SINGLE FACTOR EXPERIMENTATION ON LOW PLASTICITY BURNISHING PROCESS FOR AISI 4340

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ABSTRACT

A single factor experimentation using low plasticity burnishing (LPB®) tool is carried out to identify and studied the effect of process parameters on surface layer characteristics. Output parameters for deciding surface characteristics are surface roughness, hardness, fatigue life. Input variables considered are Number of passes Ball Diameter, Burnishing Pressure, Speed, Initial surface roughness, Feed, Oils used and Ball material. Experimentation is aimed at understanding the system behavior and significance of these input parameters on output parameters for steel alloy AISI 4340.

LPB® is a registered trademark of Lambda Technologies group.

Keywords: LPB®, surface roughness, surface hardness, fatigue life, number of passes, ball diameter, Burnishing Pressure, Speed, Initial surface roughness, Feed, Oils used and Ball material.

I.INTRODUCTION

The recent methods reported in literature for mechanical surface treatments of metals includes conventional burnishing, shot peening, laser peening, water peening, liquid peening, etc [1]. The burnishing is simple in tooling, economical and efficient compared to grinding, honing, super finishing and polishing. These surface enhancement methods have shown their applicability with different degree of freedom. Burnishing process has additional advantages such as increased hardness and fatigue life as a result of compressive residual stresses, wear resistance, etc. [2]. Low Plasticity Burnishing(LPB®) differ from other conventional burnishing processes such as ball burnishing and roller burnishing in a way that it produces less cold work with higher depth of compression. Some of the surface characteristics which can be improved with LPB are surface finish, micro hardness of the surface, low and high cycle fatigue strength, foreign object damage (FOD) tolerance, corrosion resistance, out of roundness and straightness, wear resistance, etc. [3].

LPB produces minimal cold work which offers greatest resistance to thermal relaxation at elevated temperature. Residual stress distribution can exceed well beyond depth of corrosion pits so as to suppress fatigue cracks initiation and corrosion. Residual stress and cold work distribution by other surface treatment methods are compared with LPB for 1N718 [4]. Fatigue life of AA 7075-T6 is at least 100 times greater for LPB caused due to reduction in corrosion mechanism [5]. The investigation for IN718, Ti-6Al-4V, 17-4Ph steel have been carried out to find out the relation between percentage of cold work, depth of compressive layers and residual stresses [6]. LPB (for Ti-6Al-4V) is used to improve high cycle fatigue damage tolerance of turbine engine compressor components [7]. The experimental models for surface finish, hardness and fatigue life are developed using factorial design of experiment, considering ball diameter, speed pressure and no, of tool passes as a significant factor for AISI 1045 material [3]. Mathematical model is presented based on Hooke's law and is validated using Taguchi orthogonal array considering speed, part diameter and no. of passes [8]. The experimentation on depth and magnitude of compression and fatigue and damage tolerance has been carried out for turbine blades. The micro cracks are found to be fully arrested by LPB to the depth of 0.75mm. [9]. Correlation of surface roughness depends on the work material, as order of significant factors is different for 316 L SS, Ti-6Al-4V. Experimentation with factorial design and ANNOVA gives relation for surface roughness [10].

For traditional roller and ball burnishing much of the knowledge is available as these methods are studied by the many investigators for different applications. However, a little knowledge is available for LPB process to get its maximum efficiency particularly for steel material. Literature review reveals that more study is required to emphasize the benefits of LPB on steel material, particularly for the steel material which has to sustain high load, high temperature, high corrosion environment, etc. there are some materials which can inherently sustain the above requirement due to their desired material composition. But the cost of these materials may be very high. It is required to introduce all the above properties to get benefits of high cost material with low cost material also. LPB proved its utility to enhance the above surface properties with low cost. In this paper a preliminary experimentation is presented to find out the significant factors for a steel alloy AISI 4340 which is comparatively low in cost.

