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Optimisation of Ball Burnishing Parameters For Surface Finish in AL6082 using Bacterial Foraging Optimization

Ashish Bahendwar[1], **Dr. Achal Shahare**[2]

[1]G H Raisoni University, Mechanical Engineering Department, Amravati Maharashtra, India.

[2]G H Raisoni University, Faculty of Mechanical Engineering, Amravati, Maharashtra, India

ABSTRACT:

Burnishing process is a surface enhancement technique, which improves the surface finish of the component along with surface properties of the component. It is a cost effective process, mostly used in aerospace, biomedical, and automobile industries to improve reliability and performance of the component. In burnishing process, response parameters depends on burnishing process parameters, tool, and material on which burnishing is done. The key driving forces for newer production technologies and material development are strength to weight ratio of materials, performance and reliability improvement. The availability of appropriate manufacturing methods plays a vital role with respect to both material properties, cost. Authors tried to investigate the effect of various parameters of ball burnishing on Aluminium AL6082 to optimize the surface finish enhancement using biologically inspired Bacterial foraging optimization technique.

Keywords: Burnishing Tool, Surface Integrity, Optimization, Burnishing Process Parameters

INTRODUCTION

In the present scenario, a major concern in aerospace, biomedical and automobile industry is to manufacture all machine components with complete reliability, maximum safety and predictable performance of the component. This needs development and deployment of predictive analytical models for various manufacturing processes and optimized processes parameters so that we can predict various surface characteristics of the component. In burnishing process, the material is plastically deformed to produce highly finished surface. There is no material removal in this process; surface finish is obtained due to plastic deformation of the material. It is a chip-less process. This offers many advantages over other finishing processes like honing, lapping and grinding. Due to chip-less surface finishing processes, cold working of material is done at relatively high force. The applied force slightly exceeds the yield strength of the material and plastic deformation takes place. Due to plastic deformation of material along with a surface finish of the component, wear resistance, fatigue strength, foreign object property and surface microhardness of the component gets improved.

BURNISHING MECHANISM

All machined surfaces consist of series of peaks and valleys of irregular height and spacing. As a result of uneven surface and high pressure, finishing process at the beginning of operation is extremely intensive but gradually slackens off. In burnishing, the motion of ball or roller deforms the peaks into the valleys, thus makes the surface of component finished one. In certain cases, burnishing is the only method to by which technical requirements of the surface can be satisfied. The effectiveness of burnishing process in the improvement of surface integrity has attracted researchers and engineers. In this paper, work done by researchers on the effect of various burnishing process parameters on surface roughness of AL6082 specimens is presented

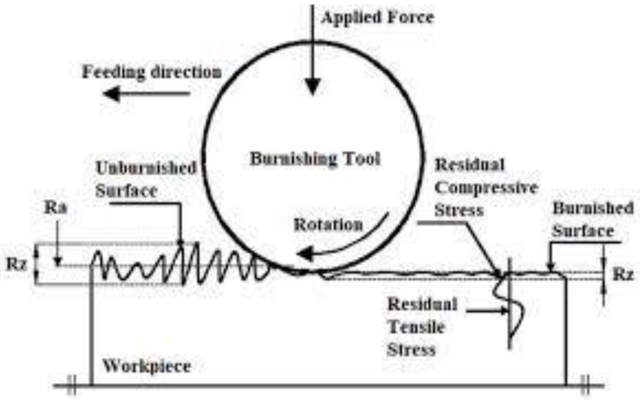


Figure 1. Burnishing Mechanism [1]

LITERATURE REVIEW

Numerous researchers have experimented to study the parametric effect in ball, roller and other forms of burnishing and considered variety of work materials like Brass and Cast Al-Cu alloy, EN series material, Aluminium alloys, Titanium alloy, Mild steel etc. As the current study deals with Aluminium alloy, the survey is focussed on the work in the same domain.

