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FINITE ELEMENT ANALYSIS OF BALL BURNISHING PROCESS OF ALUMINIUM ALLOY 6061 T6

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Abstract: *In this paper, ball burnishing as a mechanical surface treatment for improving productivity and quality of rotating shafts is presented. When this method is applied after conventional turning, the resulting process is rapid, simple and cost effective, directly applicable in lathes and turning centers of production lines. This process provides good surface finish, and surface hardness increment of the surface layer, which in turn improves wear resistance, increases corrosion resistance, improves tensile strength, maintains dimensional stability and improves the fatigue strength of the work piece. This paper deals with finite element analysis of burnishing process on aluminum alloy 6061 T6 material using Lathe machine. The input parameters are speed, feed& Burnishing force and the output parameter is surface roughness.*
Results show that burnishing is an economical and feasible mechanical treatment for the quality improvement of surface roughness of rotating components.

Keywords*- Ball Burnishing process, Ball burnishing tool, Finite Element Analysis, Aluminium, Surface roughness.*

I. INTRODUCTION

In today's manufacturing industry, special attention is given on surface finish along with dimensional accuracy and geometrical tolerance. Comparing with other finishing process such as grinding, honing, burnishing is chip less process. Burnishing is a cold working surface finishing process which is carried out on material surfaces to induce compressive residual stresses and enhance surface qualities. A burnishing tool typically consists of a hardened sphere which is pressed onto across the part being processed which results in plastic deformation of asperities into valleys. In burnishing process the initial asperities are compressed beyond yield strength against load. The surface of the material is progressively compressed, then plasticized as resultant stresses reach a steady maximum value and finally wiped a superfine finish.

1.1 Burnishing Operation

The burnishing process, shown in Fig 1 is based on the rolling movement of a ball against the work piece surface, a normal force being applied at the tool. As soon as the yield point of the work piece material is exceeded, plastic flow of the original asperities takes place. This phenomenon leads to a smoother surface. At the same time, compressive stresses are induced in the surface layer, followed by strain hardening and a series of beneficial effect on mechanical properties. Burnishing can improve both the surface strength and roughness. The increase of surface strength mainly serves to improve fatigue resistance under dynamic loads.

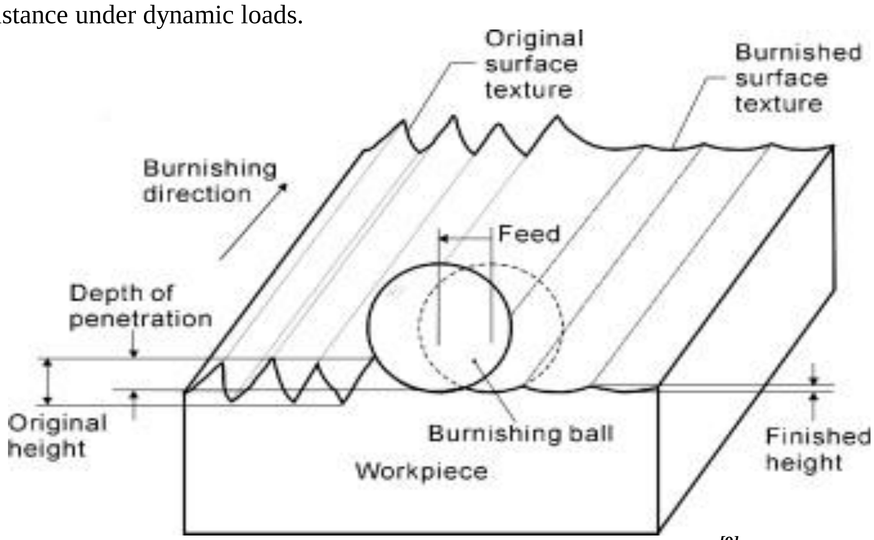

Fig 1 Schematic diagram of Ball Burnishing Process[9]

Burnishing is a cold working process in which plastic deformation occurs by applying a pressure through a ball or roller on metallic surfaces as shown in Fig 2. It is a finishing and strengthening process. Improvements in surface finish, surface hardness, wear resistance, fatigue resistance, yield and tensile strength and corrosion resistance can be achieved by the application of this process.

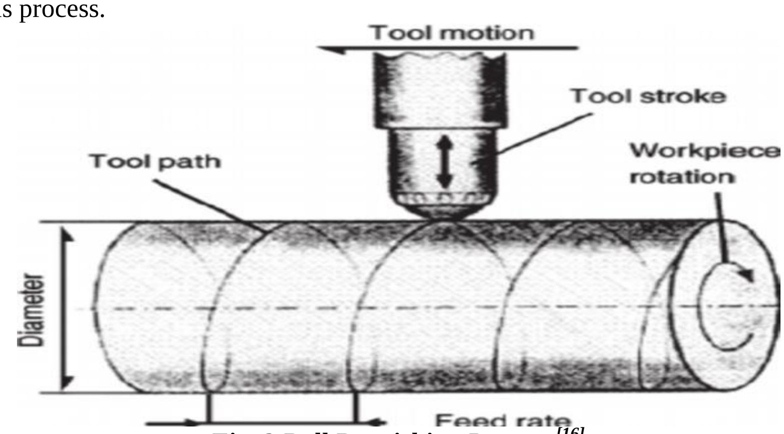

Fig. 2 Ball Burnishing Process [16]

