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Effects and Optimization of Superficial Plastic Deformation Treatment on XC18 Steel

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Abstract: In mechanical systems, surfaces of machine parts are often requested and most exposed to the external phenomenon. These are of various natures such as friction, wear, corrosion, tiredness, etc. High mechanical performances of parts in service are conditioned by physical and geometrical properties of surface layers. These properties can be obtained by the choice of a material with high performances, these results on an increasing cost. One of the solutions which appear to be the simplest and the less expensive consist of integrating some structural modifications which can confer to a basis material an important new property on superficial layers. This study is focused on mechanical surface treatments giving particular properties to superficial layers of a steel piece in applying mechanical surface treatments based on a Superficial Plastic Deformation (SPD) such as the ball burnishing. The analysis of the results obtained by applying this treatment on premachined (turned) samples, offers significant improvements in surface Roughness (Ra) and superficial Hardness (Hv). These two properties seem to be strongly linked to treatment parameters which their effects are studied in this research work. As a result a specific optimal regime to each characteristic (Ra and Hv) is defined in order to obtain a maximum effect.

Key words: Ball burnishing, plastic deformation, work-hardenning, roughness, hardness

INTRODUCTION

A final product competitiveness needs a manufacturing process which guarantees a better ratio quality-price. A higher surface quality tends to appeal to another process which is not limited to removing chip-forming. The superficial layers are being often requested in service. Its micro-geometric properties (roughness) and superficial hardness accomodate in decisive way the behaviour and life time of mechanical organs working by contact and friction. Moreover, these two properties are more requested to improve fatigue strength[1]. Some mechanical surface treatments such as ball burnishing[2,3] and rolling[4,5] induce a plastic deformation of superficial layers and act on surface properties. Superficial layers are characterised by their physical and geometrical aspects. In this way the process is more and more used to finishing and strengthening good working pieces.

This study is based upon the application of ball burnishing process on samples prepared by turning as recommended by A.C.E. Mendar[6]; however, knowing that the initial state of surface and treatment conditions (SPD) play a fondamental role in obtaining good results[2,4,7].

The aim of this study is to investigate the effects of the parameters and their impact on considered material properties. Using a developed computed programme based upon experience plan methods[8] working under windows environment; the adopted model allows to conduct experimentation and to appreciate the contribution of the treatment on Roughness (Ra) and hardness of superficial layer (Hv) by calculation and optimization of operating parameters.

EXPERIMENTS

The material studied is ordinary steel delivered in a tempering state by MITTAL-STEEL co (Algeria) Fig. 1; its characteristics are illustrated in the Table 1.

Samples are prepared by turning with a cutting tool of gradation P10 (ISO) and an appropriate cutting regime[9]. The sample is divided in eighteen parts, where two are reserved for optimal treatment regimes.

The turned surface is characterised by an initial roughness of Ra = 1.76÷2.24 μm and average hardness of Hv = 185 daN mm^{-2}.

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Table 1: Material characteristics

Chemical composition	C	Mn	Si	S	P
	0.18 %	0.6 %	0.18 %	≤ 0.035 %	≤ 0.035 %
Mechanical characteristics	Re (MPa)		Rm (MPa)		A (%)
	240		430		>20

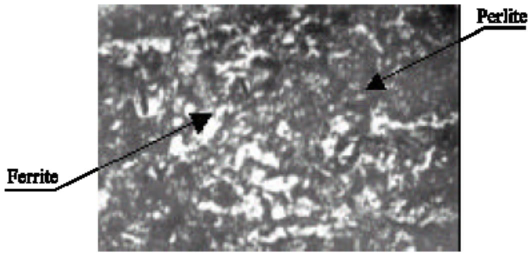
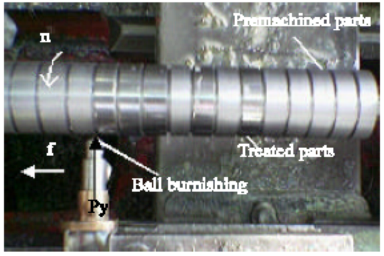


