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Analyzing effect on R_a after super finishing of Stainless Steel ball bearings using Magneto Rheological fluid

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ABSTRACT

The work deals with improving surface roughness with the use of Magneto Rheological fluids for polishing of non-magnetic bearing balls. A special equipment has been designed and fabricated to suit the requirements with reduce components of the system. This has been affected through the use of 3D printing technology to improve the quality and reduce the weight of the components. The feasibility of the process has been analyzed and the output of the process is proved through roughness testing. The results show a clear variation in the surface parameter i.e. R_a before and after polishing. The system has been run for various time intervals and the variations were observed and documented. Atomic force microscopy was used to analyze the results further to understand the change in surface parameters in the nanometer scale.

KEY WORDS: Magnetic float polishing, 3D printing, Roughness, non-magnetic bearing material, Atomic Force Microscopy.

1. INTRODUCTION

In modern times great emphasis has been put on the service life of a component. Efforts have been continuously taken to improve the quality of the component and thus improve customer satisfaction. As demand grows for reliable products with less maintenance costs, manufacturers focus on the methods to improve the surface finish of rolling element bearings. Methods involving the use of Magneto rheological fluids doped with abrasive particles to be used to super finish bearing balls are materialized and equipment for performing the same are being developed. The most common type of bearing balls commercially used is made of steels of different grades for varied applications. The common types for corrosion resistant use are made of AISI 314 and AISI 304. The materials have excellent corrosion resistance but suffer due to lack of hardness and inability to be hardened. In such bearings abrasive wear is prominent and hence they are restricted to light load applications. Such bearings can be optimized by further finishing the surface. The surface asperities are the fundamental reason for the initiation of abrasive wear. Thus the aim was to analyze the reduced surface roughness by the elimination of asperities (Jitender Panchal, 2013). The asperities have peak heights in the micron levels. These asperities cannot be machined easily using conventional methods as it increases the cost to a large extent. The magnetic polishing process employed gives way for this removal by the action of hard abrasives over the softer work piece material. This has been identified to be one of the applications of MR Fluids currently under study (Spaggiari, 2012). Magnetorheological fluids have been employed in the process and the abrasive media is prepared through the addition of abrasive particles to the MR fluid (Kciuk, 2006; Turczyn, 2006). Proof for the ability of MR fluid based abrasives to surface finish steel balls is theoretically studied (Anil Malpotra, 2014). The custom equipment designed and fabricated has implied the concepts developed through the analysis and the bearing balls were processed for different times to obtain the results. The testing has been done to prove the effectiveness of the process by providing the R_a values for the balls before and after processing. The processing times have been iterated and altered to achieve feasibility in operation.

Working Principle: The equipment is made based on several theories, the concept has been adopted with modifications based on the requirements. For super finishing action to take place on a ductile material, the fundamental requirements are,

- There should be small load acting on the ball to keep it in contact with the abrasive MR fluid.
- There should be some relative motion between the abrasives and the ball.
- The size of abrasives should be optimum and hence selection of MR fluid is important.
- The selection of surfactants and additives is solely based on application requirements.
- The abrasives must be able to remove the asperities and disperse them in the fluid.

The main modes of wear occurring in ductile materials to reduce the life of the component are adhesive and abrasive wear (Jitender Panchal, 2013). Adhesive wear can be compensated by inducing boundary lubrication between the bodies in relative motion. Abrasive wear on the other hand is a critical component. The asperities are the peaks that are present on the surface of the component. They are weaker portions of the system and have yield strengths as low as 1/10 of the yield strength of the material itself. This is due to a thin cross section and improper material resistance to loading. The asperity tends to shear off or deform depending on the loading conditions and when it shears off the released particles of the parent material act as wear inducers.

Rate of abrasive wear can be approximated based on the loading conditions, type of abrasive used, materials young's modulus, work hardening abilities etc. (Shimada, 2007). The experimental results provide more accurate description.

An equipment carrying the MR Fluid, bearing balls and neodymium magnets has been fabricated as shown below in Fig 1. Few components are 3D printed to make the equipment flexible and easy in manufacturing. A motor rotates the materials carrying element at 1500 to 3000 rpm and can be controlled by a regulator. The design complies with ASME Y14.5-2009 standards of dimensioning.

