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Surface Structure Improvement of Mild Steel and Aluminium by Roller Burnishing

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ABSTRCT

In an experimental analysis study, a mix of burnishing parameters was varied to obtain the optimum roller conditions that produce superlative surface smoothness and hardness. The analysis was undertaken on roller burnished mild steel and aluminium using a purpose designed and manufactured tool. The effects of burnishing parameters on both the surface roughness and hardness of mild steel and aluminium work pieces materials were observed and analysed. The parameters included; burnishing speed, feed, force and the number of the tool passes. The results indicated that, depending on the work piece material, surface finish and hardness improvements of around (75%) and (50%) respectively were obtainable at optimum values of the mentioned parameters.

Keywords: Roller burnishing; Burnishing parameters; Surface roughness; Surface hardness.

تحسين هيكل السطح لفولاذ الطري وألمنيوم بواسطة الصقل الاسطواني

الخلاصة

في دراسة عملية تحليلية , تم تغيير مزيج مؤشرات الصقل لغرض الحصول على شروط الصقل الاسطواني الامثل التي تنتج افضل نعومة وصلادة سطحية. اجري التحليل على عينات من الفولاذ الطري والألمنيوم التي تم صقلهما اسطوانيا باستعمال اداة صقل تم تصميمها و تصنعيها لهذا الغرض.

تم ملاحظة و تحليل تاثير مؤشرات الصقل والتي شملت سرعة الصقل, التغذية, القوة وعدد مرور الاداة على كل من خشونة السطح والصلادة السطحية لمشغولات الفولاذ الطري و الالمنيوم . اشارت النتائج أنه، واعتماداً على مادة قطعة العمل, يمكن الحصول على حوالى (75%) و (50%) تحسين فى نعومة و صلادة السطح على التوالي عند القيم المثلى للمؤشرات المذكوره

INTRODUCTION

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Roller burnishing is a finishing, post machining and forming process, which is usually used to improve some mechanical and physical properties of the work piece, such as_surface finish and hardness [1, 2, 3]. It involves plastic deformation under cold working conditions by pressing a hard and highly polished roller against the work piece surface. The tool (ball or roller) surface finish and hardness must be superior to that of the work piece, which is usually driven positively while the roller rotates as a result of friction with the work piece. This creates a high compressive stress in the peaks of the surface finish that in turn grounds the flow of the material and hence the plastic deformation.

The evidence from the literature review demonstrates that the burnishing process offers some additional specific advantages in comparison with precision cutting processes. The superior surface finish and hardness improvements are the most prominent features of the process [1, 2, 3 – 11]. Other burnishing benefits and features include increasing compressive residual stress [5, 8, 9, 12], improved visual appearance of the burnished work piece [11, 13], improving fatigue strength [7, 11 – 14], improving corrosion resistance [7, 11, 13, 14], improving wear resistance [4, 10, 11, 13] and the overall improvements of the mechanical and physical properties of the surface layer of the burnished work piece [11, 13, 14].

The aim of this paper is to study and determine experimentally the effects of a range of roller burnishing parameters on the surface finish and hardness of two types of work piece materials; mild steel and aluminium. The secondary aim is to obtain the optimum values of these parameters; specifically those that offer the best surface finish and surface hardness together and not individually. The considered roller burnishing parameters are the number of the tool passes, burnishing force, burnishing feed, and burnishing speed. These parameters are regarded to be the dominant factors that affect the surface structure [3, 5, 6].

EXPERIMENTAL DETAILS

Work Piece Materials

Aluminium alloy AA6463-T1 Extruded (AAE) and Mild steel ASTM A113 – grade A were used as material types for the work piece specimens. The materials have been selected to represent a soft and a hard type respectively, which differ prominently in their general properties, behaviour and machinability.

The mechanical properties and the indicative partial composition of the two materials used are shown in Table 1, beside their chemical composition and the as per ASTM (American Society for Testing Method) equivalent notation.

