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Investigations in Contact Stress Analysis in Roller Burnishing Process

B. Pattabhi Reddy
M.Tech (CAD/CAM),
Department Of Mechanical Engineering,
Malla Reddy College Of Engineering

C. Shashikanth
Assistant Professor
Mechanical Engineering Department
Malla Reddy College Of Engineering

Abstract:

In today's production of machines and instrument components, finishing processes are becoming more and more important. Increasing attention is being paid to the quality of the surface finish obtained. Surface finish is a characteristic of any machined surface. To achieve this, the residual stresses which are developed in them during the machining processes are required to be estimated for which one has to know the elastic and plastic stress components. The machining processes, which can easily improve surface roughness of machine parts. Burnishing is a surface modification Process, which involves Plastic Deformation of material at the surface of component due to application a highly polished and hard roller under pressure. This paper describes the contact stress between two cylindrical components in a roller burnishing process. Surface finish has a positive and prolonged effect on the functioning of the machined parts. Roller burnishing is used to get a high quality surface finish on materials like aluminum and mild steel. Investigation on surface characteristics like Surface Hardness and Surface Roughness of roller burnishing components are performed by considering different parameters like Speed, Feed, Force and Passes. Statistical approach like Regression analysis is to be performed based on Surface characteristics by considering different parameters like Speed, Feed, Force and Passes for both Mild steel and Aluminum work Pieces. Analysis is performed by ansys software. The Results from the ansys are compared with Results obtained from different theories and Contact Models of FEA analysis.

Keywords: ***Contact Stress Analysis, Surface Finishing, Burnishing Process, Roller Burnishing.***

Introduction:

In manufacturing engineering it is imperative to improve the surface quality of the machine parts, which ensures their durability and reliability. In today's production of machines and instrument components, finishing processes are becoming more and more important. Increasing attention is being paid to the quality of the surface finish obtained. Surface finish is important not only as an appearance it also has a positive and prolonged effect on the functioning of machine parts. Surface finish is a characteristic of any machined surface. It is sometimes called as surface texture or roughness. To achieve this, the residual stresses which are developed in them during the machining processes are required to be estimated for which one has to know the elastic and plastic stress components. The machining processes, which can easily improve surface roughness of machine parts.

Surface roughness

The surfaces of engineering components will provide link between manufacturing and their function in use. The main causes of machine failures (80%) are wear of contact surfaces in mating parts. wear resistance of rubbing parts can be improved by reducing the initial wear of components. In this line, it is better practice to make the sliding surfaces with a roughness equal to that of worn-in parts.

The advantages of good surface finish are:

- Good surface finishes increase the wear resistance of two work pieces in an assembly.
- Good surface finishes reduce the friction between two work pieces in an assembly.
- Good surface finishes have cosmetic affect and make parts look good.

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- Good surface finished permits the proper function of static and dynamic O-ring seals in hydraulic and pneumatic equipment.
- Good surface finishes increase the load carrying capacity, tool life.
- Good surface finishes increases the corrosion and fatigue life of the components.

Burnishing

Burnishing is also called as chip less finishing process. It cold works the metal surfaces by applying the forces that exceed the yield strength of the material through hardened roller or ball. This allows the peaks are flows into the valleys. This process eliminates grinding and honing while improving the surface finish, surface hardness, wear-resistance, fatigue resistance and corrosion resistance of a part. This can also termed as unconventional finishing operation.

Principle of Roller Burnishing

Roller Burnishing is a cold working process which produces a fine surface finish by the planetary rotation of hardened rolls over a bored or turned metal surface. Roller Burnishing involves cold working the surface of the work piece to improve surface structure.

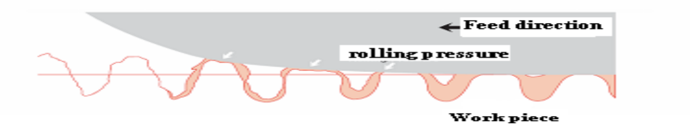


Figure : Burnishing operation

Related Work:

C. S. Jawalkar* and R. S. Walia. et all [1] are discussed about Roller burnishing process is a superior cold forming finishing process. It is done on machine or ground surfaces for both external and internal surfaces. In his process, a smooth, hard object (under considerable pressure) rubs over the minute surface irregularities that are produced during machining or shearing. The hardened rolls of the tool press against the surface and deform the protrusions to a more nearly flat geometry. Applying Taguchi's design of experiments on the specimens, the aim is to find optimized values for enhancing the surface quality and hardness economically. On experimental analysis, he found that all the process parameters significantly affect the quality and in EN-8 the micro hardness values are larger due to work-hardening effect.