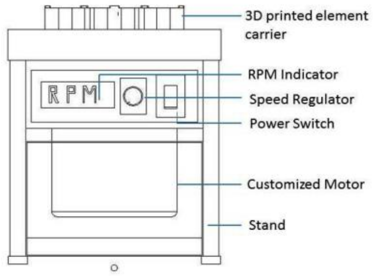

Figure.1. Polishing Machine

The calculated centrifugal force can exert a load near to 1 kgf or 0.1N on the bearing ball to push them towards the walls. The magnetic field to hold the iron particles to the walls is provided by strong rare earth magnets and the abrasive particles get embed in the resulting viscous fluid. As the MR fluid changes its viscosity when a magnetic field is applied, it provides the necessary force required for the abrasives to remove the asperities. The fine particles were mechanically fabricated for use in magneto rheological fluids. Oleic acid was used as a surfactant for the dispersed substance for preparing the hydrophobic fluid with silicon oil as a dispersing medium (Taeghwan Hyeon, 2002). The oleic acid is adsorbed into the surface of the Fe particles and thus forms a stable colloidal solution with Si particles being held by the viscosity change and hard particle models are apparent. The proportion of Fe and Si particles is experimental. For the apparatus, the solution has been prepared to 15% wt of Fe particles and 7.5% wt of Si particles for the given weight of solution. The particle size for the experiment is chosen to be 1-2 microns and that of silicon carbide is 3-4 microns. The MR fluid has been designed to suit the requirements. These particles can bring down the finish to sub-micrometer scale.

2. METHODS & METERIALS

Material Specifications: The material data sheets for the components used have been tabulated below. The material is selected as per machining requirements. Table 1 shows the nature of the silicone oil. It is also to be noted that the sealing of silicone oil is very difficult and thus have to be carefully handled. Table 2 provides the data on oleic acid, its physical and chemical properties. Table 3 shows the properties of silicon carbide, its particle size, density etc. Similarly, Table 4 gives data on iron carbonyl, its particle size with respect to the sieve used and hydrogen loss data.

Table.1. Data on silicone oil

Specifications Data	Value
Chemical Name	Silicone Oil
Chemical Composition	(...Si−O−Si−O−Si...) end capped with trimethylsilyl groups
Density	971 kg/m³
Boiling point	65ºC
Viscosity	1000 cSt
Supplier	Lab Chemicals, Chennai, India.

Table.2. Data on oleic acid

Specifications Data	Value
Chemical Name	Oleic Acid
Chemical Composition	$C_{18}H_{34}O_2$
Density	895 kg/m³
Boiling point	360 °C
Supplier	Lab Chemicals, Chennai, India.

Table.3. Data on silicon carbide

Specifications Data	Value
Chemical Name	Silicon Carbide
Chemical Composition	SiC
Particle Size	3-4 microns
Manufacturer	SoMit Textrade Private Limited, Surat, India.

Table.4. Data on iron carbonyl

Specifications Data	Value
Apparent Density	1.3g/cm^3 max
Particle Size	1.5- 2.5 microns
Manufacturer	SoMit Textrade Private Limited, Surat, India.

Measurement Data: The roughness of the surface is the measurement under consideration for analysis. Roughness means the deviations in the normal direction of a real surface from its ideal level. Ideal surface is the one which has zero asperity levels or in other words perfectly smooth. For the parameters under consideration, the average roughness value (R_a) has been considered. The average roughness is the value which is taken over a sampling length and then the averages of the peaks and valleys are taken over a modulus. This is done mainly to understand the surface profile in a generalist manner and thus conclude whether the surface has undergone any changes in the topographical consideration. The apparatus used is a Surfcorder SE 3500 D which measures the roughness profile of a given surface. The apparatus is a contact type profilometer and thus a stylus probe touches the surface of the component and traverses across the profile. Graph is generated based on the height of the asperities and thus the average height is calculated by the software. Venkatraman (2015), to remove these errors off the equation in manufacturing dies, one of the modern techniques of manufacturing, Electrical Discharge Machining (EDM) can be implemented. Precision is important in die making; punches and dies must maintain proper clearance to produce parts accurately.