Lv Jinlong and Luo Hongyun [1] investigated the impact of burnishing on 2024-T3 aluminium alloy grain texture and oxidative behaviour.. Using a cylindrical-ended PCD (Polycrystalline diamond) burnishing tool, the authors achieved a burnishing depth of 20 nm at a tool speed of 3000 rpm. The EBSD scans were used to assess the electro-chemical condition of the surface after burnishing. Grain alteration of burnished surfaces resulted in an improved corrosion resistance. The surface quality and tribological behaviour of Aluminium 6061 were examined in relation to roller contact width and burnishing orientation throughout the investigation. El-Tayeb et al. [2] A 40 percent improvement in surface roughness may be achieved by burnishing with a reduced roller contact width. A 35 percent reduction in surface roughness can be achieved by burning with a force greater than 220 N. The use of lubricant instead of dry burnishing resulted in a better output. This study shows a negative influence on the wear resistance of burnished 6061 aluminium surfaces caused by increasing the burnishing force. U.M. Shirsat and B. B. Ahuja [3] On aluminium alloy, a parametric study of the combined turning and ball burnishing process was carried out.... A certain amount of force was shown to improve micro hardness, but only to a certain level. P N. Patel et al. [4] used the Taguchi approach to find the best parameters to increase the surface hardness of Al 6061. They found that a burnishing speed of 250 rpm and feed rates of 0.06 mm/rev, force of 8 Kgf, and the number of passes of 5 were the best parameters for hardness, and they came to the conclusion that speed promotes surface hardness. Decreases in hardness as speed increases. Fathi Gharbi et al. [5] a novel ball burnishing tool was used to improve the ductility of aluminium 1050A rolled sheet. As burnishing speed, feed, or force are increased, they found that the mean roughness decreased until it reached a minimal value, after which it began to rise as the burnishing parameters were raised. Amit Patel et al. [6] Response surface approach was used to examine the impact of the roller burnishing procedure on the surface roughness of 6061 - T6 aluminium alloy. As feed rate rises, so does the utility of roller burnishing. Passes enhance surface roughness; the greatest results were achieved with a reduced feed rate of 0.06 mm/rev, an applied force of 15-20 kgf, and four passes. El-Axir, Othman and Abodiena [7] A decrease in beyond-roundness, but no change in surface micro hardness was found when RSM was used in internal ball burnishing of Al 2014 utilising C-Cr steel balls, employing RSM as the basis for the study. There was a significant decrease in beyond-roundness and an increase in surface micro hardness after using a range of burnishing feed rates (from 0.2 to 0.35 mm/rev). Maheshwari and Gawande [8] The surface micro hardness of AA6351 was examined in relation to the impact of a newly developed burnishing tool. Researchers found that depth of penetration was the most important element in enhancing surface micro hardness, with a contribution of 64.52 percent followed by the number of passes. Stalin John & Vinayagam [9] RSM was used to conduct roller burnishing on Al6340 utilising a specially developed and constructed tool with replaceable springs for the procedure. Burnishing force was 1200 N, feed was 200 mm/s, and there were two passes, resulting in a surface roughness of 0.141 m and a hardness of 44 HRB for the finished product. Dadmal and Kurkute [10] showed how the roller burnishing process's transient structural analysis was used to construct a 2D FEA model. Experimental and FEA findings were determined to have an error margin of less than 10%, according to the study's authors. D. M. Mate and P. S. Chaudhari [11] The Al-2014 spherical surface burnishing tool was used to construct a mathematical model of the material. The author's LPP is based on the calculated findings, which give useful guidance for reducing E, Ra, and t in order to achieve greater performances..

METHODOLOGY FOR EXPERIMENTATION

Ball burnishing parameters have a significant impact on the surface roughness of aluminium Al6082 specimens, as shown in this work. On a Kirloskar Turmaster T 40 lathe, a specifically developed ball burnishing tool was used to perform the experiment (Fig 1). Roughness (Ra) of the burnished surface was tested using the Surftest 211 series (Mitutoyo Japan make). Perpendicular to the burnishing path, a surface roughness traverse was taken with a cut-off value of 0.25 millimetres.
Using a cutting tool with a Carbide insert 16T304, cylindrical Al6082 specimens were premachined to 30mm in diameter (Widia make). From 0.55 to 0.78 m, the surface roughness may be measured; (Ra). With various diameters, hardness, and pressures, the surface was simultaneously burnished with a variety of balls. As seen in Table 1 Uses 6.30 kg/mm flat-ended spring to produce the appropriate compression force for burnishing. With the help of the push rod and locking screw, the ball in the cap is kept firmly in place by bearing no. 608k. (Fig 2). Machine speed is 400 rpm, and the feed rate is 1/16th of an inch per minute for this investigation. Cutting Depth (for turning): 0.2 mm. Feed 0.045mm/rev.