Table (1). The composition and mechanical properties of the specimens

The Roller-Burnishing Tool

For the experimental work, a roller-burnishing tool holder was specifically and purposely designed and manufactured as shown in Figure 1. The surface properties of the rotating roller tool material had to be superior to that of the work piece materials.

Due to the simple and suitable design of the roller tool holder, it could be easily mounted in the tool post holder of the lathe machine, the roller could rotate (due to friction) with the work piece rotation and it could be cleaned and lubricated during the operation. The tool was also mountable in the force measurement dynamometer for the measurements of the applied burnishing force (Py).

The roller material (the rotating part 1 in Fig.1) has the following composition and specification: high chromium-carbon steel, En 31 alloy, 1%C, 1.4%Cr, 0.2%V; super finish surface of (Ra) < 0.03 µm; Vickers hardness number (HV) > 750 Kg/mm^2 with dimensions of 16 mm in diameter and 6 mm in width.

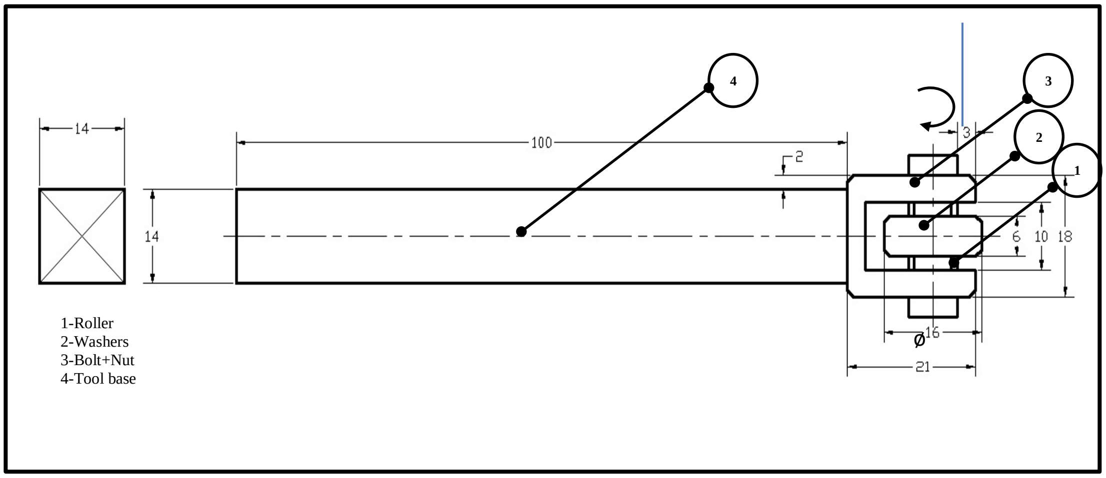


Figure (1). The roller – burnishing tool

Metals	(ASTM) Specifications	Indicative partial composition	Strength MPa	Hardness HV Kg/mm^2
1-Aluminium specimen	Aluminium Alloy Extruded (AAE). AA6463-T1	98.5% Al, 0.4% Si, 0.7% Mg, 0.3% Fe.	Yield 90 Ultimate 150	114
2- Mild Steel specimen	A113, grade A	0.3% C, 0.6% Mn, 0.04% P, 0.05% S, 0.3% Si, 0.2% Cu.	Yield 230 Ultimate 490	225

Burnishing Conditions

A range of burnishing parameters and the work piece specification values were chosen and applied for the experimental part of the investigation. Table 2 shows the data with other burnishing conditions and variables.

These settings were selected in order to study the influence of process parameter variations on the work piece surface finish (Ra) and micro hardness (HV).

For each experiment, one of the process parameters of feed, force, number of tool passes (NTP) and speed was varied within its range (Table 2) whilst the other variables were kept unchanged.

These conditions are illustrated in Figures (3 to 10) of the results section.