Burnishing is one of the important finishing operations carried out generally to enhance the fatigue resistance characteristics of components. Burnishing tools are used to impart a gloss or fine surface finish, often in processes that involve the cold working of metal surfaces. Burnishing tools are also used for the sizing and finishing of surfaces. Burnishing process can be typically classified into two categories as:

1. Based on deformation element
   a. Ball burnishing
      i. Flexible
      ii. Rigid
   b. Roller burnishing

2. Based on the motion of the tool, on the surface
   a. Normal or ordinary
   b. Impact
   c. Vibratory

1.2 Process Parameters of Burnishing Operation

The ball Burnishing process can be controlled by the various process parameters which are known as ball burnishing process parameters. All these process parameters need to be controlled and optimized to get the best results. The various parameters are as follows:

1. Burnishing speed
2. Feed Rate
3.Burnishing Force

1.2.1 Burnishing Speed

It is the speed at which the work piece rotated during burnishing operation. The Burnishing speed is given to either work piece or tool. In curved surface burnishing operation the workpiece is rotated and in the flat surface burnishing operation the tool is rotated and the work piece remains stationary. Burnishing speed is mainly given in rev/min or mm/min or rad/sec.

1.2.2 Feed Rate

Feed rate is the linear velocity with which the tool is fed i.e. advanced against the work piece. The feed rate is mainly measured in mm/rev. The feed rate mainly depends on the amount of surface finish desired. So, the feed rate should be optimized for better surface finish.

1.2.3. Burnishing Force

During the Burnishing operation the burnishing tool is pressed against work piece and the force exerted by the Burnishing tool is called Burnishing Force. It acts perpendicular on the surface of the work piece. It is the most critical burnishing parameter amongst all other parameters for better surface finish. As when the burnishing tool is pressed against work piece the force exerted on the surface of the workpiece which modify the surface asperities and the material flows from peaks into the valleys.

II. LITERATURE SURVEY

N. M. Qureshi, Et.al.[1] This experimental study focuses on effect of various parameters and optimization of burnishing processes on surface finish of EN8 material during burnishing operation. In industry various surface finishing operations are used such as lapping, honing, etc. in which removal of the material from its surface takes place. In the present experimentation, ball and roller burnishing processes which are used with varying machining parameters to achieve the desirable surface finish. By the use of the Taguchi methodology optimum machining parameters obtained gives improved surface finish.

J.N. Malleswara Rao, Et.al.[2] In this paper the process of burnishing is performed by applying a highly polished and hardened ball or roller with external force onto the surface of a cylindrical work piece. In the present experimental work, both ball and roller burnishing tools are used. Experiments are conducted to study the performance of the ball and roller burnishing tools on lathe, along with the influence of number of burnishing tool passes on the surface roughness and surface hardness of brass specimens. The results revealed that improvements in the surface finish and increase in the surface hardness are obtained by the increase of the number of burnishing tool passes in both ball burnishing and roller burnishing on the brass specimens.

M.R. Stalin John, Et.al.[3] The paper deals with finite element analysis of burnishing process on the D3 tool steel material using CNC lathe. The input parameters are speed, Burnishing force, and feed. The Output parameters are surface roughness, residual stress, micro-hardness and out of roundness. Surface Roughness generated after the turning operation is used to model the surface roughness pattern which is further used to simulate ball burnishing process using finite element based software DEFORM-2D. For Tool steel, improvement in the surface roughness values achieved after ball burnishing process is 86.2%. The Surface roughness and residual stress results of FEM Simulations are compared with experimental results. The minimum and maximum deviation between the experimental and simulation values of surface roughness is 3.22% and 8.69%, experimental residual stress is 0.63% and 3.94% and theoretical values of residual stress are 1.23% and 3.57%, respectively.

D.B. Patel and T.M. Patel[4], In the present work, the influences of the main burnishing parameters (speed, feed, force, number of tool passes, and ball diameter) on the surface roughness are studied by using Taguchi's L25 orthogonal array which has 25 rows corresponding to the number of tests with 5 columns at 5 levels. It is found that the burnishing forces and the number of tool passes are the parameters that have the greatest effect on the work piece surface during the burnishing process.

Pavan Kumar, Purohit G K[6], This paper presents study about the design and developmental issues of Ball burnishing tool. As today's metal processing industries are often interested to induce compressive residual stress in the several components which they will come across the fabrication processes. The conventional methods of finishing process viz. grinding, broaching used to improve the surface finish of the metallic components, but the burnishing process which is having same role to play in finishing process has many advantages associated with it fulfilling above said requirement successfully. The tools are used to perform burnishing process successfully by controlling different parameters.