Fig. 1: Material microstructure at 400 X

a-Testing device



b-Ball burnishing

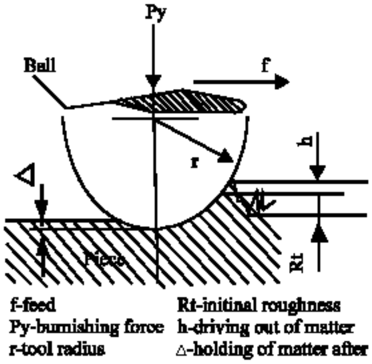


Fig. 2: Treatment by superficial plastic deformation

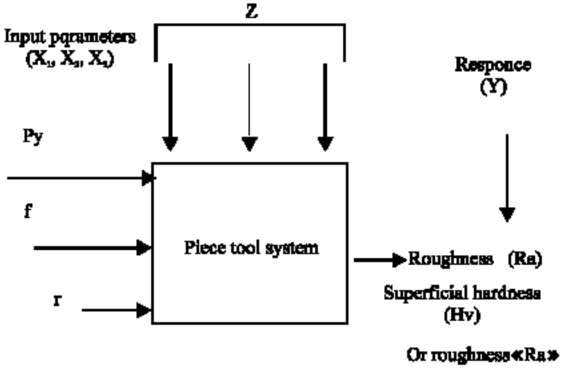
Table 2: Tests matrix

Operating parameters	Codes	Variation levels Minimal	Medium	Maximal
Py (Kgf)	X1	8	12	16
f (mm rev^{-1})	X2	0.054	0.091	0.11
r (mm)	X3	2	2.5	3

Tests are carried out on the rig shown in Fig. 2; the penetration mouvement is obtained by diamante ball action with an adjustable effort. The deformation is obtained by sample rotation and burnishing tool advance which is controlled by a longitudinal tray. During the tests sample surfaces are treated by lubrification.

Taking into consideration sample hardness, machine tool capacities and recommandations[2], the parameters adopted are: Burnishing force Py = 8÷16 (kgf); feed f = 0.054 ÷ 0.11 (mm rev^{-1}); tool radius r = 2÷3mm; burnishing speed Vc = 10÷ 80 (m/min).

To put in evidence all recommended system range in order to observe parameter effects on surface state and superficial hardness during ball burmishing, tests are carried out by applying the experiment planification methods[8] according to the diagram below:



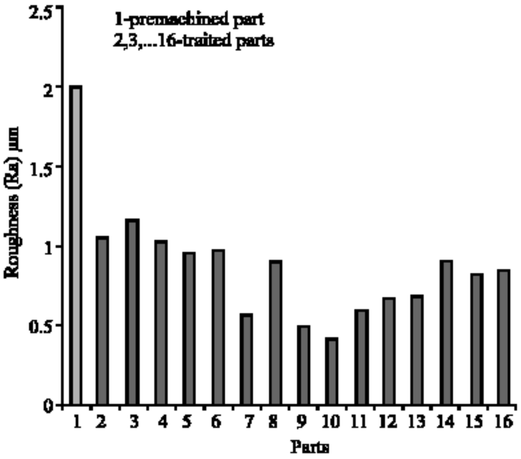


Fig. 3: Evolution of ball burnished roughness (Ra)

The (Z) parameters (sample rotational frequency (n), lubrification, system inflexibility, environment, etc...) are maintained constant during the operation.

The adopted planning model experiment take into consideration three levels and three factors. It is developed according to experimental matrix Table 2.

The operations were conducted by a computed programme[10] working under windows, the obtained substitution matrix, mathematical treatments and test statistics have lead to the results discussed below.

RESULTS AND DISCUSSION

The obtained results showed that ball burnishing has a benefic effect with regard to the roughness. The effect of relative treatment on each part is shown in Fig. 3.

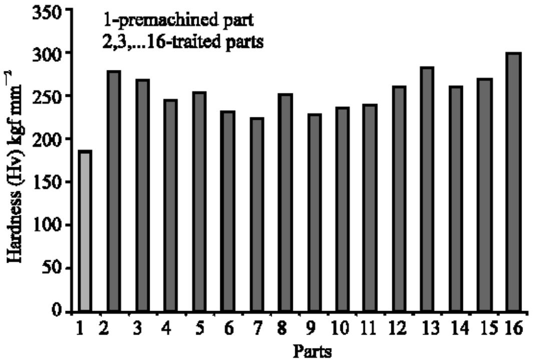


Fig. 4: Evolution of ball burnished superficial hardness (Hv)