Table (2). The burnishing conditions

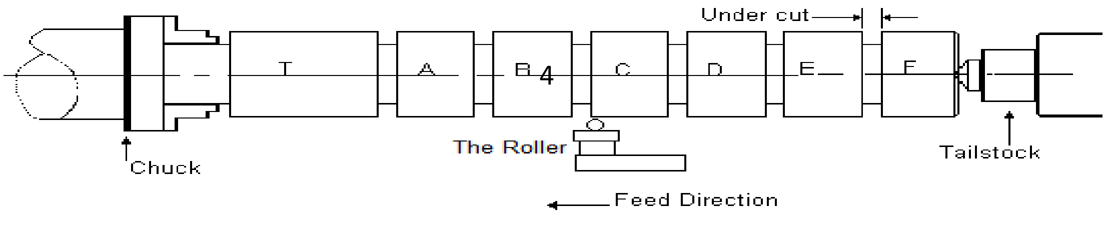
1- Work piece	**Cylindrical bars.** Length - 200 to 300 mm. Diameter - 30 to 45 mm.
2- Number of tool passes (NTP)	1, 2, 3, 4, 5, 6 and 7
3- Burnishing feed (f)	0.05 to 0.44 mm/rev
4- Burnishing force (Py)	1 to 50 kgf
5- Burnishing speed (*v*)	5 to 42 m/min
6- Burnishing condition	lubricated (light engine oil)

Experimental Procedure

As the burnishing process was carried out on cylindrical shape work piece bars, they were held between the lathe machine's chuck and headstock. By using a turning cutting tool, the work piece was then turned to the desired diameter (Table 2) and the length partitioned into several equally-sized segments (A to F in Fig. 2)

Using the roller- burnishing tool that was held in the lathe's tool holder and with the above work piece setting, each segment was then burnished and used as a medium for a different burnishing condition. The last segment (T) was reserved (un-burnished) as a reference turning condition, from which the initial surface finish (Rai) and initial surface hardness (Hvi) were obtained. Drops of light engine oil were used as a lubricated coolant between the tool and the work piece during the process. The tool and the work piece were cleaned regularly during the burnishing process to prevent the presence of any foreign particles in the burnishing zone.

A piezo-electronic dynamometer type (KISTLER 9441) was used to measure the corresponding burnishing force Py, while the values of other burnishing parameters were either calculated as in burnishing speed or obtained directly from the lathe machine itself as in burnishing feed.



T is the reference turning segment

A,B,C,D,E and F segments are for different burnishing variables.

Figure (2). The experimental setup, the tool and the work piece

RESULTS AND DISCUSSIONS

Effect of the Number of Tool Passes (NTP) on Surface Roughness (Ra) and Hardness (HV)

The effect of the number of tool passes (NTP) on the surface roughness (Ra) is illustrated by figure 3. For both the mild steel (M.St.) and aluminium (Al) work pieces, the graphs show that Ra decreases with an increase in NTP until the fourth tool pass, which is considered to be the optimum NTP for both materials. Beyond the optimum fourth tool pass the surface roughness increases with increasing tool pass repetition. This is believed to be due to the surface over - hardening and as a consequence some flaking of the surface layer occurs.