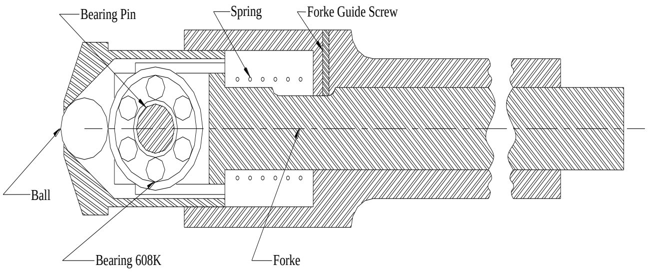


Fig. 2. Burnishing Tool Assembly

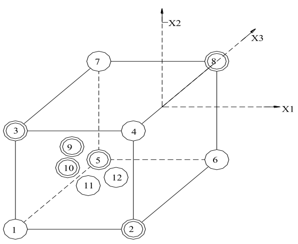


Fig. 3. Trial Numbers of Composite Design

MODIFIED FACTORIAL DESIGN

A statistical technique known as Factorial design is frequently used in engineering analysis and has several benefits over the classic one variable at a time approach in terms of ease and convenience. In 1951, GEP Box [12] proposed it as part of a chemical process engineering optimization research. M. A. Baradie [13] employees it in developing model for turning Grey Cast Iron. As well S. M. Wu [14], U. M. Shirsat [3] successfully implemented this methodology on tool life testing and burnishing.

For present work, the range of parameters for work material Aluminium AL 6082 is

i) Ball Materials- High Carbon High Chromium steel HCHCr (783VHN),
Titanium Nitride Coated bearing steel (2300VHN),
Titanium Aluminium Nitride coated bearing steel (3000VHN)

ii) Ball Diameters – 10.9 mm, 13.9 mm and 16.1 mm

iii) Burnishing Force- 15 kgf, 25 kgf, 40 kgf

Table 1. Experimental Parameters

WORK MATERIAL – Aluminium AL 6082						
Level	Ball Diameter mm	Ball Material Hardness VHN	Burnishing Force Kgf	Coding levels		
				X1	X2	X3
High	16.1	3000	40	+1	+1	+1
Centre	13.9	2300	25	0	0	0
Low	10.9	783	15	-1	-1	-1

1. Development of Mathematical Model

In the modified factorial Design technique, the burnishing operation's reaction surface roughness and the examined independent variables are linked by an equation

$$\mathbf{Ra = C * D^{k} * M^{l} * F^{m}}$$

Where Ra is the surface finish in micrometres, D is Ball Diameter (mm); M indicates Ball Material (VHN) and F is Burnishing force (kgf).

2. Experimental observations and analysis

The output response of the experimentation carried out are noted and tabulated as shown.

Table 2. Experimental Observations-Aluminium AL 6082

Trial No.	Diameter mm	Ball Material VHN	Burnishing Kgf	Surface Finish (Ra) µm		
				Turning	Burnishing 1st pass	Burnishing 2nd pass
1	-1	-1	-1	0.74	0.11	0.13
2	+1	-1	-1	0.54	0.08	0.05
3	-1	+1	-1	0.64	0.09	0.08
4	+1	+1	-1	0.65	0.11	0.22
5	-1	-1	+1	0.78	0.13	0.18
6	+1	-1	+1	0.74	0.07	0.14
7	-1	+1	+1	0.73	0.25	0.88
8	+1	+1	+1	0.65	0.26	0.28
9	0	0	0	0.55	0.19	0.36
10	0	0	0	0.68	0.20	0.29
11	0	0	0	0.56	0.16	0.32
12	0	0	0	0.63	0.18	0.30

The outcome of experimentation is analysed by dividing set of observations into three blocks

- First block (trial nos. 2,3,5,8,9,10),
- Second block (trial nos. 1,4,6,7,11,12) and
- Combined block (trial nos. 1 to 12).

The modified fractional method, Fig 3, is adopted [12]. Computations performed for analysis purpose resulted into the postulated model and regression coefficient (R2) for each block as below

Table 3. AL6082 postulated models for three blocks (1st pass)

Block	Postulated Model	Regression coefficient R2
First	$Y1 = -4.1315 + 0.8004 \ln D + 0.3018 \ln M + 0.7881 \ln F$	0.8808
Second	$Y1 = +3.1090 - 1.7711 \ln D + 0.4737 \ln M + 0.1880 \ln F$	0.9352
Third	$Y1 = -0.5111 - 0.4853 \ln D + 0.3018 \ln M + 0.4881 \ln F$	0.6033