3. RESULTS

The cutoff length is the minimum length for which the probe has to travel so that it can provide useful readings. Hence care should be taken while selecting a sampling length. Here the cutoff length for the machine is about 0.8 mm and the traverse length has been fixed to 2.4 mm. The testing is performed as per ASME B46.1 1995 and the results have been analyzed.

The results of analysis are shown in the below figures. The Fig 2. Shows the average roughness value of an untreated ball, Samples have been processed for different time intervals. Fig 3. Clearly shows that there is a large improvement of the surface roughness when the ball is treated for 2 hours. The average roughness value decreases from 1.88 microns to 0.52 microns (Fig.4).

Figure.2. Roughness Test of the specimen before finishing process

The probe travel generates the necessary deflection of the tip which is translated into the graph showing the amplitude of movement in the vertical direction when the probe traverses. The results show clearly that the average heights of the asperities have dropped from 1.88 microns to about 0.53 microns.

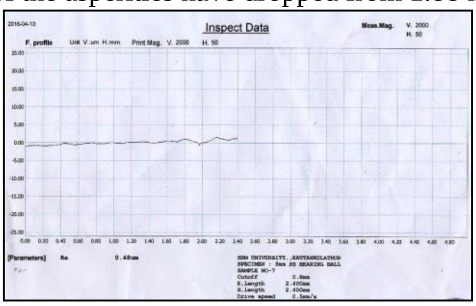

Figure.3. Roughness Test of the specimen after 2 hour run

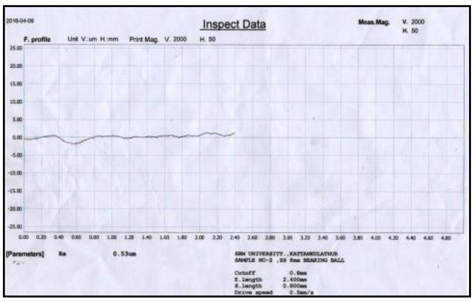

Figure.4. Roughness Test of the specimen after 4 hour run

Table.5. Roughness Results for varying runtimes

Sample Number	Run time(hrs)	Roughness Average (R_a) (microns)
1	0	1.88
1	2	0.48
2	4	0.53

Imaging Results: The surface topography has been analyzed in Olympus optical imaging microscope and the results are shown below. In a 20X Magnification scale over an area of 3 mm diameter was taken for consideration. The Figure 6 shows the stock component under the microscope. The image shows large troughs in the surface of the specimen. These are generally crack initiators. In Fig 7, the surface has been abraded by the silicon carbide particles thus showing large number of scratches on the surface. It is also seen that the number of crack initiators and their size has been reduced. In Figure 8 the surface has been removed from the scratches and troughs by the further action of silicon carbide particles and thus showing a large improvement on the surface of the specimen. The results thus validate the roughness test and bring about an understanding about the nonlinear material removal and surface improvement.

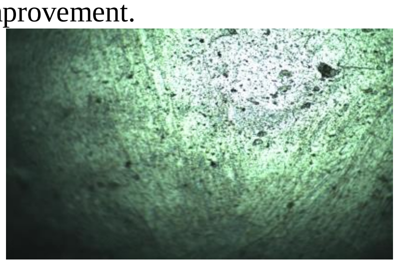

Figure.6.Image result of unfinished specimen

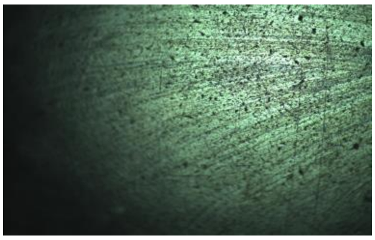

Figure.7.Image result of specimen after 2 hours run

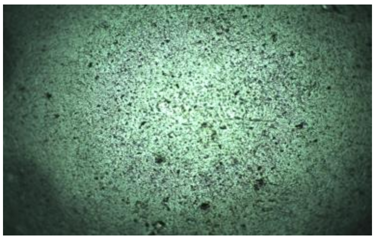

Figure.8.Image result of specimen after 4 hours run

Atomic force microscopy results and analysis: Use of atomic force microscope to study the topography of surfaces have been discussed in many research works. It gives a clear understanding of the changes in the topography in the nanometer scale (Gerd, Bennig, 1988).

