: Specimens after treated thermally must be turned to remove the oxidation layer on their surfaces, in this study the specimens turned to diameter of 18 mm according to the optimum cutting conditions of turning operations for annealed AISI 3115

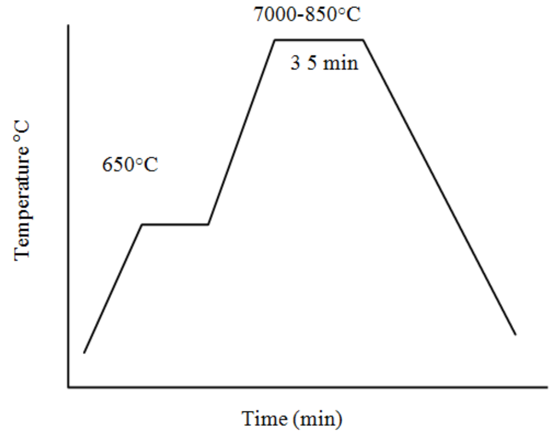

Fig. 1: Annealing regimes of AISI 3115 alloy steel

alloy steel shown in Table 2 with using suitable cutting fluid for all cutting operations.

Roller burnishing process: The tool used in the study is shown in Fig. 2. The tool contains a flexible part in order to ensure that the necessary pressure is applied on the workpiece surface. The tool was inclined at 45° from the axis of the holder to keep contact between the workpiece and the tool to a minimum. While rotating, the burnishing roller moves along the workpiece surfaces by an appropriate pressing feed rate. The burnishing tool was previously calibrated to use necessary load corresponding to the indicator reading.

The specimens were fixed in the lathe machine chuck and the burnishing tool clamped on the tool post of the lathe machine as shown in Fig. 3.

The effect of different burnishing parameters on surface roughness and hardness were studied in this study, namely; spindle speed, burnishing feed and burnishing force.

Surface roughness and hardness testing: Microhardness and roughness values of all specimens' regions surfaces were determine by using (microhardness machine tester model HWDM-3) and (sursoorder, SE3500) respectively before and after burnishing operation.

Microstructure testing: In this study, the microstructures of AISI 3115 alloy steel specimens were tested, to study the effect of heat treatment on the microstructures of different temperatures. The surfaces of the test piece are 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 μ m until achieving a mirror surface, the polished surfaces are etched by NITAL etching solution for 15 s. Finally, photographs, with magnification of 200×, of the microstructure are taken using a Nikon Epiphot 200 metallurgical microscope equipped with a digital camera.

Fig. 2: Roller burnishing tool

Table 1: 3115 Alloy steel initial hardness and chemical compositions

AISI alloy steels	Hardness HV	%C	%Si	%Cr	%W	%Mn	%Mo	%V
3115	228	0.15	0.25	0.8	1.2	0.9	0.1	-

Fig. 3: Roller burnishing process on lathe machine

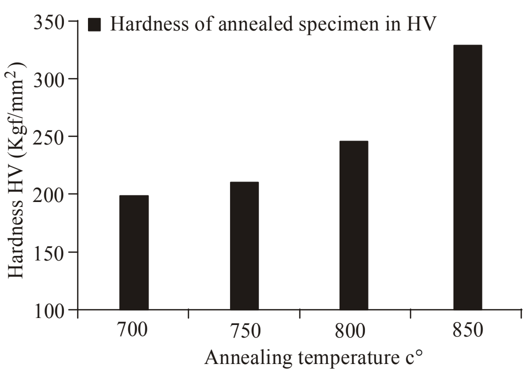

Fig. 4: The effect of annealing temperatures on hardness of AISI 3115 alloy steel

Table 2: Optimum cutting conditions

Materials AISI	Cutting velocity (m/min)	Feed (mm/rev)	Depth of cut (mm)	Cutting tool material
3115 alloy steel	34	0.18	1	HSS

RESULTS AND DISCUSSION

The effect of annealing temperatures on hardness of 3115 alloy steel: It can be seen from Fig. 4 that the alloy steels hardness was increased by increasing the annealing temperature. Where the heat treatment temperatures for AISI 3115 alloy steel is 700°C. When the alloy steels heated to its heat treatment temperatures, the structure then contains proeutictoid ferrite with inhomogeneous austenite for AISI 3115 alloy steel. The microstructure then may contain relatively inhomogeneous coarse lamellar pearlite with a proeutictoid phase.