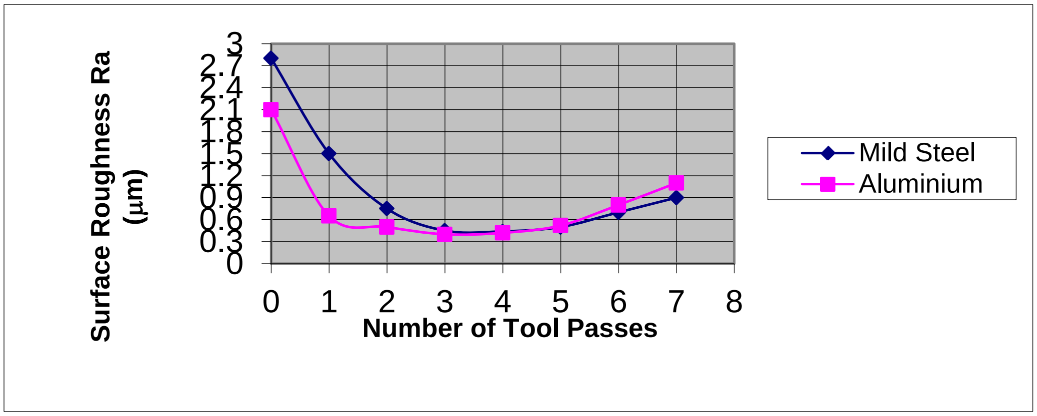


Figure (3). Effect of NTP on surface roughness at v = 23.6 m min^{-1}, f = 0.08 mrev^{-1} M.St: Py = 8 kgf, Rai = 2.8 µm. Al: Py = 3 kgf, Rai = 2.1 µm

Figure 4 shows the effect of increasing the number of tool passes (NTP) on the surface hardness (HV) for both work piece materials. The HV increases with the increase of the NTP for both materials up to the seventh NTP that used in this paper. This behaviour can be attributed to the strain hardening and the increase in the physical uniformity of the surface layers, as the NTP increases. The aim is to obtain the optimum NTP that improves both the Ra and HV and not merely HV alone. The fourth NTP is therefore considered to be the optimum improvement number, as beyond that the Ra increases.

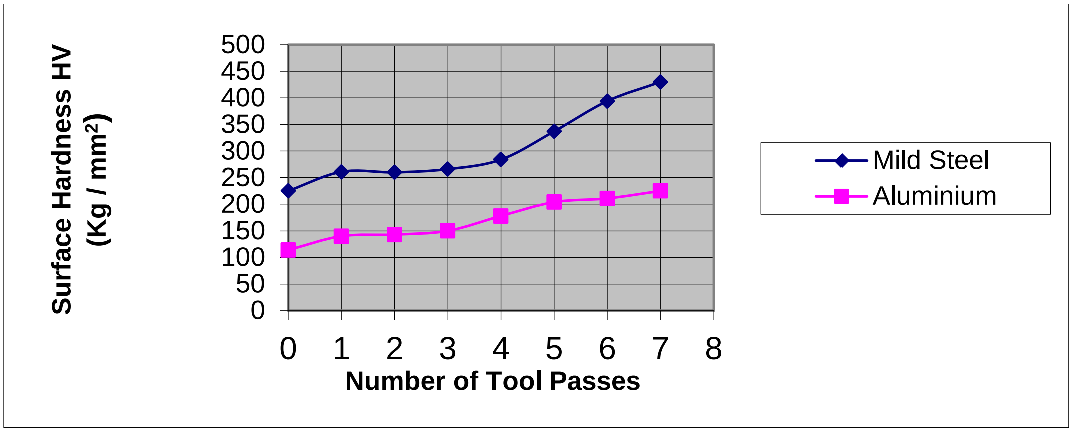


Figure (4). Effect of NTP on surface hardness at v = 23.6 m min^{-1}, f = 0.08 mm rev^{-1}. M.St: Py = 8 kgf, Hvi = 225 Kg mm^{-2} Al: Py = 3 kgf, Hvi = 114 Kg mm^{-2}

Effect of Burnishing Force (Py) on Surface Roughness (Ra) and Hardness (HV)

The effect of the burnishing force (Py) on the surface roughness and hardness is shown in figures 5 and 6 respectively for both work piece materials.

It is important to highlight that the burnishing force (Py) is the applied perpendicular force of the tool (roller) in Kgf on the work piece surface in the direction of the axis of rotation. This force is the equivalent to the depth of the penetration by the tool in mm.

Figure 5 shows the decrease of the surface roughness with the increase of the applied force Py up to the optimum values of around 5 Kgf for Al and in the range of 15 to 30 Kgf for M.St.