II.MATERIAL AND EQUIPMENT

2.1 Material

The experimentation is carried out on AISI 4340 steel alloy containing chromium, nickel and molybdenum. The material has high toughness and strength in the heat treated condition. The composition and properties of AISI 4340 steel is given in table 1. AISI 4340 mostly used in applications requiring higher tensile/yield strength. Some typical applications are aircraft landing gear, heavy duty shafts, gears, axles, spindles, couplings, and pins in automobile industries. It also used in heavy duty applications like oil and gas mining drilling and machine buildings, etc. [11].

Table 1 Chemical composition and properties of AISI 4340 alloy steel

Element	Content (%)
Iron, Fe	Balance
Nickel, Ni	1.75 - 2.01
Chromium, Cr	0.700 - 0.900
Manganese, Mn	0.65

Carbon, C	0.377
Molybdenum, Mo	0.200 - 0.300
Silicon, Si	0.24
Sulfur, S	0.0400
Phosphorous, P	0.0350

Properties	**Metric**
Tensile strength	745 MPa
Yield strength	470 MPa
Bulk modulus	140 GPa
Shear modulus	80 GPa
Elastic modulus	190-210 GPa
Poisson's ratio	0.27-0.30

2.2 Specimen Preparation and Measurement

Standard specimens, as shown in Fig 1, were prepared for selected AISI 4340 material and heat treated before turning. Mitutoyo Surface roughness tester with a least count of 0.02 µm was used. Initial surface hardness was measured on micro hardness tester with a load of 1 N and Initial surface hardness found to be 209 Hv. Un-burnished standard specimens were tested on fatigue testing machine for fatigue life and was found to be 2, 45,326 numbers of cycles. The speed of rotation of specimen was 4500 rpm with bending moment of 20 Nm.

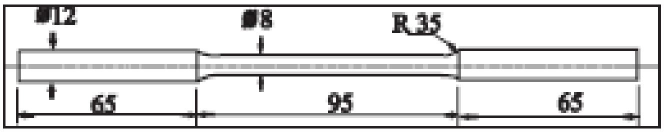

Fig 1 Standard fatigue specimen

2.3 LPB Tool

Figure 2 shows the basic principle of LPB process, in which a ball is supported in a spherical hydrostatic bearing. The tool can be held in CNC machine or by industrial robot, depending on the application. The machine tool coolant is used to pressurize the bearing with continuous flow of fluid to support the ball. The ball does not contact the mechanical bearing seat, even under load. The ball is loaded at a normal force to the surface of a component with a hydraulic cylinder that is in the body of the tool.

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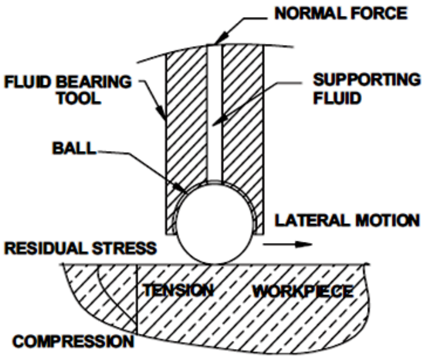

Fig 2 Principle of low plasticity burnishing

The ball rolls across the surface of a component in a pattern defined in the CNC code, as in any machining operation. The tool path and normal pressure applied can be designed to create a distribution of compressive residual stress. Since there is no shear being applied to the ball, it is free to roll in any direction. As the ball rolls over the component, the pressure from the ball causes plastic deformation to occur in the surface of the material under the ball.

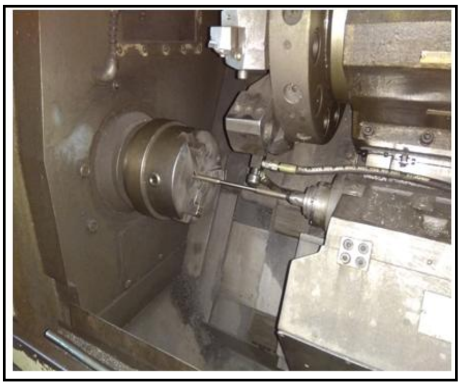

Fig. 3 Experimental setup LPB tool on CNC machine

Single factor experimentation using newly developed LPB tool (fig 3) is carried out to identify and study the effect of process parameters on surface layer characteristics. Output parameters for deciding surface characteristics are surface roughness, hardness, fatigue life. Input variables considered are Number of passes Ball Diameter, Burnishing Pressure, Speed, Initial surface roughness, Feed, Oils used and Ball material. Experimentation is aimed at understanding the system behavior and significance of these input parameters on output parameters for steel alloy AISI 4340.