K.Eshwar Prasad, R.Murali Krishna. et all [2] are discussed that Burnishing is a surface modification process which involves plastic deformation of the Material at the surface of the component due to the application a highly polished and hard roller under pressure this results in the improvement of the surface finish of the component and induces residual compressive stresses on the surface of component. The present work deals with the optimization of burnishing force for the best surface finish, at constant speed and feed for aluminum and mild steel work pieces. A 3-dimensional finite element model is proposed for the simulation of burnishing process, and analysis is carried out at the optimum force determined experimentally. The induced compressive stress in the components is determined from the finite element analysis and this valve is then compared with the results obtained from X-ray diffraction technique.

M.H. El-Axir et all [3] developed that Burnishing, a plastic deformation process, is becoming more popular as a finishing process, thus, how to select the burnishing parameters to reduce the surface roughness and to increase the surface micro hardness is especially crucial. This paper reports the results of an experimental program to study the influence of different burnishing conditions on both surface micro hardness and roughness: namely, burnishing speed, force, feed, and number of passes. From an initial roughness of about *R*a 4.5 □m, the specimen could be finished to a roughness of 0.5 µ. It is shown that the spindle speed, burnishing force, burnishing feed and number of passes have the most significant effect on both surface micro hardness and surface roughness and there are many interactions between these parameters. The maximum residual stress changes from tensile to compressive with an increase in burnishing force from 5 to 25 kgf. With a further increase in burnishing force from 25 to 45 kgf.

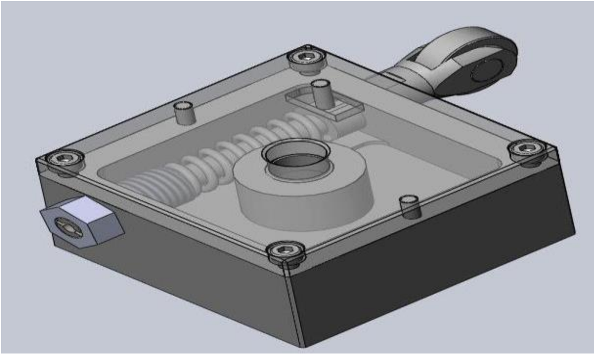
J. Naga Malleswara Rao, A. Chenna Kesava Reddy and P.V. Rama Rao et all [4] there work is , an attempt has been made to design and fabricate a new type of dynamometer to measure radial component of cutting force using strain gauges. Dynamometer is required to measure the components of cutting force in any metal cutting process. In roller burnishing, a hard roller is pressed against a rotating cylindrical work piece and parallel to the axis of the work piece on lathe. Optimum values of burnishing force and the corresponding surface roughness value (Ra) are obtained for different lubricant applications in roller burnishing operation. This dynamometer can be manufactured at a low cost and it can be used for tests on lathe in metal cutting laboratories and engineering colleges.

Y. C. Lin Æ S. W. Wang Æ H.-Y. Laiet all[5] their investigation examines burnishing using a microscopic perspective and elucidates the mechanism of surface roughness improvement by asperity deformation. This study uses tribology theory to propose a burnishing factor Lb to explain why the same burnishing result can be obtained in different burnishing conditions. The burnishing factor was determined by appropriate experiments, and the results demonstrated that a quadric curve relationship exists between surface roughness and burnishing factor and is analogous to the Steinbeck curve in lubrication regimes.

Assembly of The Tool Post:

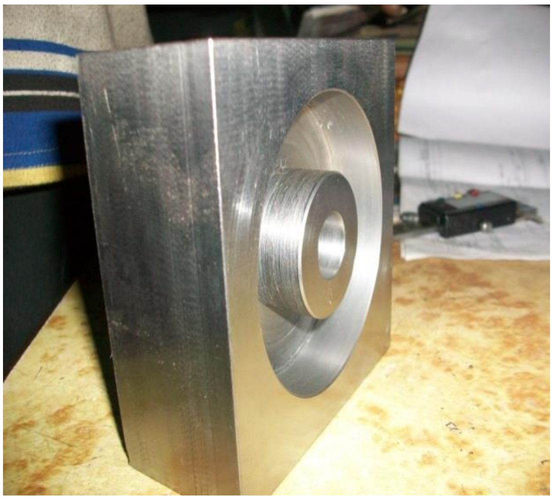
The tool post assembly consists of the following parts and the assembled view is as shown in the figure below.