Further increase of the applied force Py beyond the above optimum values increases the surface roughness Ra. This behaviour could be attributed to the fact that the bulge of metal in front of the tool becomes large and the region of the plastic deformation widens which damages the already burnished surface i.e. increases the surface roughness.

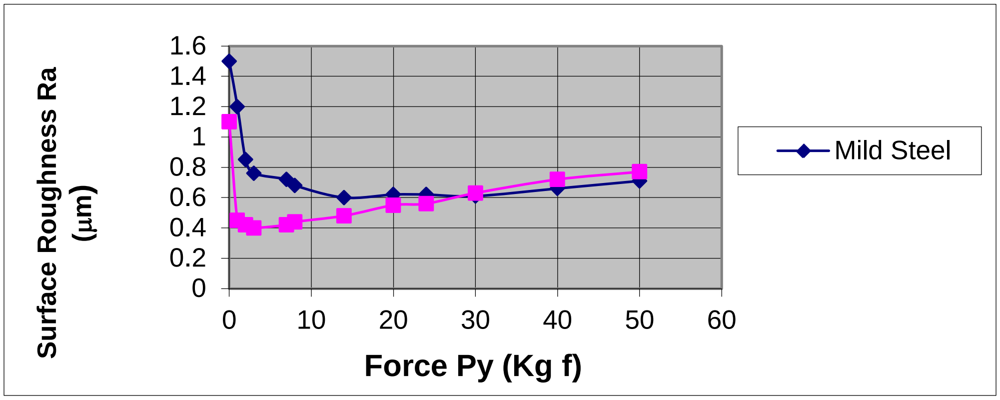


Figure (5). Effect of burnishing force on surface roughness

M.St: v = 19.8 m min^{-1}, f = 0.08 mm rev^{-1}. Rai = 1.6µm, NTP =1 Al: v = 29.2 m min^{-1}, f = 0.08 mm rev^{-1}. Rai = 1.1µm, NTP =1

Figure 6 shows the direct proportional relation between the surface hardness (HV) and the applied force (Py), which indicates an increase in force casus an increases in surface hardness for both materials under the boundary of the experimental conditions used. This is usually due to the increase of the tool pressure and the increase in metal flow that leads to an increase in the amount of deformation and more voids being filled. This also leads to an increase in the internal compressive residual stresses, which in turn increase the surface hardness.

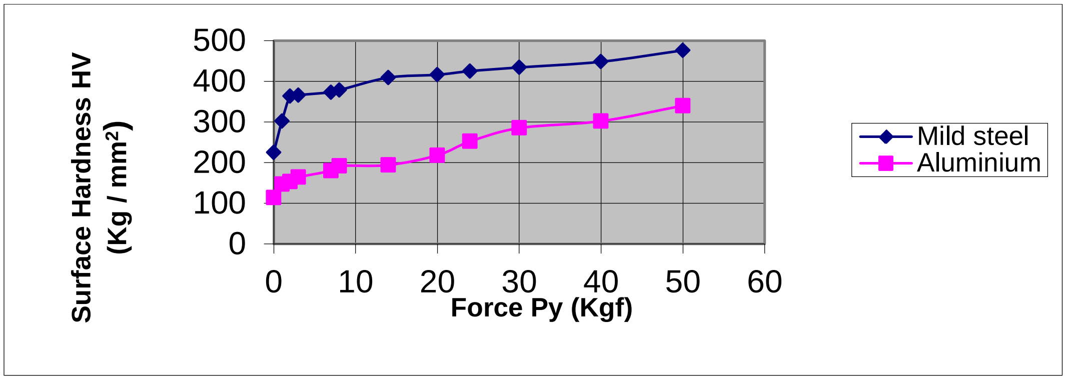


Figure (6). Effect of burnishing force on surface hardness M.St: v = 19.8 m min^{-1}, f = 0.08 mm rev^{-1}. Hvi = 225 kg mm^{-2}, NTP =1 Al: v = 29.2 m min^{-1}, f = 0.08 mm rev^{-1}. Hvi = 114 kg mm^{-2}, NTP =1

It was found that increasing the applied force is physically similar to increasing the number of tool passes, which is applying further pressure to the work piece surface in both cases. Hence, the effects of these two parameters were also found to be similar on the surface roughness and hardness of both materials used, as is illustrated in figures 3 and 4 for the NTP compared to figures 5 and 6 for the applied force Py.