According to the statistical technique, the best postulated model is the one whose regression coefficient is high. Therefore, the best model or surface roughness predicting equation for burnishing Al 6082 is

$$Y1 = +3.1090 - 1.7711 \ln D + 0.4737 \ln M + 0.1880 \ln F$$

Or In terms of surface finish

$$Ra = 0.2239 * D^{-1.7711} * M^{0.4737} * F^{0.1880}$$

Similarly after second pass,

Table 4. AL6082 postulated models for three blocks (2nd pass)

Block	Postulated Model	Regression coefficient R2
First	$Y1 = -4.8912-0.0392 \ln D + 0.3394 \ln M + 1.5622 \ln F$	0.6766
Second	$Y1 = -1.5224 - 1.8257 \ln D + 0..8801 \ln M + 0.9004 \ln F$	0.9648
Third	$Y1 = -3.2068 - 0.9324 \ln D + 0.6098 \ln M + 1.2313 \ln F$	0.6586

Therefore, the best model or surface roughness predicting equation for burnishing Al 6082 is

$$Y1 = -1.5224 - 1.8257 \ln D + 0...8801 \ln M + 0.9004 \ln F$$

Or In terms of surface finish

$$Ra = 0.002182 * D^{-1.8257} * M^{0.8801} * F^{0.9004}$$

Adequacy of the postulated model is checked by making analysis of Variance table.

OPTIMIATION OF BURNSIHING PARAMETERS USING BACTERIAL FORAGING

Optimization algorithms are extensively used in engineering design problems where the emphasis is on maximizing or minimizing a certain goal. For over the last five decades, optimization algorithms like Genetic Algorithms (GAs), Evolutionary Programming (EP), Evolutionary Strategies (ES), which draw their inspiration from evolution and natural genetics, have been dominating the realm of optimization algorithms. Bacteria Foraging Optimization Algorithm (BFO), proposed in 2002 by Passino [15], is a new comer to the family of nature-inspired optimization algorithms besides Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO).

BFO uses foraging strategies of the E. coli bacterium cells. It follows chemotaxis (swimming and tumbling), swarming, reproduction and elimination, dispersal events. In chemotaxis, the flagellum is a left-handed helix configured so that, as the base of the flagellum rotates counter clockwise, it produces force against the bacterium and pushes the cell. Otherwise, each flagellum operates relatively independent of the others; rotates clockwise and the bacterium tumbles. During swarming, the bacteria move out from their respective places in a ring of cells by moving up the mean square error to the minimal value. During reproduction, the least healthy bacteria die and others split into two, are placed in the same location. This causes the population of bacteria to remain constant. The elimination and dispersal events are based on population level long-distance motile behaviour. They assist nearest required values.

The BFO algorithm is presented below.

Bacterial Foraging Optimization Algorithm

For initialization, you must choose $p, S, N_c, N_s, N_{re}, N_{ed}, p_{ed}$, and the $C(i)$, $i = 1,2,\ldots,S$. If you use swarming, you will also have to pick the parameters of the cell-to-cell attractant functions; here we will use the parameters given above. Also, initial values for the θ^i, $i = 1,2,\ldots,S$, must be chosen. Choosing these to be in areas where an optimum value is likely to exist is a good choice. Alternatively, you may want to simply randomly distribute them across the domain of the optimization problem. The algorithm that models bacterial population chemotaxis, swarming, reproduction, elimination, and dispersal is given here (initially, $j = k = l = 0$). For the algorithm, note that updates to the θ^i automatically result in updates to P. Clearly, we could have added a more sophisticated termination test than simply specifying a maximum number of iterations.

1) Elimination-dispersal loop: $l = l + 1$
2) Reproduction loop: $k = k + 1$
3) Chemotaxis loop: $j = j + 1$
    a) For $i = 1,2,\ldots,S$, take a chemotactic step for bacterium i as follows.
    b) Compute $J(i,j,k,l)$. Let $J(i,j,k,l) = J(i,j,k,l) + J_{cc}(\theta^i(j,k,l), P(j,k,l))$ (i.e., add on the cell-to-cell attractant effect to the nutrient concentration).
    c) Let $J_{last} = J(i,j,k,l)$ to save this value since we may find a better cost via a run.
    d) Tumble: Generate a random vector $\Delta(i) \in \Re^p$ with each element $\Delta_m(i)$, $m = 1,2,\ldots,p$, a random number on $[-1,1]$.
    e) Move: Let