III. EXPERIMENTATION

As per the newly developed LPB tool, the experimentation is conducted on standard fatigue specimen for a steel alloy AISI 4340. The influence of each of the above variables on surface roughness (Ra), surface hardness (H_W) and fatigue life (FL) has been shown in figs 4 to 11.

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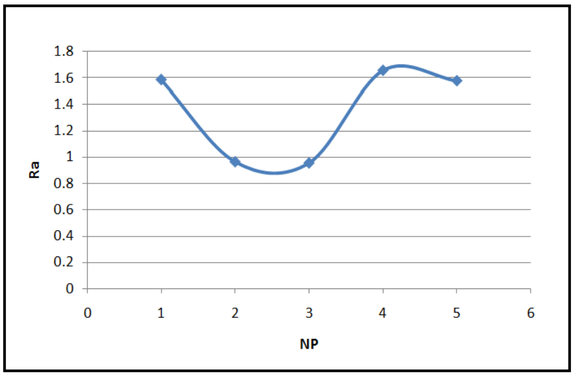
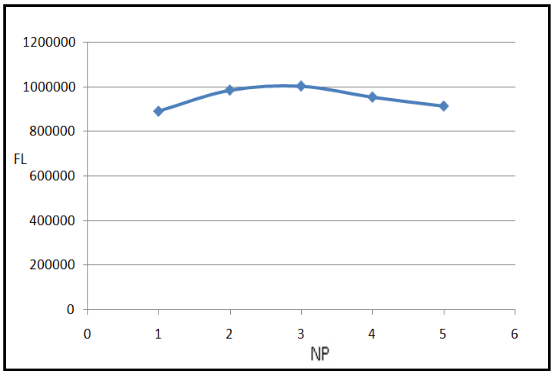
3.1 Effect of Number of passes (NP) on Ra and FL

The influence of number of passes on Ra(µm), as shown in figure 4(a), indicates that surface finish improves with increase in number of passes upto 3 as it increases the structural homogeneity. Later it decreases as repetition of burnishing action on same surface results in excessive plastic deformation. Increased surface finish results into improvement in fatigue life which is shown in fig 4(b). It is due to elimination of flaws on the surface.

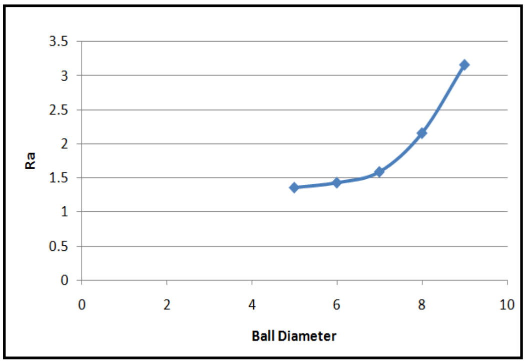


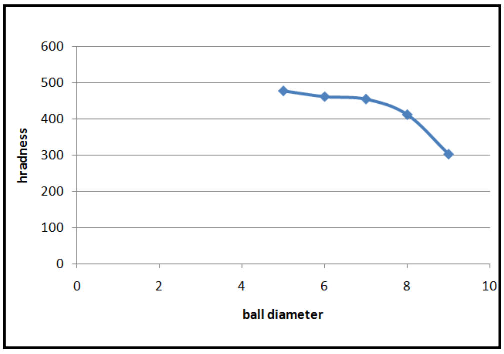


(a) (b)

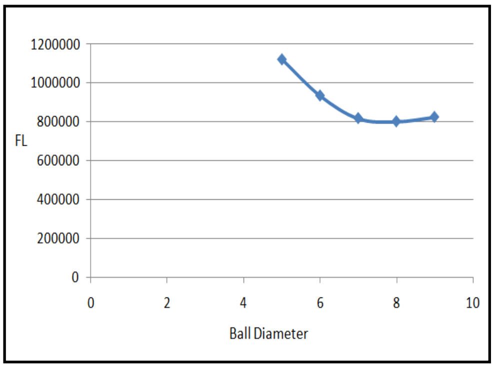
Fig 4 Effect of Number of passes (NP) on Ra and FL