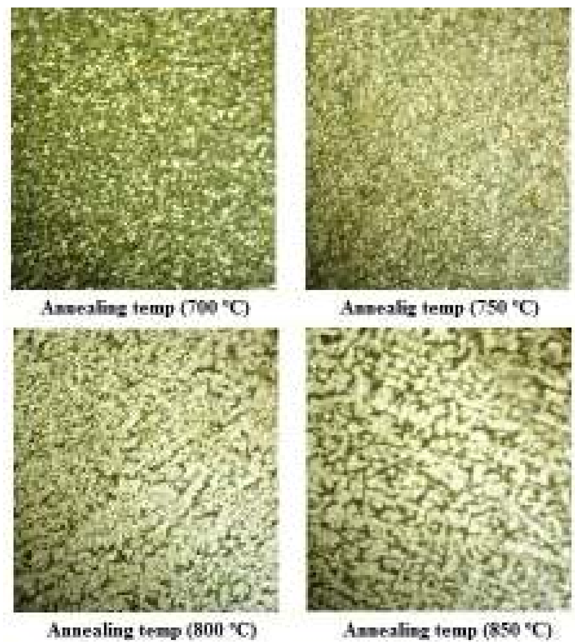

Fig. 5: The effect of annealing temperature on the homogeneity of AISI 3115 alloy steel structures, X200

To explain the previous results, we studied the structure of AISA 3115 alloy steel specimen under the different annealing regions. For intercritical treatment temperatures, the homogeneity of the austenite depends on time and temperature. And while the holding time is constant for all treatments the more homogeneous structures developed at higher austenitizing temperatures tend to promote lamellar carbide structures on cooling, as seen in Fig. 5. So by increasing the annealing temperature the product then may contain Fe_3C layers relatively thin and homogeneous and that harder than coarse lamellar pearlite.

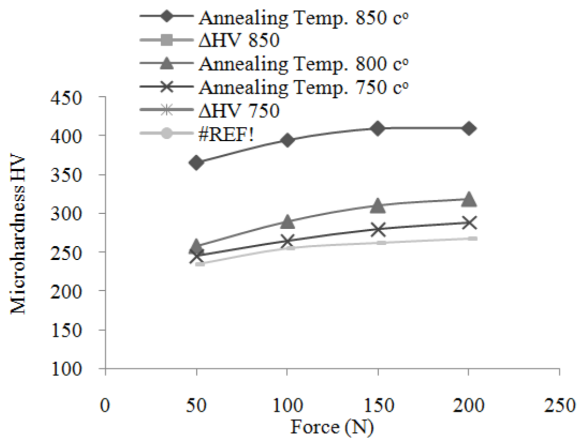

Fig. 6: The effect of the roller burnishing force on the microhardness of annealed AISI 3115 alloy steel (where is the feed = 0.04 mm/rev and Spindle speed = 260 rev/min)

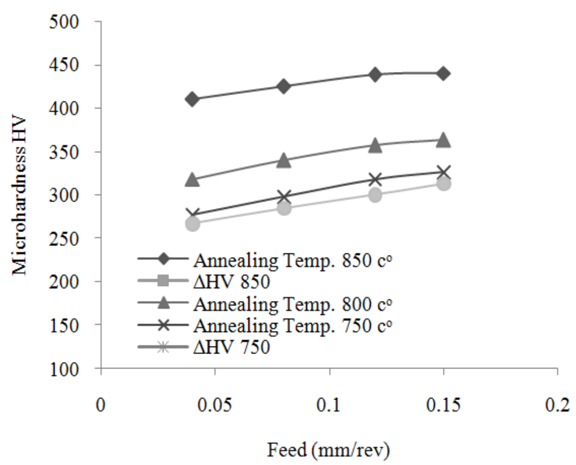

Fig. 7: The effect of the roller burnishing feed on the microhardness of annealed AISI 3115 alloy steel (where is the Force = 200 N and Spindle peed = 260 rev/min)