Effect of Burnishing Feed (f) on Surface Roughness (Ra) and Hardness (HV)

Figures 7 and 8 signify the effects of burnishing feed on the surface finish and hardness respectively for both the mild steel and aluminium work piece materials. The results show that the surface roughness increases with the increase of the burnishing feed (fig.7), while the surface hardness decreases with the increase of feed (fig.8).

Accordingly, the optimum surface roughness and hardness via roller burnishing and under the applied experimental conditions is considered to be obtainable by an optimum feed value of around 0.1 mm rev^{-1} for both work piece materials.

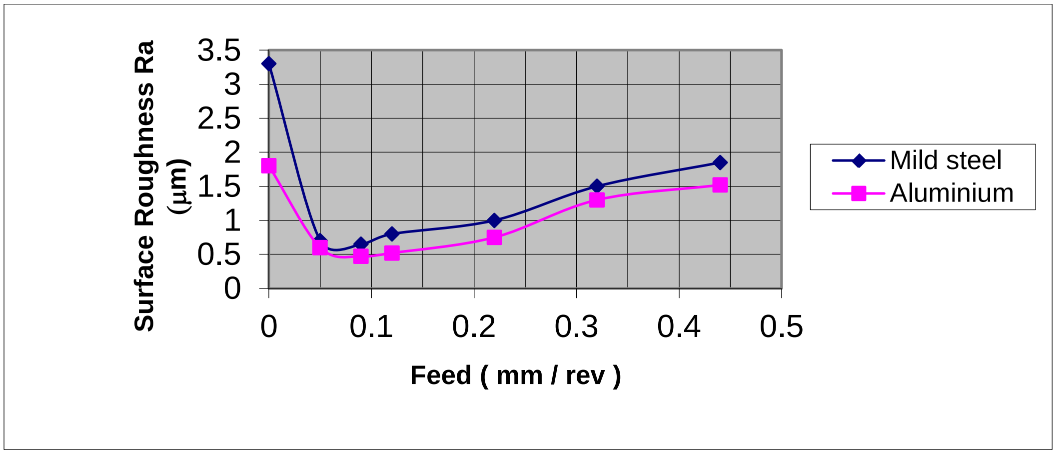


Figure (7). Effect of burnishing feed on surface roughness
M.St: v = 26 m min^{-1}, Py = 17 kgf. Rai = 3.3µm, NTP =1 Al: v = 29.8 m min^{-1}, Py = 3 kgf ^{1}. Rai = 1.8µm, NTP =1