3.2 Effect of Ball Diameter on Ra, H_W and FL





(a) (b)



(c)

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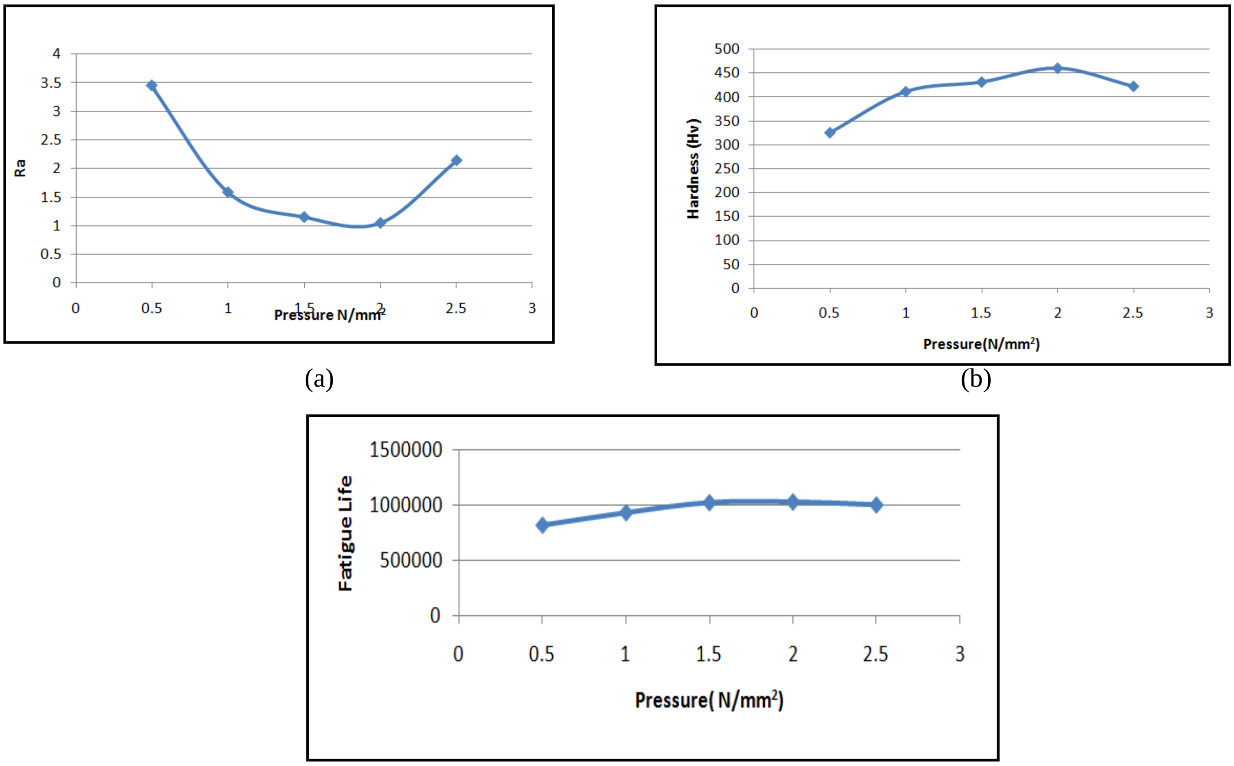
Fig. 5 Effect of Ball Diameter (BD) on Ra, H_W and FL

Preliminary experimentation reveals that the least ball diameter results in the maximum performance on surface roughness, hardness and fatigue life (refer fig 5a, 5b and 5c). It is so because larger ball diameter increases contact area between the ball and working surface which in turn minimizes the burnishing pressure per unit area. This reduces ball capacity to penetrate and compress the asperities which is also responsible for deformation of the surface.