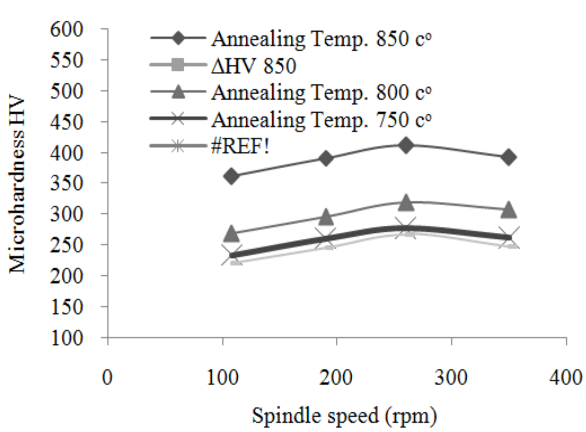

Fig. 8: The effect of the roller burnishing spindle speed on the microhardness of annealed AISI 3115 alloy steel where is the Force = 200 N and (feed = 0.04 mm/rev)

The effect of roller burnishing on microhardness of AISI 3115 alloy steel: It can be seen from Fig. 6 that the microhardness was increased by increasing the burnishing force by range of (50-200) N for the AISI 3115 alloy steel. The best result obtained at 200N burnishing force for all annealed AISI 3115 alloy steel temperatures. Where the maximum force (200 N) generates a maximum number of dislocations and maximum volume of plastic deformation in direction of specimens' core and that gives maximum microhardness.

It can be seen from Fig. 7 that the microhardness was increased by increasing the burnishing feeds over range of (0.04-0.15) mm/rev for AISI 3115 alloy steel. While increasing feed increases the force in direction parallel to specimen axis and that causes plastic deformation in the same direction. And where increasing of force increases the number of generated dislocations the microhardness of the AISI 3115 alloy steel increases.

It can be seen from Fig. 8 that the microhardness was increased by increasing the roller burnishing spindle speed by range of (108-260) rpm. After that, any increase in spindle speed more than 260 rpm results in a decrease in the microhardness. Increasing of spindle speed more than 260 rpm increases the volume of plastic deformation rate, thus the material does not take a suitable time to deform plastically.

The effect of roller burnishing on surface roughness of AISI 3115 alloy steel: The initial average surface roughness of AISI 3115 alloy steel specimen were 1.02, 1.14, 1.2 and 1.3 that annealed at 700, 750, 800 and 850°C, respectively It can be seen from Fig. 9 that the average surface roughness was decreased by increasing the roller burnishing force over range of (50-200) N for the AISI 3115 alloy steel. The best result obtained at 200N burnishing force for all annealed AISI 3115 alloy steel temperatures. Where the maximum force (200 N) causes a maximum volume of plastic deformation in direction of specimens' core and that gives the maximum elimination of the surface irregularities in same direction.

It can be seen from Fig. 10 that the average surface roughness was decreased by increasing the roller burnishing feed over range of (0.04-0.12) mm/rev and increased over range of (0.12-0.15) mm/rev for the 3115 AISI alloy steel. Where increasing the feed increases the volume of plastic deformation in the feed direction and that increases the elimination of the surface irregularities to some limit. After that any increasing in burnishing feed increases the volume of plastic deformation, which makes tearing in the deformed surface material and that increases the average surface roughness as occurred over range of (0.12- 0.15) rpm.

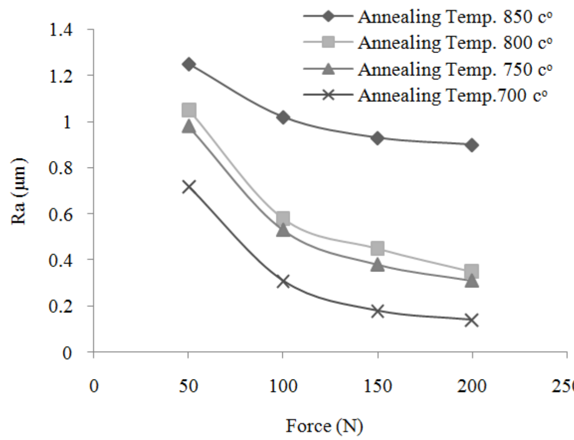

Fig. 9: The effect of the roller burnishing force on the average surface roughness of annealed AISI 3115 alloy steel (where the feed = 0.04 mm/rev and Spindle speed = 260 rev/min)