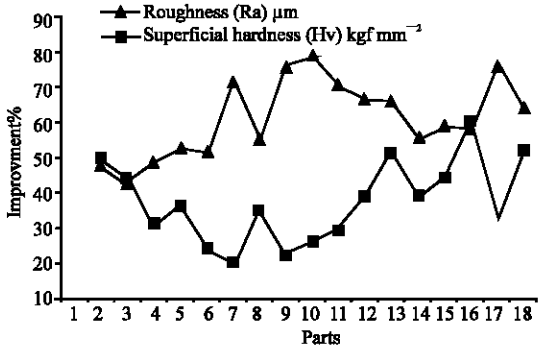


Fig. 5: Simultaneous evolutions of ball burnished roughness and superficial hardness according burnishing parameters

In the same way, work-hardening resulting from plasticization increases superficial hardness. The effect of working relative regime to each part is illustrated in Fig. 4.

The superficial roughness and hardness improvement rates related to each part are illustrated in Fig. 5.

The maximum effects brought to these two characteristics (Ra) and (Hv) are obtained with distinctive regimes. To estimate the effects of each parameter of treatment regime on these responses, a graphic treatment by a program according to the used mathematical model has permitted to obtain Fig. 6 and 7.

The superficial roughness and hardness distribution values are simulated by a computer program. Thus an exhaustive examination of burnishing parameters influence can be carried out. The red zones characterize the high values and blue zones characterize the low values.

In considering a burnishing force Py = 8 Kgf Fig. 6a, it can be observed that: Combining low advance values to an important tool radius, surface roughness is improved to Ra = 0.6 µm. Combining average tool radius and important advances in contrast provoke more important roughness Ra ≈ 1.10 µm.

a) Ra = F(r,f) ; burnishing force fixed at Py = 12 kgf

b) Ra = F(r,f) ; burnishing force fixed at Py = 12 kgf

c) Ra = F(r,f) ; burnishing force fixed at Py = 16 kgf

Fig. 6: Influence of burnishing feed (f), force (Py) and tool radius (r) on roughness Ra

a) Hv = F(r,Py) ; feed fixed at f = 0.054 mm rev^{-1}

b) Hv = F(r,Py) ; feed fixed at f = 0.091 mm rev^{-1}

c) Hv = F(r,Py) ; feed fixed at f = 0.11 mm rev^{-1}

Fig.7: Influence of burnishing feed (f), force (Py) and tool radius (r) on superficial hardness (Hv)

Fixing a burnishing force at a value of Py = 12 Kgf Fig. 6b, it can be note that: for the feed diapason used, the roughness is limited to Ra ˜ 0.90 µm; the reduction of tool radius provokes an increase of the roughness; the roughness declines and reaches a value of Ra ≈ 0.39 µm for a higher tool radius and during feed decrease.

Fixing a burnishing force at a value of Py = 16 Kgf Fig. 6c, it can be recorded that: an increase of the burnishing force provokes a roughness increase; the average tool radius combined to all feed values allowes roughness Ra to go beyond 0.90 µm; the combination of high tool radius values and low feed advance values allow roughness lower values Ra reaching 0.55µm.

Fixing the feed value at f = 0.054 mm rev^{-1} Fig. 7a, it can be noted that: Increasing the average radius tool and the burnishing force raise the superficial hardness; the most important radius tool as well as the lowest or the most important efforts offer a low increase of the superficial hardness. Combining average radius to burnishing force values around 12 Kgf allow a significant improvement of the superficial hardness going up to Hv = 267 Kgf mm^{-2}.

Fixing the feed at f = 0.091 mm rev^{-1} Fig. 7b, it can be remarked that: Combining the highest or the lowest efforts to high radius tool values offer a low increase of the superficial hardness. In the same way, combining the lowest radius tool values to high or low burnishing force values do not allow to reach an important superficial hardness value. Combining average radius tool values as well as average burnishing force values offer an important improvement of superficial hardness (Hv) going up to 265 Kgf mm^{-2}.

Fixing the feed at a value of f = 0.11 mm rev^{-1} Fig. 7c, it can be observed that : the lowest hardness values are obtained with the lowest burnishing force values combined to the lowest tool radius. Combining the highest tool radius to highest burnishing force values provide a more important superficial hardness (Hv) with regard to precedent cases going up to 250 Kgf/ mm^{2}. Average burnishing force values as well as average tool radius (r = 2.5 mm) provide a considerable improvement of the superficial hardness (Hv) going up to 270 Kgf mm^{-2}.