3.3 Effect of Pressure on Ra, H_W and FL

Figures 6a, 6b and 6c show effect of pressure on Ra, H_W and FL, respectively. Increase in pressure result into increase in deformation and hence gives favorable effect on all responses. The response pattern also indicates that Ra, Hw and FL start deteriorating after 2 N/mm^2, which may be because spherical ball starts vibrating due to excessive supply of fluid (pressure).



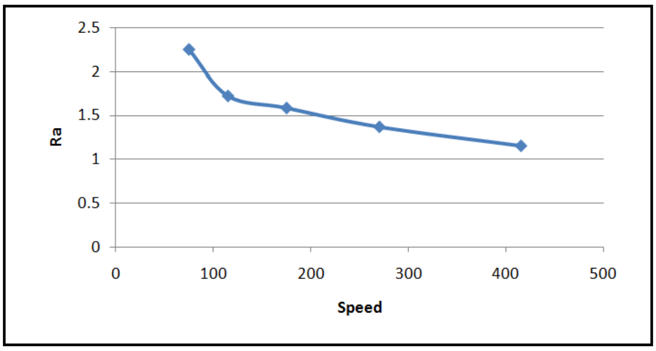
(a) (b)

(c)

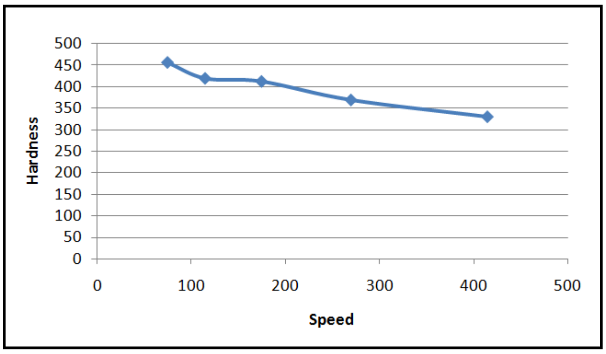
Fig. 6 Effect of Pressure on Ra, H_W and FL

3.4 Effect of Speed on Ra, H_W and FL

With high burnishing speed, the roughness as well as fatigue life improves (ref fig 7a and 7b) because the superficial layer of deformed zone tends towards the state of soft contact which reduces friction in tool part system and improves roughness. However rigidity of tool also plays an important role. Hence increasing a speed beyond certain values is not desirable. Surface hardness gets decreased with increase in speed, as shown in fig 7c. It is so because less time shall be available for strain hardening, when speed is more.



(a)



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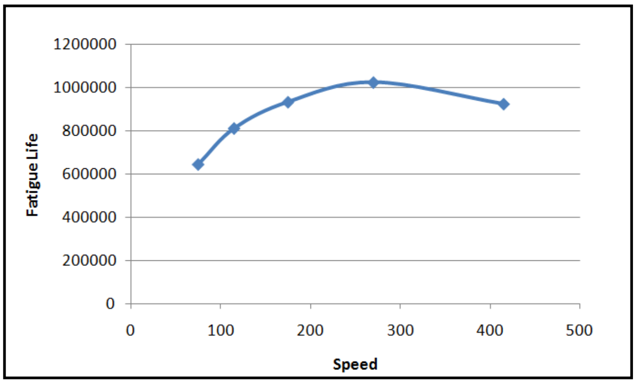
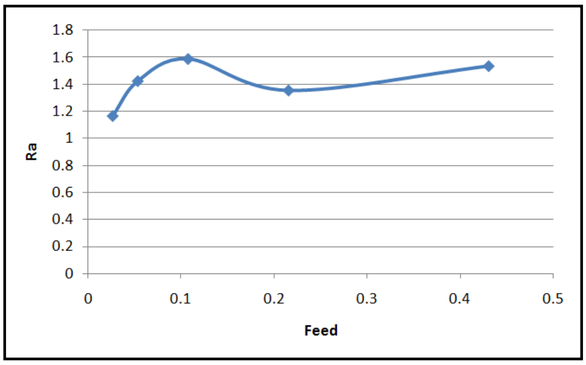


(c)