1) Body of the tool post
2) Top plate of the tool post
3) Tool holder
4) Burnishing tool
5) Dowel pin connecting the tool and tool holder
6) 4 Align screws hold tightly the top plate and body
7) 2 Dowel pins on the body through the top plate
8) Spring used to give the spring tension and calculate the load
9) Dial indicator to show the displacement of the tool. The assembled part will be blackened for reduction of wear.



Tool Post assembly.

Individual Components:



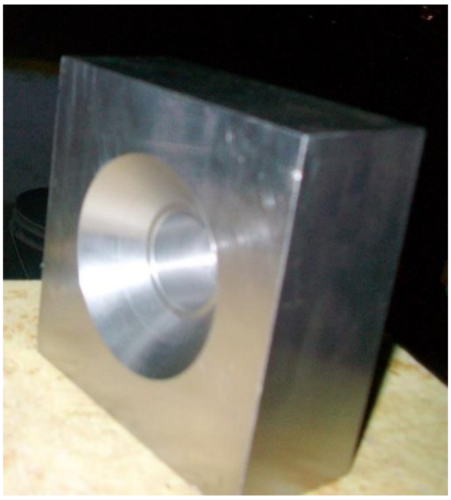


Fig. Top and bottom plate

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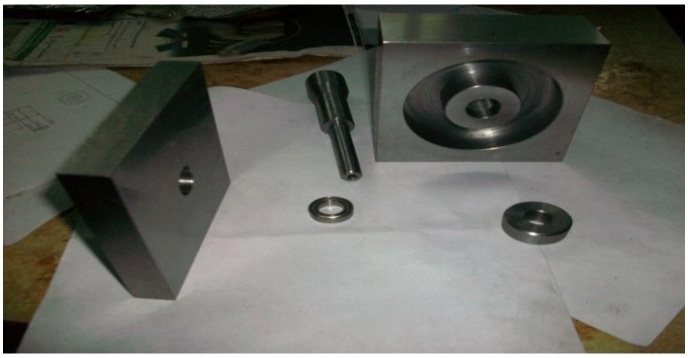

Fig. Different parts of tool post Assembly

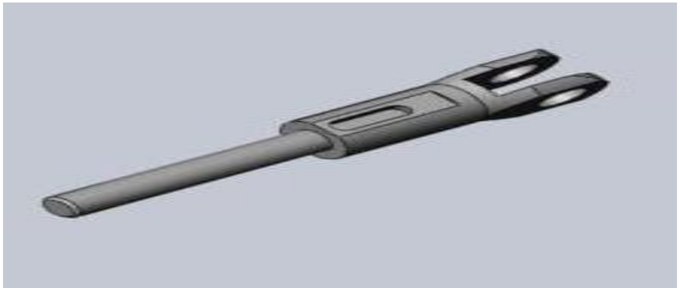

Fig. Tool Holder

Burnishing:

The process consists of the elements which are required for setting up the experiment. Lathe machine most important feature of our experiment, it is a main source to hold the tool post. The tool post is designed to be fitted for the lathe machine. The tool post has assembled parts like dowel pins, screws, tool holder, spring and a plunger to hold the tension in the spring. The tool holder holds the tool which is freely revolving with help of a dowel pin. There is a slot on the top side of tool holder a pin guides the movement of the tool holder to move in forward and backward direction. When a load is applied on the burnishing roller, the tool holder moves into tool post creating a tension in spring.

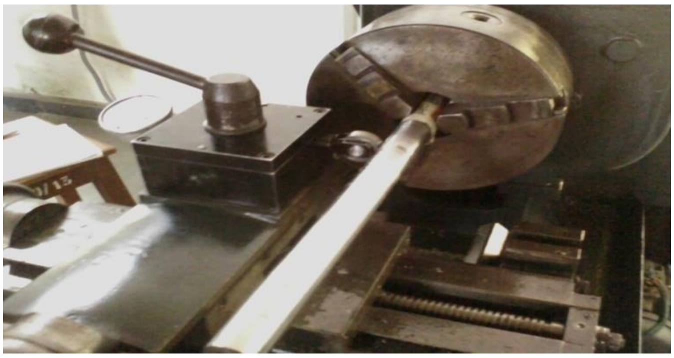

Fig. Burnishing process performed on specimen.

Experimental Analysis

Analysis is carried out to measure Properties like Surface Hardness and Surface Roughness for both Aluminum and Mild Steel.