Ball burnishing is a plastic deformation process of the surface layers. The obtained results from the superficial plastification tend to: the peak asperities must be flattened in filling hollow furrows, which is given in[2, 11-13] and confirmed by the tests conducted in the study. The passage of the tool enables to level hallows and gives a totally polished surface with improvement of the roughness compared to the one produced by grinding process.

The importance of burnishing tool radius increases the surface contact tool-piece, which permit to better flatten the hollows. A moderate value of the deformation effort combined with important values of the burnishing tool radius give better improvement to surface state (up to 80%).

Increasing the feed is unsuitable, it increases the stride furrows such a case of cutting tool machining provoking damage to the surface aspect (increase of Ra value). However, obtaining a better roughness after deformation depends on initial surface state resulting from turning[7].

It is therefore a question of well choosing cutting conditions of premachined pieces for burnishing treatment. In the case studied, the initial Roughness (Ra) obtained by turning is in order of 2.0 μm which is near the recommended one. Conditions giving appreciable roughness values are represented by blue zones Fig. 6. The optimal treatment conditions provided by the calculation programme and verified, correspond to the follwing parameters values ($Py = 11.7$ Kgf ; $f = 0.054$ mm rev^{-1} ; $r = 3$mm) and provide a response ($Ra = 0.38$ μm) with an error of±0.1 μm.

The physical state improvement characterised by the superficial hardness is the result of strengthing superficial layers following their plastification. The low values of ball burnishing radius secure a strong penetration into the superficial layer. Its combination with low feed contributes to a superficial hardness improvement. In fact, this results from combining burnishing parameters which act between them and provide an improvement of 20 to 60%. The increase of the burnishing force offers a better improvement of superficial hardness. On the other hand, increasing feed values and ball burnishing radius decreases superficial hardness. Conditions presenting values of the substentiel superficial hardness are shown by the red zones Fig. 7. Finally, the obtained optimal response is specific to a determined treatment. The optimal conditions provided by the programme and verified by test correspond to:

> ($Py = 12$kgf; $f = 0.054$ mm rev^{-1}; $r = 2.3$ mm) and offer a response $Hv = 283$Kgf mm^{-2} with an error of±13 Kgf mm^{-2})

CONCLUSION

The plastic deformation by Ball burnishing changes mechanical and geometrical properties of materials. During the tests carried out according to the mathematical method confirm the benefic effects on the process as shown in the literature[11-13]. As a result there is a roughness improvement of 80 % and a hardness increase of 60%. Nevertheless, it is observed that the material admits a high ductility, which needs a lot of care during its preparation in turning (the use of studied conditions).

The ball burnishing is consequently a way of surface mirror finishing pieces; it permits to give a response to some imposed technical requirements during manufacturing and conception of mechanical parts. Its success is linked to the pre-machined process. The burnishing effects given to the considered material are summarized as follows:

- A strengthening of superficial layers which increases superficial hardness.
- Plastic deformation insures levelling hollows machining which improve surface roughness.

However, the benefical effects depend on initial state and burnishing parameters. The better results occuring at low roughness is charactrized by moderate burnishing force, the lowest feed associated to a larger tool radius values. Again, to obtain a most important superficial hardness on recommanded low feed values combined with high force and a less important tool radius

Realising tests based on experimental plans has permitted to observe the influence of the considered parameters (Py, f, and r) over the material behaviour towards the responses (Ra, Hv). The mathematical model adopted has permitted with a minimum of tests to have some information on optimal surface conditions and related some interactions between the burnishing parameters.

APPENDIX 1: PARAMETERS DEFINITION

Re : Yield strength (MPa)
Rm : Tensile strenght (MPa)
A : Ultimate elongation (%)
Ra : Roughness (μm)
Hv : Superficial hardness (Kgf mm^{-2})
Py : Burnishing force (Kgf)
f : feed (mm rev^{-1})
r : Tool radius (mm)
n : Rotation frequency
Vc : Speed of cat
F : Variable of SNEDECOR
R^2 : Coefficient of Determination
SPD : Surface Plastic Deformation

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