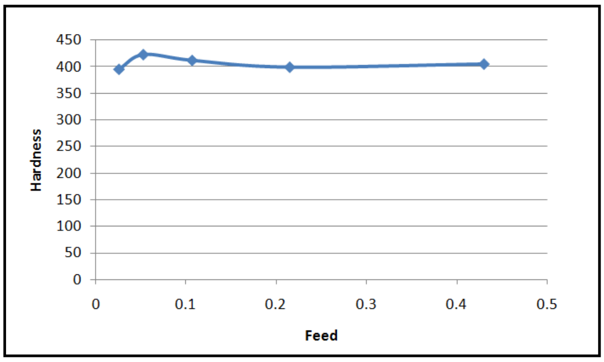
Fig. 7 Effect of Speed on Ra, H_W and FL

3.5 Effect of Feed on Ra, H_W and FL

The effect of feed on Surface Roughness (Ra), Surface Hardness ($H_{W)}$ and Fatigue Life (FL) is shown in fig. 8a, 8b and 8c. The preliminary experimentation indicates that there is no significant change in responses. Due to small diameter of the component less than 10 mm) further increase the feed is not possible. In other words, for larger diameter of the workpiece, the possibility of effect of the feed on the responses cannot be denied.



(a)



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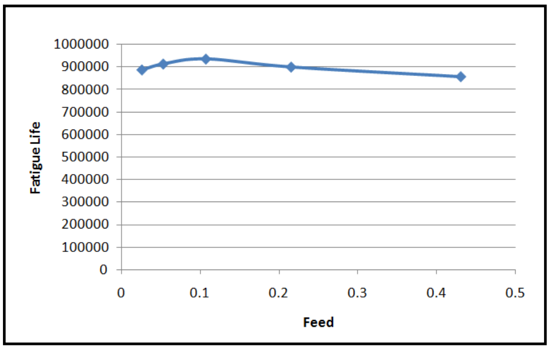
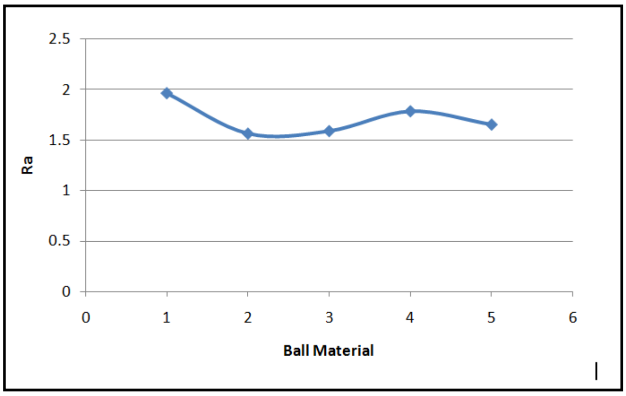


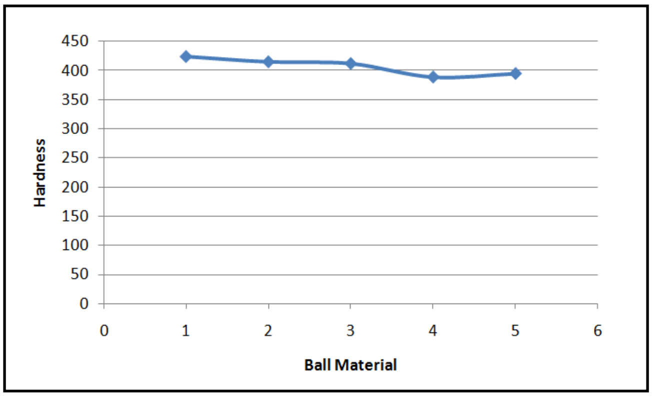
(c)

Fig. 8 Effect of Feed on Ra, H_W and FL

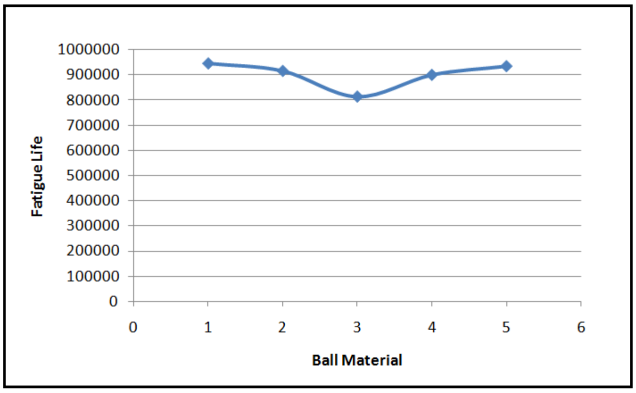
3.6 Effect of Ball Material on Ra, H_W and FL