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}.$$

    This results in a step of size $C(i)$ in the direction of the tumble for bacterium i.
    f) Compute $J(i,j+1,k,l)$, and then let $J(i,j+1,k,l) = J(i,j+1,k,l) + J_{cc}(\theta^i(j+1,k,l), P(j+1,k,l))$.
    g) Swim (note that we use an approximation since we decide swimming behavior of each cell as if the bacteria numbered $\{1,2,\ldots,i\}$ have moved and $\{i+1, i+2,\ldots,S\}$ have not; this is much simpler to simulate than simultaneous decisions about swimming and tumbling by all bacteria at the same time):
        i) Let $m = 0$ (counter for swim length).
        ii) While $m < N_s$ (if have not climbed down too long)
        - Let $m = m + 1$.
        - If $J(i,j+1,k,l) < J_{last}$ (if doing better), let $J_{last} = J(i,j+1,k,l)$ and let

$$\theta^i(j+1,k,l) = \theta^i(j+1,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$$

          and use this $\theta^i(j+1,k,l)$ to compute the *new* $J(i,j+1,k,l)$ as we did in f).
        - Else, let $m = N_s$. This is the end of the while statement.
    h) Go to next bacterium $(i+1)$ if $i \neq S$ (i.e., go to b) to process the next bacterium).
4) If $j < N_c$, go to step 3. In this case, continue chemotaxis, since the life of the bacteria is not over.
5) Reproduction:
    a) For the given k and l, and for each $i = 1,2,\ldots,S$, let

$$J^i_{health} = \sum_{j=1}^{N_c+1} J(i,j,k,l)$$

    be the health of bacterium i (a measure of how many nutrients it got over its lifetime and how successful it was at avoiding noxious substances). Sort bacteria and chemotactic parameters $C(i)$ in order of ascending cost J_{health} (higher cost means lower health).
    b) The S_r bacteria with the highest J_{health} values die and the other S_r bacteria with the best values split (and the copies that are made are placed at the same location as their parent).
6) If $k < N_{re}$, go to step 2. In this case, we have not reached the number of specified reproduction steps, so we start the next generation in the chemotactic loop.
7) Elimination-dispersal: For $i = 1,2,\ldots,S$, with probability p_{ed}, eliminate and disperse each bacterium (this keeps the number of bacteria in the population constant). To do this, if you eliminate a bacterium, simply disperse one to a random location on the optimization domain.
8) If $l < N_{ed}$, then go to step 1; otherwise end.

Fig. 4. General Code for Bacterial Foraging [15]

ADAPTATION OF BFO MODEL

In this approach following parameters are selected for BFO simulations.

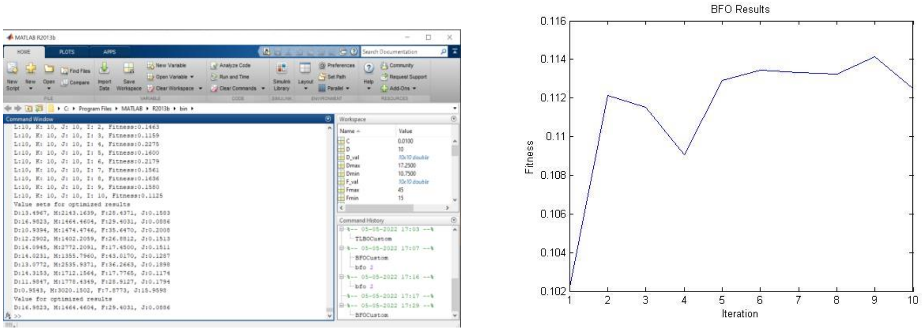
i) Number of BFO Estimators, Ne = 10
ii) Number of Rounds, Nr = 10,
iii)Number of Communicating Foraging Bacteria, Nc = 10
iv)Number of Particles, Np = 10
v) Number of Solutions, Ns = 10
vi) Incremental Factor, D = 10
vii) Learning Rate, C = 0.01
vi)Probability of Elimination and Dispersal, Ped = 0.9