Initial analysis for 0 hour sample shows that the roughness for the localized region contains asperities and 3d topography shows the irregularity on the surface. The average roughness value was observed at 16.976 nm and the RMS roughness value was seen to be at 22.622 nm. This is represented in Fig 9.

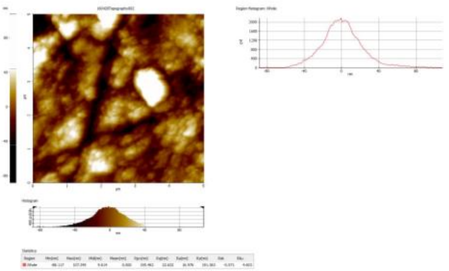

Figure.9.AFM roughness image for 0 hours sample

Analysis of Fig 10 which shows the results for 2 hour sample shows that the roughness for the localized region contains asperities has reduced considerably and 3d topography shows the irregularity on the surface reduced after 2 hours of polishing. The scratches left over by the action of abrasion are seen as dark streaks over the surface of the metal. The asperities have shown considerable yielding after constant action of the abrasives over their surface. The average roughness value was observed at 10.891 nm and the RMS roughness value was seen to be at 14.267 nm.

Analysis for 4 hour sample shows that the roughness for the localized region has reduced exponentially and 3d topography shows improved surface finish of the sample. The surface has been clearly abraded and the roughness average value has been depreciated. The asperities have been removed to a large extent and the surface has been cleared of the debris also. The silicone oil has acted in removing the debris and settling it to the bottom. The average roughness value was observed at 9.471 nm and the RMS roughness value was seen to be at 12.766 nm. This is shown by Fig 11.

Analysis: The analysis of the data shows clearly that the roughness value of the specimen decreases non linearly till the 8 hour runtime. It then gradually increases as we approach the 16 hour runtime. This is mainly because the mode of wear is unbalanced and the vibration energy balance could have affected the performance over time. Thus the peak cutoff time for the process is fixed at 8 hours and the specimen roughness has been reduced from 1.88 microns to 0.53 microns. The analysis proves the working of the MR fluid over the surface of the specimen. The lubrication adsorption on the surface can now be uniform and boundary lubrication conditions work more uniformly over the topography.

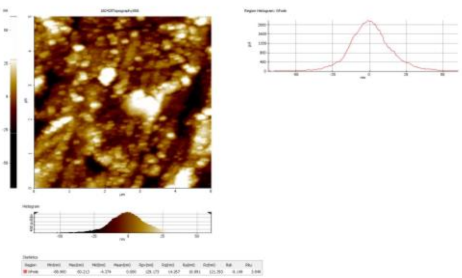

Figure.10.AFM roughness image for 2 hours sample

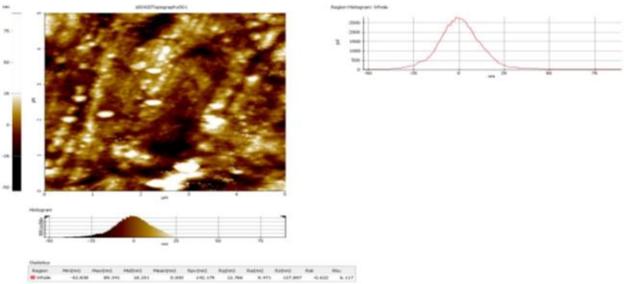

Figure.11.AFM roughness image for 4 hours sample

4. CONCLUSION

The results clearly show a reduction in the R_a value of the surface of the sample. This indicates that the process in experimental conditions is feasible and has further scope of improvement. The component possesses better wear life and thus service period has been improved. Further, the bearing balls can be coated with chrome alloys to improve the surface characteristics. The surface roughness obtained is well within the limits as if there is any further reduction, the chances of adhesive wear under boundary lubrication conditions is prominent. Hence the balance has been maintained for the same. Atomic force microscopy has provided a clear insight on the surface topography on a nanometer scale. The observed results show improvement in the surface roughness over the sample area. This provides the inference that the surface roughness can be effectively improved using the implied method and the custom fabricated machine provides satisfactory results.

5. ACKNOWLEDGEMENT

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