W. Bouzid Sai, K. Sai.[12] The aim of this study is to analyze the evolution of surface roughness finished by burnishing. Burnishing is done on a surface that was initially turned or turned and then ground. In this paper, they have defined a finite element model in which the elasto-plastic behavior of the piece is taken into account to determine the material displacement δ. This model has also permitted the calculation of the residual stresses related to the macroscopic contact geometry. Good correlations have been found between experimental and finite element results when burnishing an AISI 1042 steel.

III. EXPERIMENTAL SETUP

3.1 Work piece material

In this work, Aluminium alloy 6061 T6 was used as a workpiece material. Which were received as 40 mm diameter round bars. These bars are cut to suitable lengths of 200 mm and then turned to 38 mm diameter. Each work piece was divided into 5 regions of 30 mm each by a slot of 2 mm length and 2 mm depth. The chemical composition and mechanical properties of the material are shown in Tables 1 & 2.

Table 1. Chemical composition

%Si	0.640
%Fe	0.140
%Cu	0.220
%Mn	0.100
%Mg	0.970
%Cr	0.079
%Zn	0.001
%Ti	0.037
%Ni	0.003
%Al	97.80

Table 2. Mechanical properties

Hardness, HV5	99.33
Ultimate Tensile Strength	275-375 MPa
Elongation %	4.0-16.0

This material is selected due to its importance in aeronautic/aerospace industries and also in automobile industries.

3.2 Ball Burnishing Tool

Many researchers have done their experiments by developing different types of burnishing tools like ball burnishing tool and roller burnishing tool and use them with conventional machine tools. Like that we have made ball burnishing tool which we have used in Lathe machine as shown in Fig. 3. The design is made in such a manner that the tool is simple, cheaper and can be used easily.

Fig. 3 Ball Burnishing Tool

The burnishing tool designed shown above consists of parts namely Adapter, Spring loaded end, Cover, Square casing, Force Controlling Pin, Ball and spring. The ball is made up of EN31 (High carbon alloy steel) having diameter 10 mm and other parts are made up of EN9 material. The design is made in consideration with the parameters in the work i.e. input parameters which are speed, Feed rate& Burnishing Force and output parameter which is Surface Roughness.

3.3Machine Tool

3.3.1 Lathe Machine

The Experiment was carried out on HMT Craftmaster TL 20 Lathe Machine tool shown in Fig. 4

Fig. 4 Lathe machine tool

3.3.2. Roughness Tester

The roughness tester used for measuring surface roughness of aluminium bar is Mitutoyo SJ210 roughness tester shown in fig. 5 and its measurement range is -200µm to 160µm.

Fig. 5 Surface Roughness Tester

IV. EXPERIMENTATION

The Experiments were planned according to L25 orthogonal array, which has 25 rows corresponding to the number of experiments with 3 columns at 5 levels, as shown in Table 3.

Table 3. Parameters and their levels.

Parameters	Level 1	Level 2	Level3	Level 4	Level 5
Burnishing Speed (rpm)	45	75	120	190	300
Feed rate (mm/rev)	0.068	0.085	0.1	0.154	0.205
Burnishing force (N)	50	100	150	200	250

Initially the work piece was measured for its initial surface roughness i.e., 1.762 µm then the Experiment was carried out with the parameters and levels mentioned in table 3 as shown in Table 4.

Table 4. Experimental data for Surface Roughness

Burnishing Speed (rpm)	Feed (mm/rev)	Burnishing Force (N)	Surface Roughness (μm)
45	0.068	50	1.543
45	0.085	100	1.198
45	0.1	150	0.845
45	0.154	200	1.12
45	0.205	250	1.4
75	0.068	100	1.1
75	0.085	150	0.67
75	0.1	200	0.52
75	0.154	250	1.047
75	0.205	50	1.597
120	0.068	150	0.717
120	0.085	200	1.005
120	0.1	250	1.08
120	0.154	50	1.3
120	0.205	100	1.28
190	0.068	200	0.693
190	0.085	250	0.4
190	0.1	50	1.02
190	0.154	100	1.29
190	0.205	150	1.42
300	0.068	250	0.864
300	0.085	50	1.36
300	0.1	100	1.27
300	0.154	150	1.205
300	0.205	200	1.15

The roughness of the burnished surface was measured at each specified region with the help of the Mitutoyo SJ210 surface roughness tester and the work pieces after Burnishing are shown in Fig 6.

Fig. 6 Work pieces after Burnishing

V. FINITE ELEMENT ANALYSIS

Finite Element Analysis as applied in engineering is a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing the complex problems into small elements, as well as the use of software program coded with FEM algorithm. FEA allows us to evaluate the detailed and highly complex structure on a computer while planning the structure. As earlier when FEA was not available the developments of structures were highly dependent on hand calculation which might lead to small errors and this may result in significant change in design which will increase the risk. So it is also being known to increase the efficiency of structure that were somewhat over designed for the time when FEA was not available. With the help of FEA the weight of a design can be decreased and there can be reduction in number of prototype built. The 2D Finite Element Model of ball burnishing process (meshing structure during contact) is shown in Fig. 7