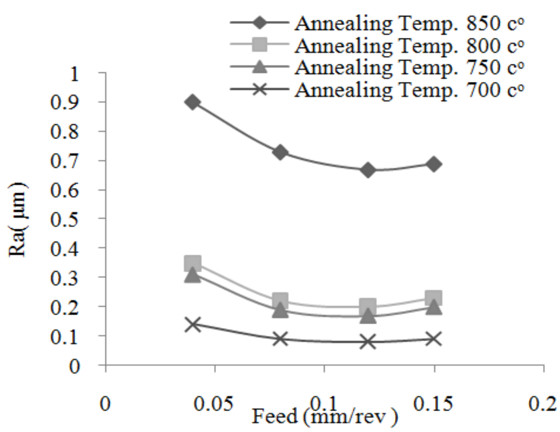

Fig. 10: The effect of the roller burnishing feed on the average surface roughness of annealed AISI 3115 alloy steel (where is the Force = 200 N and Spindle speed = 260 rev/min)

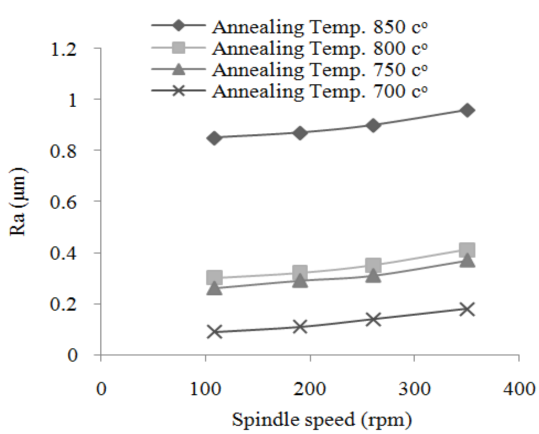

Fig. 11: The effect of the roller burnishing spindle speed on the average surface roughness of annealed AISI 3115 alloy steel (where is the Force = 200 N and feed = 0.04 mm/rev)

It can be seen from Fig. 11 that the average surface roughness was increased by increasing the roller burnishing spindle speed over range of (108-350) rpm for the AISI 3115 alloy steel. Where increasing the spindle speed increases the volume of plastic deformation rate, thus the materials didn't take the suitable time to deform plastically which makes tearing in the deformed surface material and that increases the average surface roughness.

CONCLUSION

The effect of annealing and roller burnishing processes in some surface properties of AISI 3115 alloy steel was studied. The following points can concluded from the experiment results:

- The output responses of the burnished surface are mainly influenced by the four parameters used, namely: burnishing speed, burnishing feed, burnishing force and initial hardness of the specimens. The burnishing force, feed and speed can change the surface properties significantly, thus they can be considered important input parameters in burnishing process.
- The initial hardness of specimen plays a significant role in controlling the results of burnishing process. There are many interactions between initial hardness of material and other parameters used in this study.
- An increase in burnishing force leads to a considerable increase in the surface microhardness and decrease in the average surface roughness, over range of (50-200) N.
- An increase in burnishing speed leads to an increase in the microhardness, by range of (108-260) rpm.
- An increase in burnishing feed leads to an increase in microhardness, over range of (0.04-0.15) mm/rev and decrease the average surface roughness, but the subsequent increase of burnishing feed (more than 0.12 mm/rev) gets worst average surface roughness.
- An increase in annealing temperature leads to a considerable increase in the structure homogeneity and hardness of alloy steels.
- The increasing percentage of microhardness decreases with increasing of burnishing force, feed and spindle speed.
- The average surface roughness depends on the initial value for each specimen. But in general, it decreases with increasing burnishing force and with feed to some limit. Increasing of burnishing increases the average surface roughness.

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