The effect of ball material on Surface Roughness (Ra), Surface Hardness (H_W) and Fatigue Life (FL) is shown in fig. 9a, 9b and 9c. The different ball materials are (1) Steel (740 Hv), (2) Carbon chromium steel ball(790 Hv), (3)Tungsten carbide ball (968 Hv), (4)Tin coated carbide ball(819Hv), (5)Heat treated steel ball (811 Hv). The preliminary experimentation indicates that there is no significant change in responses. As the floating action of the rolling ball compensate the final contact pressure between the ball and workpiece, the increased hardness of the ball material gives negligible effect on the responses.





(a) (b)

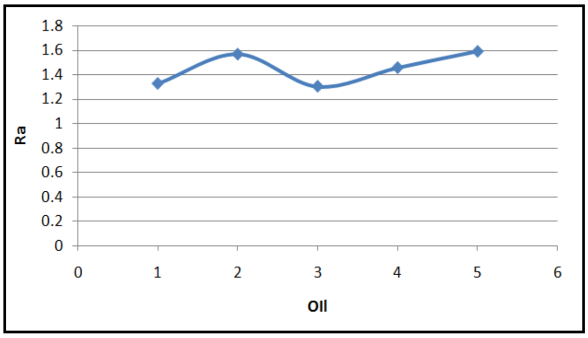


(c)

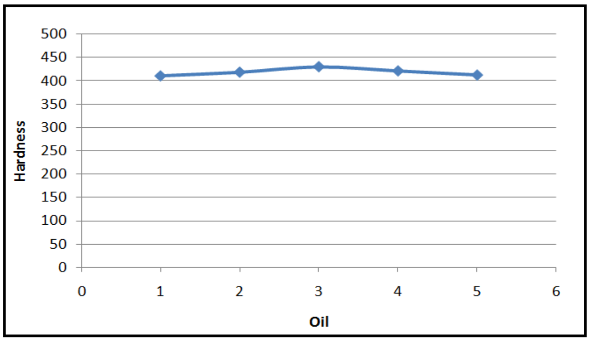
Fig. 9 Effect of Ball Material on Ra, H_W and FL

3.7 Effect of oil (Viscosity) on Ra, H_W and FL

For preliminary experimentation, the oils with different viscosity (SAE30 (1), SAE40 (2), SAE50(3), SAE60(4) and SAE 70(5)) are considered. Effects of different oils on Surface Roughness (Ra), Surface Hardness (H_W) and Fatigue Life (FL) are presented in fig. 10a,10b and 10c. The figures demonstrate negligible effect which may be due to almost negligible variation in viscosity of oils. Also after the contact between the ball and the workpiece oil loses its viscosity.



(a)



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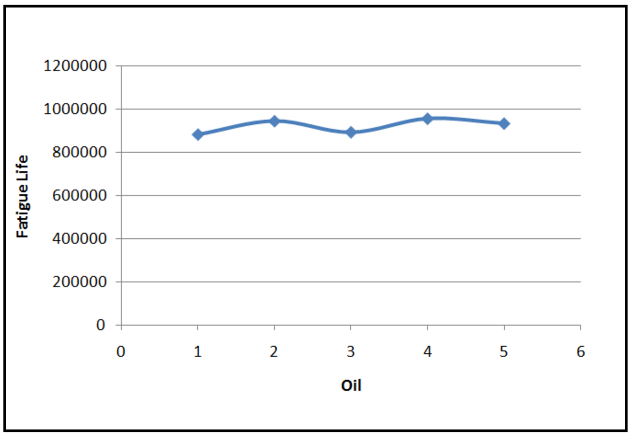
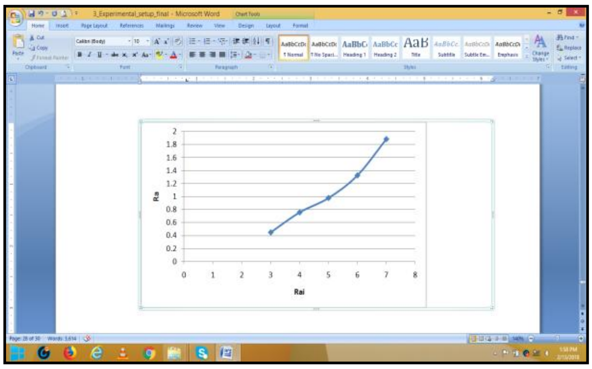