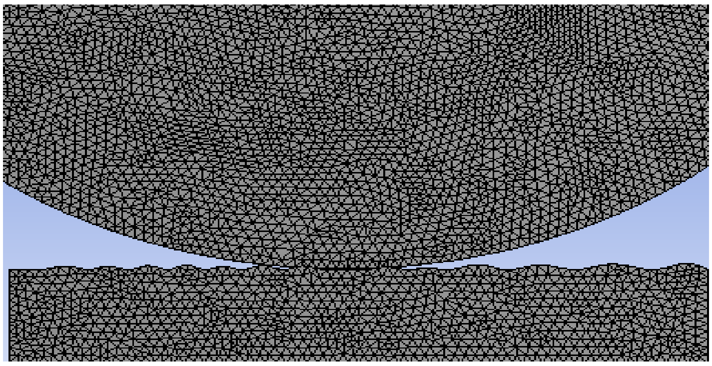

Fig.7. 2D Finite Element Model of Ball Burnishing Process

ANSYS is general purpose software which creates simulated computer models of structures, electronics or machine components to simulate strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow and other attributes. ANSYS is used to determine how a product will function with different specification, without building actual products. ANSYS program works in two different modes i.e. interactive mode or batch mode. General steps for solving any engineering problems using FEA are:

1. Pre-Processing: In this step we define the type of material using, geometry of the structure, meshing structure and provides the contact details.

2. Processing/Solution: In this step we define the boundary conditions and other required details.

3. Post-Processing: In this step the result or the report is generated. On the basis of above two steps the software provides the result or generates the report.

In ANSYS Workbench there are five main steps for the Static structural analysis are as follows:

1. Engineering data
2. Geometry
3. Model
4. Set up
5. Solution

Engineering Data

In engineering data, we define the material to be used for studying whose analysis is to be done. In engineering data sources, there are various data sources like general materials, general non-linear materials, explicit materials, hyper elastic materials, magnetic B-H curve, thermal materials, fluid materials, composite material etc. and under these data sources the different material options are available to choose the required materials for analysis. In engineering Data source structural steel is selected by default, so for different material we have to choose the required material and the workbench software will takes its physical properties automatically. But if the material required is not available in the engineering data source then we have to manually define the required material and its properties. As our workpiece material is aluminium alloy 6061 T6 which is not available in the engineering data source, so we have to manually define the material and its properties.

Geometry

In this step we have to define the geometry of the structure, which can be made in the software itself or can be import from any modelling software like CATIA, CREO, Solid works, etc. For simple geometries we can use this software but complicated real life problem models are difficult to develop hence for this we have to build the model in any modelling software and then import the model in the ANSYS.

In our study, as the model is simple, it can be directly developed in ANSYS itself as 2D FEM model. For this FEM model we have measured the height of surface roughness peak as 1.762 µm. For modelling we have select the line option from sketching and drawn the line model as per above measured value. From line model surface is developed using surface tab from sketches which is in concept option. Now the surface created is repeated seven times towards right side linearly using pattern option as shown in Fig. 8

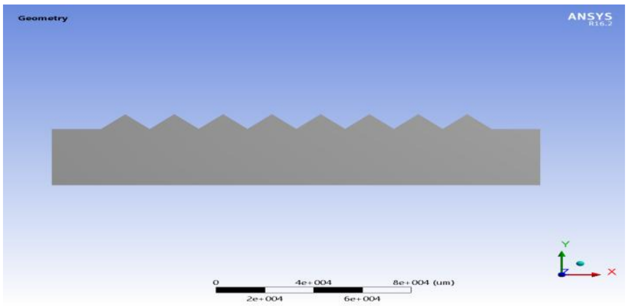

Fig.8. 2D FEM Model/ Geometry

Model

After geometry next step is define model. In this we have to provide various parameters to the geometry like thickness and also assign the material if we have chosen more than two materials in the engineering data, otherwise it will take structural steel, since it is a default material of ANSYS Workbench. After this we have to provide the connections for the contacts between models if any and finally we do the meshing to the geometry by using the mesh option. Meshing is the discretisation of an object into nodes and elements. For better meshing there are various options like method, sizing, contact meshing, refinement, face meshing, mesh control, etc. we can use this option depending on the geometry shape and size. While doing meshing we have to consider the parameters like solution time, computer system on which we are doing the analysis i.e., depending on the time constraint, computer system etc. we do the meshing.

In this study, first aluminium material is assigned for surface body (geometry) from material assignment option and then Meshing is done just by clicking on generate mesh option and it automatically generates the mesh to the surface body as shown in fig. 9

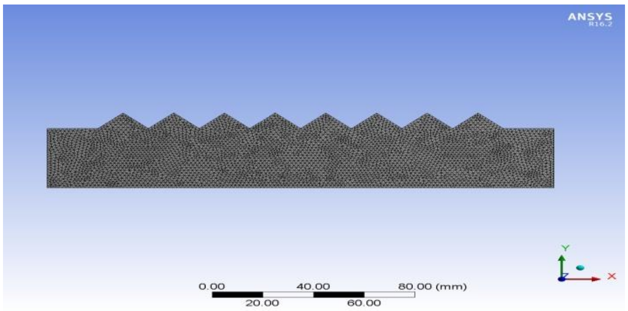

Fig.9. Model after Meshing

Setup

In this we have to define the boundary conditions depending on the problem or application. There are various boundary conditions like fixed support, force, pressure, displacement, remote displacement, velocity, rotational velocity and many more required for analysis.