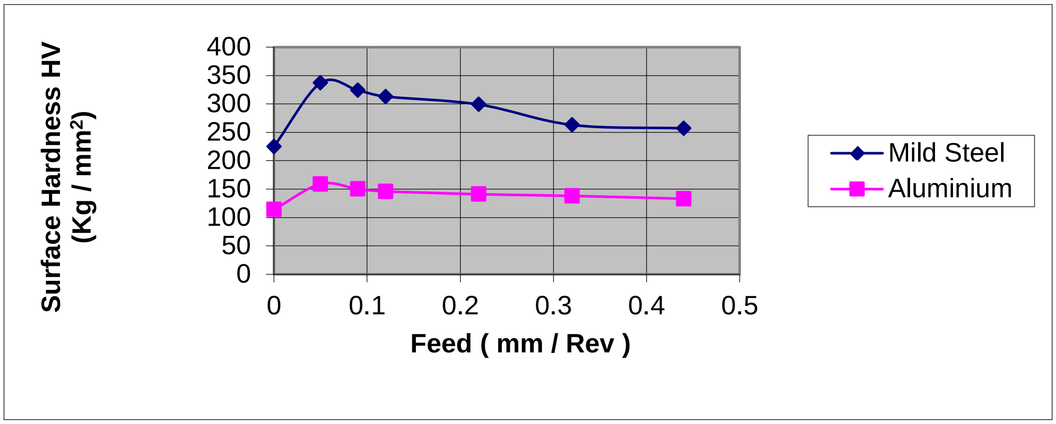


Figure (8). Effect of burnishing feed on surface hardness
M.St: v = 26 m min^{-1}, Py = 17 kgf. Hvi = 225 kg mm^{-2}, NTP =1 Al: v = 29.8 m min^{-1}, Py = 3 kgf ^{1}. Hvi = 114 kg mm^{-2}, NTP =1

Greater improvement at the (lower) feeds as opposed to the (higher) feeds is due to that the tool does not create feed marks with the edge of the roller between two consecutive indentations per a revelation of the work piece. This is because there is enough time available at the low feeds for the tool to pass the material yield point, hence imposing the plastic deformation required for enhanced surface improvements.

Tool overlapping is recommended in order to safeguard the feed value is less than the length of the contact area between the tool and the work piece, hence reducing tool marks for a higher surface quality.

Effect of Burnishing Speed (*v*) on Surface Roughness (Ra) and Hardness (HV)

The effect of burnishing speed on the surface roughness and surface hardness can be assessed from figures 9 and 10 respectively for both the M.St and Al work pieces. Figure 9 displays the decrease of the surface roughness with the increase of the burnishing speed under the experimental conditions used. This is the case until the occurrence of the optimum speed values of around 20 m/min for M.St and 30 m/min for Al, beyond which the surface roughness increases again.

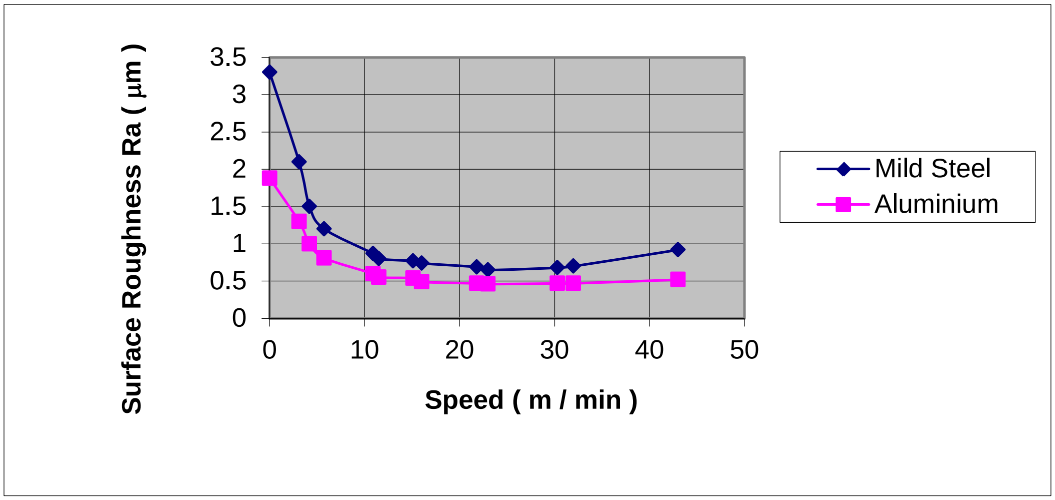


Figure (9). Effect of burnishing speed on surface roughness
M.St: f = 0.09 mm rev^{-1}, Py = 17 kgf, Rai = 3.3µm, NTP =1 Al: f= 0.09 mm rev^{-1}, Py = 3 kgf, Rai = 1.8µm, NTP =1

Figure 10 shows that surface hardness decreases with the increase of the burnishing speed for both work piece materials beyond the optimum speed of around 8 to 10 m/min.