(c)

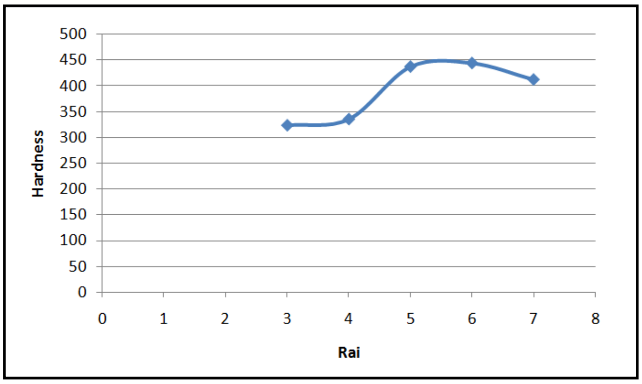
Fig. 10 Effect of oil (Viscosity) on Ra, H_W and FL

3.8 Effect of initial surface roughness on Ra, H_W and FL

Initial surface roughness (Rai) is found to play a remarkable influence on all three responses. Surface roughness, as shown in figure 11a, increases with increase in initial surface roughness which is not unnatural. It ultimately results into decrease in fatigue life, as shown in fig 11b, because of increase in surface flaws. However, hardness decreases with decreases in initial surface roughness, as less material is available for deformation which is needed for work hardening (fig 11c).



(a)



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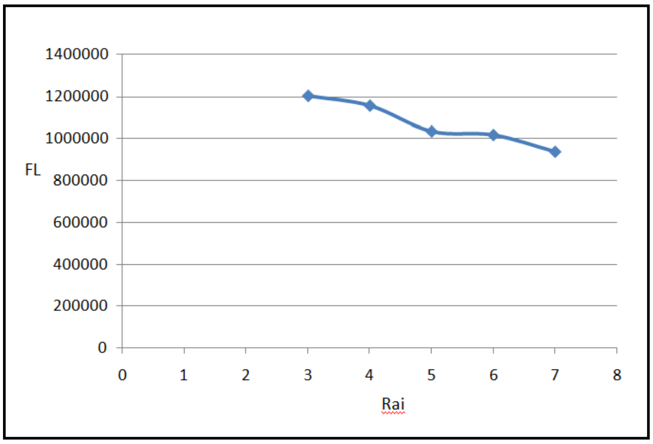

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Fig. 11 Effect of initial surface roughness on Ra, H_W and FL

IV.CONCLUSION

1. As per the experimentation from figs 4 to 11 it is seen that number of passes, ball diameter, pressure, speed and initial surface roughness are the significant factors affecting surface roughness, surface hardness and fatigue life. While the effect of feed, ball material and different oil is negligible.
2. It is also observed for surface roughness and fatigue life enhancement the effect of all input variable is same.
3. To reduce surface roughness and to increase fatigue life number of passes should be 2 to 3. Ball diameter should be at low level. Medium range of pressure gives favourable result, while speed should be at higher level. Lower value of initial surface roughness gives better result for both.
4. To increase surface hardness ball diameter should be at low level. Medium range of pressure gives favourable result, while speed should be at low level. Medium range of initial surface roughness gives increased surface hardness.
5. However the interaction of all above input parameters may give the different result. For the further optimization a scientific approach to plan the experiments is a necessity for efficient conduct of experiments.

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