In our study, fixed support, rotational velocity and force are inserted for the analysis. Fixed support is provided at the bottom edge of the model, rotational velocity is provided at side edge of the model and Forces are provided on all the eight peaks in vertically downward direction i.e., along y-axis as shown in fig. 10. Set of rotational velocities and forces taken for analyses are 4.71rad/s, 7.85rad/s, 12.5 rad/s, 19.8rad/s & 31.4rad/s and 50N, 100N, 150N, 200N & 250N. Fig. 10 shows the boundary conditions for 4.71rad/s rotational velocity and 100N force.

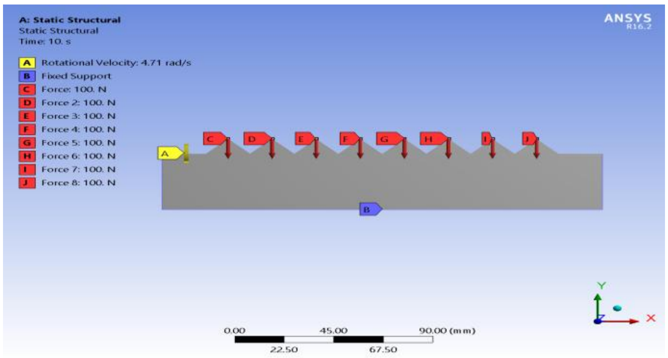

Fig.10. Model after boundary conditions

Solution

Above all steps i.e. engineering data, geometry, model and setup comes under pre-processing step. In solution or processing we have to just click on the solve icon and software internally carried out the matrix formation, multiplication, inversion and solution for unknown e.g. deformation and then finds the stress& strain for analysis. In this step we have to define the data as per the results required.

5.1. Results

After solution the next step in ANSYS Workbench is results. In this we can see the require results of analysis like stress, strain, deformation, etc. also through results we can get the verification, conclusions and we can decide about what steps could be taken to improve the design. In this we can get the full report of the required results.

In this study, we only got the deformation of the model as a result, since here we are only interested in surface roughness value after burnishing process. The following are the some models showing deformations for different readings:

- 50 N Force, 19.8 rad/s velocity

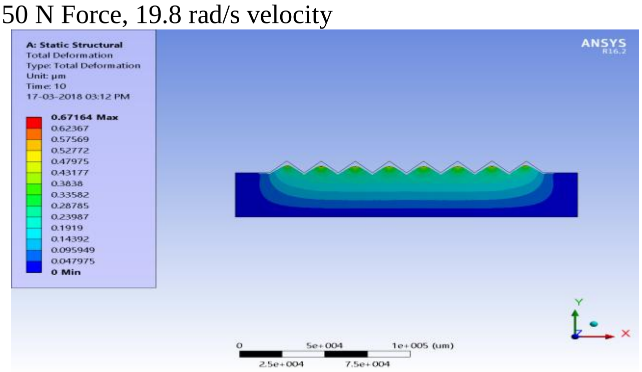

Fig.11 Deformation for 50N Force & 19.8rad/s velocity

- 100N Force, 7.85rad/s velocity

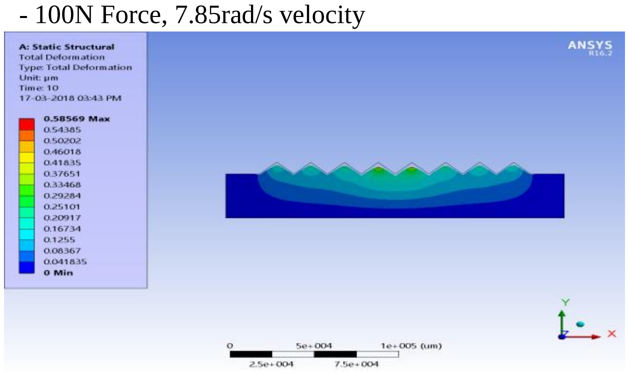

Fig.12 Deformation for 100N Force, 7.85rad/s velocity

- 150N Force, 7.85rad/s velocity

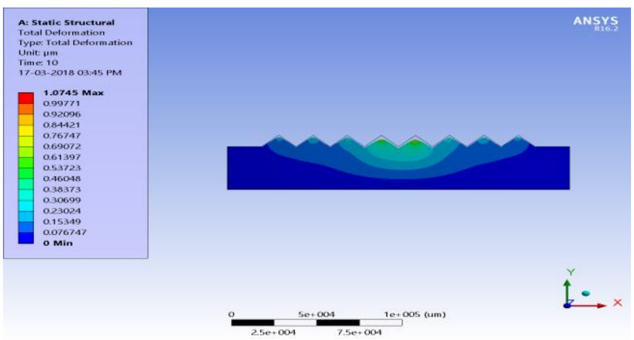

Fig.13 Deformation for 150N Force, 7.85rad/s velocity

- 200N Force, 7.85rad/s velocity

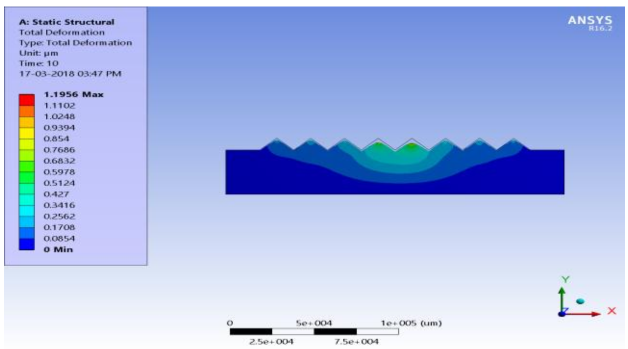

Fig.14 Deformation for 200N Force, 7.85rad/s velocity

- 250N Force, 19.8rad/s velocity

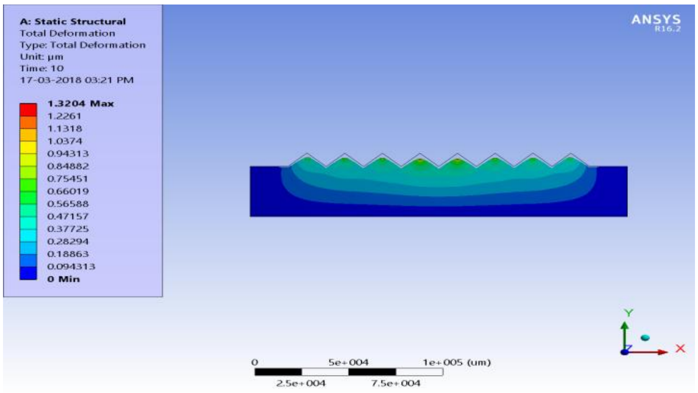

Fig.15 Deformation for 250N Force, 19.8rad/s velocity

The deformation and Surface roughness values we got through FEA for different values of parameters are shown in Table 5.

Table 5. Results of FEA

Burnishing velocity (rad/s)	Burnishing Force (N)	Deformation (µm)	Surface Roughness (µm)
4.71	50	0.2	1.562
4.71	100	0.505	1.257
4.71	150	0.886	0.876
4.71	200	0.568	1.194
4.71	250	0.263	1.499
7.85	100	0.586	1.176
7.85	150	1.074	0.688
7.85	200	1.196	0.566
7.85	250	0.639	1.123
7.85	50	0.066	1.696
12.5	150	0.957	0.805
12.5	200	0.707	1.055
12.5	250	0.644	1.118
12.5	50	0.393	1.369
12.5	100	0.456	1.306
19.8	200	1.008	0.754
19.8	250	1.32	0.442
19.8	50	0.672	1.09
19.8	100	0.436	1.326
19.8	150	0.268	1.494
31.4	250	0.873	0.889
31.4	50	0.335	1.427
31.4	100	0.403	1.359
31.4	150	0.47	1.292
31.4	200	0.537	1.225

VI. RESULTS AND DISCUSSIONS

The plot for Force Vs Roughness in FEA & Experimental, plot for Speed Vs Roughness in FEA & Experimental and plot for FEA Vs Experimental for force & speed are shown below:

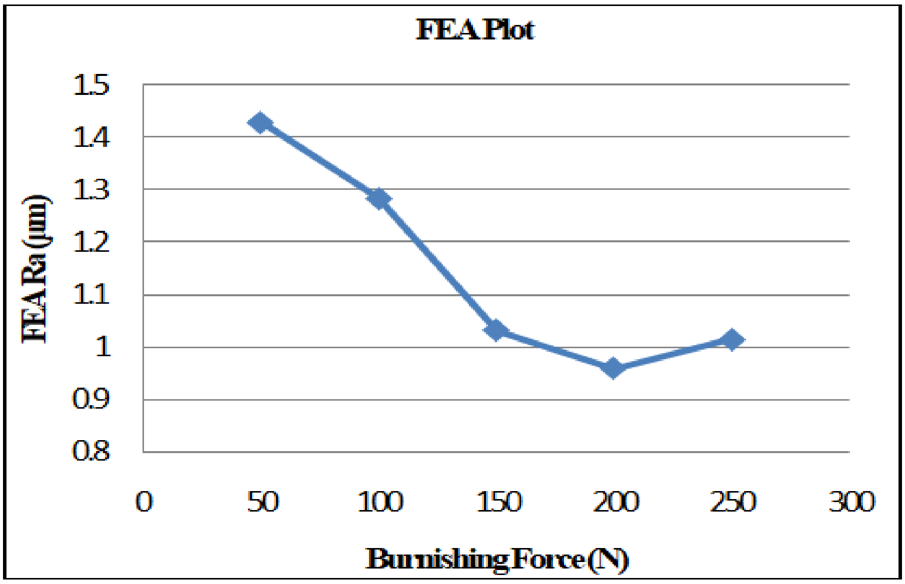

Fig.16. Roughness Vs Force FEA Plot

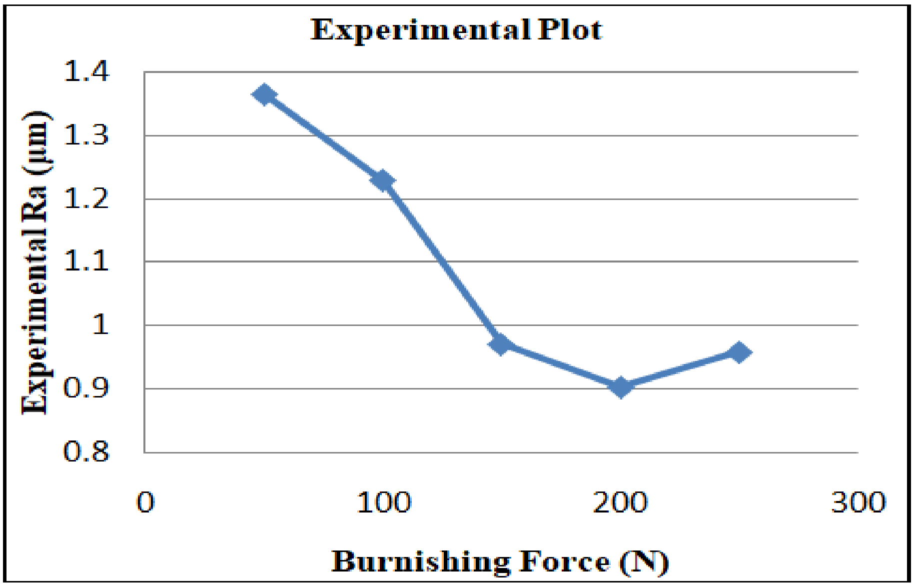

Fig.17. Roughness Vs Force Experimental Plot

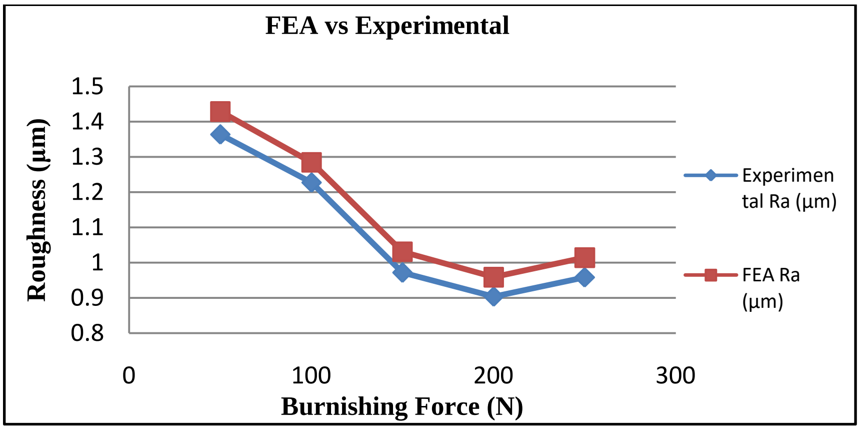

Fig.18. FEA Ra Vs Experimental Ra Plot with Force

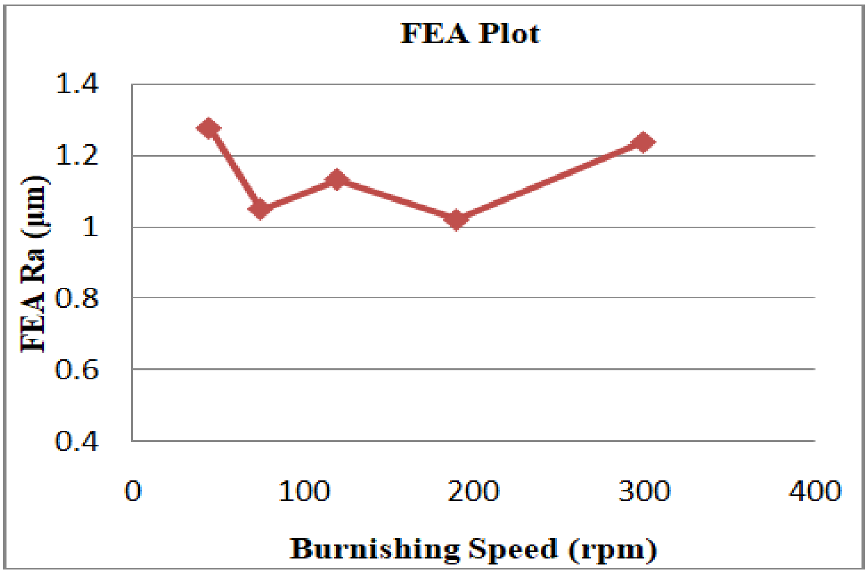

Fig.19. Roughness Vs Speed FEA Plot

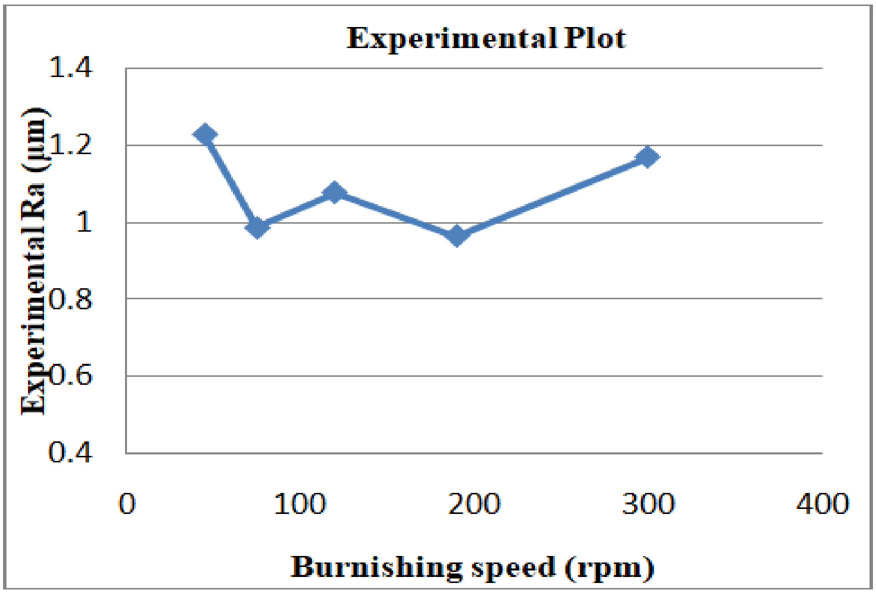

Fig.20. Roughness Vs Speed Experimental Plot

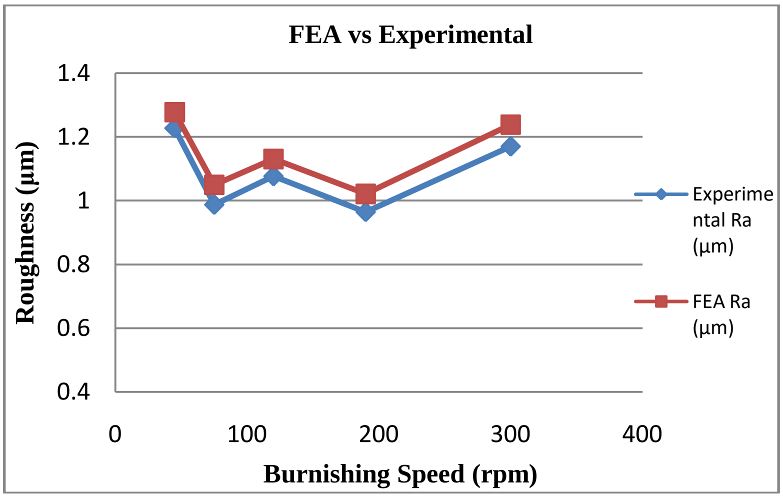

Fig.21. FEA Ra Vs Experimental Ra Plot with Speed

The surface roughness values obtained through FEA and surface roughness values obtained through experiment with the percentage error between them are shown in the Table 6.

Table 6. FEA Result Vs Experimental Result.

Burnishing velocity (rad/s)	Burnishing Force (N)	FEA Ra (μm)	Experimental Ra (μm)	% Error
4.71	50	1.562	1.543	1.2164
4.71	100	1.257	1.198	4.6937
4.71	150	0.876	0.845	3.5388
4.71	200	1.194	1.12	6.1977
4.71	250	1.499	1.4	6.6044
7.85	100	1.176	1.1	6.4626
7.85	150	0.688	0.67	2.6163
7.85	200	0.566	0.52	8.1272
7.85	250	1.123	1.047	6.7676
7.85	50	1.696	1.597	5.8373
12.5	150	0.805	0.717	10.932
12.5	200	1.055	1.005	4.7393
12.5	250	1.118	1.08	3.3989
12.5	50	1.369	1.3	5.0402
12.5	100	1.306	1.28	1.9908
19.8	200	0.754	0.693	8.0902
19.8	250	0.442	0.4	9.5023
19.8	50	1.09	1.02	6.422
19.8	100	1.326	1.29	2.7149
19.8	150	1.494	1.42	4.9531
31.4	250	0.889	0.864	2.8121
31.4	50	1.427	1.36	4.6952
31.4	100	1.359	1.27	6.5489
31.4	150	1.292	1.205	6.7337
31.4	200	1.225	1.15	6.1224

VII. CONCLUSIONS

Finite Element Analysis was employed to evaluate effect of burnishing force and burnishing speed on the surface roughness of aluminium alloy. In case of force as the force increases the surface roughness decreases and reaches to minimum value and in case of speed as the speed increases the surface roughness decreases to a certain limit and then increases. When the Finite element analysis was carried out, it was found that the results are coinciding with the values obtained from experimental results. From the Table 6, it is observed that the variations obtained have less than 11 % error.

So we may conclude that FEA can be used as prediction tool for predicting surface roughness values without doing the experiment.

Discrepancies in comparison of results may be due to the following reasons:
1. Approximate Materials Properties used in simulation since original values are different.
2. The modelling of contact by artificially creating peaks is inadequate since there are innumerable peaks to be modelled in a statistical manner. The best approach is to adopt multi-scale FEM methods.

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