OUTPUT OF BFO

The output of optimum values obtained after the simulations are

D = 16.9823, M = 1464.4604, F = 29.4031 For Ra = 0.0886µm

These values being in fractions, are rounded off to the nearest possible parametric values for testing experimentally.



```
L:10, K: 10, J: 10, I: 2, Fitness:0.1463
L:10, K: 10, J: 10, I: 3, Fitness:0.1159
L:10, K: 10, J: 10, I: 4, Fitness:0.2275
L:10, K: 10, J: 10, I: 5, Fitness:0.1600
L:10, K: 10, J: 10, I: 6, Fitness:0.2179
L:10, K: 10, J: 10, I: 7, Fitness:0.1561
L:10, K: 10, J: 10, I: 8, Fitness:0.1636
L:10, K: 10, J: 10, I: 9, Fitness:0.1580
L:10, K: 10, J: 10, I: 10, Fitness:0.1125
Value sets for optimized results
D:13.4967, M:2143.1639, F:28.4371, J:0.1583
D:16.9823, M:1464.4604, F:29.4031, J:0.0886
D:10.9394, M:1474.4746, F:35.6470, J:0.2008
D:12.2902, M:1402.2059, F:26.8812, J:0.1513
D:14.0945, M:2772.2091, F:17.4500, J:0.1511
D:14.0231, M:1355.7960, F:43.0170, J:0.1287
D:13.0772, M:2535.9371, F:36.2663, J:0.1898
D:14.3153, M:1712.1564, F:17.7765, J:0.1174
D:11.9847, M:1778.4349, F:28.9127, J:0.1794
D:0.9543, M:3020.1502, F:7.8773, J:15.9598
Value for optimized results
D:16.9823, M:1464.4604, F:29.4031, J:0.0886
>>
```

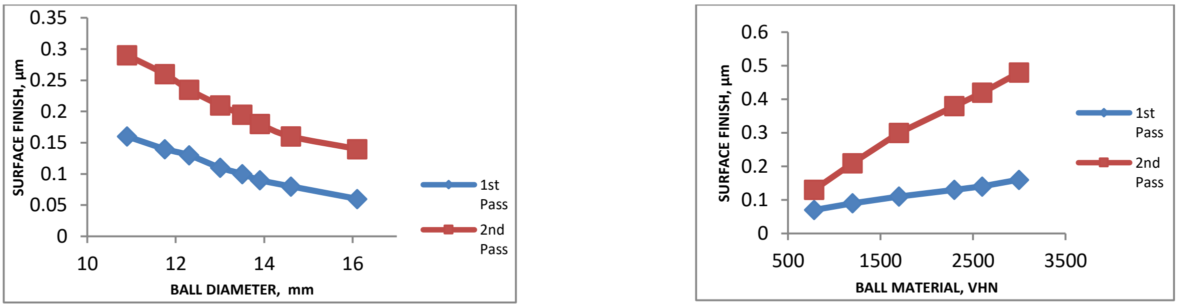
```
Name ▲     Value
C          0.0100
D          10
D_val      10x10 double
Dmax       17.2500
Dmin       10.7500
F_val      10x10 double
Fmax       45
Fmin       15
```

```
%-- 05-05-2022 17:03 --%
  TLBOCustom
%-- 05-05-2022 17:07 --%
  BFOCustom
  bfo 2
%-- 05-05-2022 17:16 --%
  bfo 2
%-- 05-05-2022 17:17 --%
%-- 05-05-2022 17:29 --%
  BFOCustom
```

Fig. 5. MATLAB BFO Output

RESULT AND CONCLUSION

The outcome values of the surface finish obtained at different levels of ball burnishing parameters are noted and indicated in graphical form as under.



(i) (ii)

Fig. 6. Relationship between i) Ball Diameter & Surface Hardness ii) Ball Material & Surface Finish

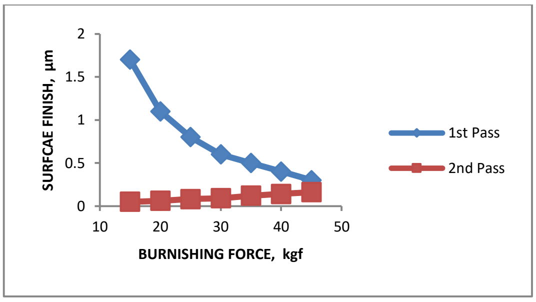


Fig. 7. Relationship between Burnishing Force and Surface Hardness

Analysis of results obtained (FIRST PASS) indicates that, increase in ball diameter improves surface finish in case of Aluminium AL 6082. Also, as burnishing force increases, the surface finish increases and surface finish decrease with increase in ball diameter hardness when all other parameters are kept constant. After SECOND PASS, Increase in all diameter improves surface finish whereas increase in burnishing force, decreases finish. As well, with increase in ball hardness, finish gets deteriorated.

The experimental verification of the optimum values suggested by BFO lead to confirmation of 94%. This effect is observed due to the rounding of the values to the available parametric range as.

D = 16.1 mm, M = 2300 VHN, F = 25 kgf to obtain Ra = 0.09 µm

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