The increase in surface roughness beyond the optimum values and the decrease in surface hardness with increasing speed are due to chattering occurring at higher speeds. This means that there is less deformation time available for the tool to smooth out more irregularities and harden the surface.

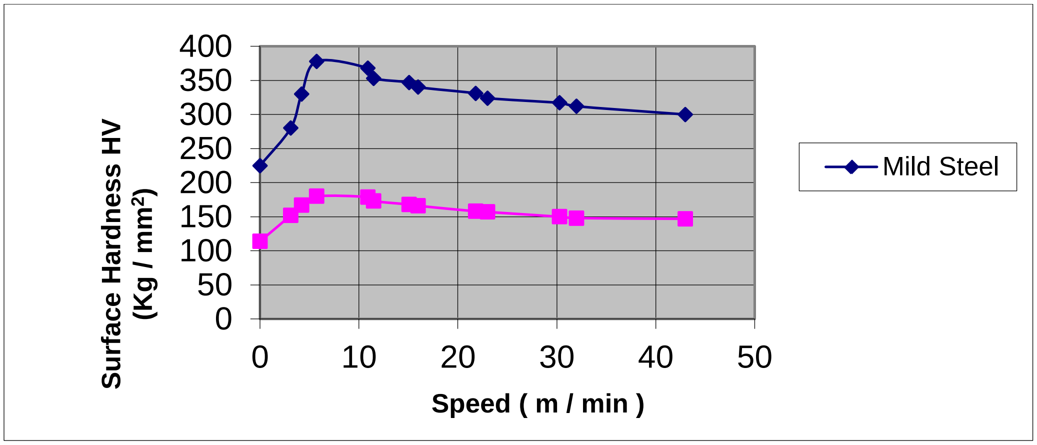


Figure (10). Effect of burnishing speed on surface hardness
M.St: f = 0.09 mm rev^{-1}, Py = 17 kgf. Hvi = 225kg mm^{-2}, NTP =1\Al: f= 0.09 mm rev^{-1}, Py = 3 kgf, Hvi = 114kg mm^{-2}, NTP =1

Effect of the Work Piece Materials

The effects of the roller burnishing parameters variations on both the surface roughness and hardness of the mild steel and aluminium work piece materials are presented in figures 3 to 10, which include the experimental conditions used for each case.

It is evident from the graphs that both the mild steel and aluminium work piece materials reveal the same trends and shapes when they are exposed to the burnishing parameters combination, apart from the optimum values due to the material nature variation.

The type of the work piece materials showed a visible effect on the optimum roller burnishing values. The aluminium material exhibited lower optimum surface roughness values generally compared to the mild steel work piece material. This could be due to its higher formability by burnishing and the initial low Rai values, regardless of the improvement proportion being slightly less or the same as in the mild steel in some cases.

The surface hardness improvements for mild steel are found to be the same or slightly higher than that for aluminium at the optimum surface roughness values, which could be owed to the higher initial Hvi value of mild steel and its hardenability.

Conclusion

- The great effects of the roller burnishing parameters on both the surface roughness and surface hardness of the work piece materials used are demonstrated by the results obtained.
- The optimum surface finish occurred at similar NTP and feed for both materials. While, less force and higher speed was needed for Al compared to M.St.
- At optimum parameters values, up to 75% improvements in surface roughness and 50% in surface hardness are obtainable by roller burnishing depending on the burnishing conditions used.

- Increasing the NTP, burnishing force, feed or speed beyond the optimum values leads to an increase in the surface roughness of both materials.
- Surface hardness of both materials is directly proportional to NTP and / or burnishing force.
- Increasing burnishing speed or feed beyond the optimum values leads to decrease in the surface hardness.

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