Surface Properties of Mild Steel

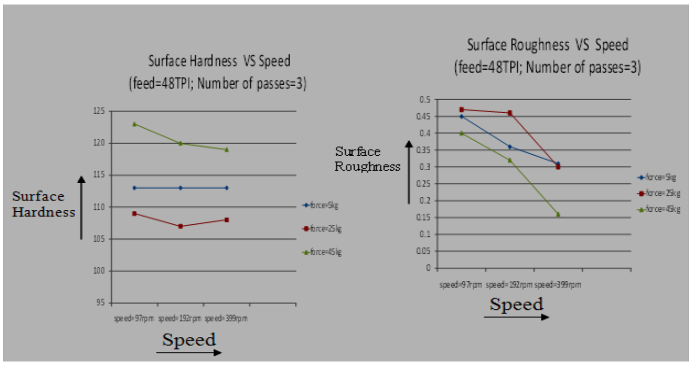

Fig: Surface Roughness and Surface Hardness Vs Speed by keeping feed, number of passes constant.

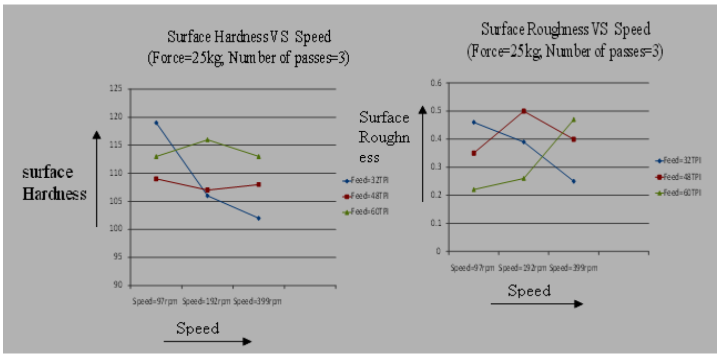

Fig: Surface Roughness and Surface Hardness Vs Speed by keeping force, number of passes are constant.

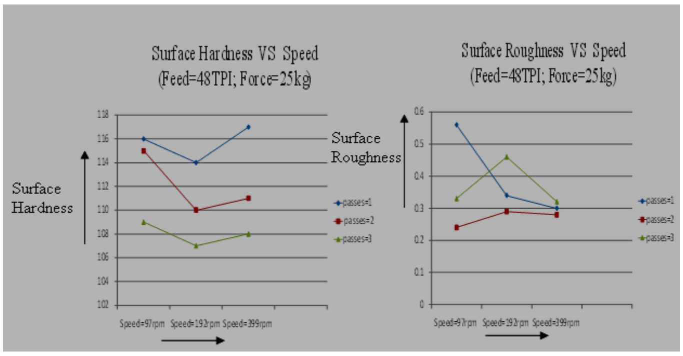

Fig: Speed Vs Surface Roughness and Surface Hardness by keeping force, feed are constant

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Surface Properties of Aluminum

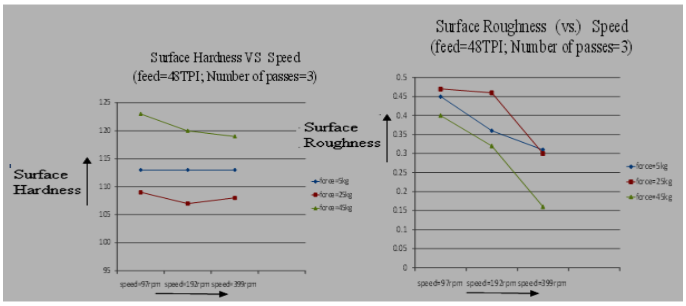


Fig. Surface Roughness and Surface Hardness Vs Speed by keeping feed, number of passes constant.

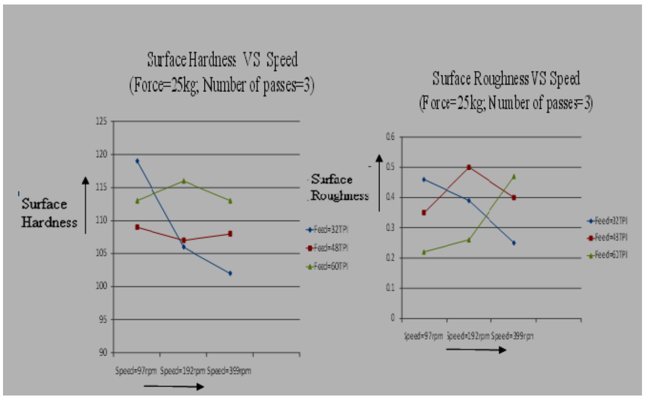


Fig. Surface Roughness and Surface Hardness Vs Speed by keeping force, number of passes are constant.

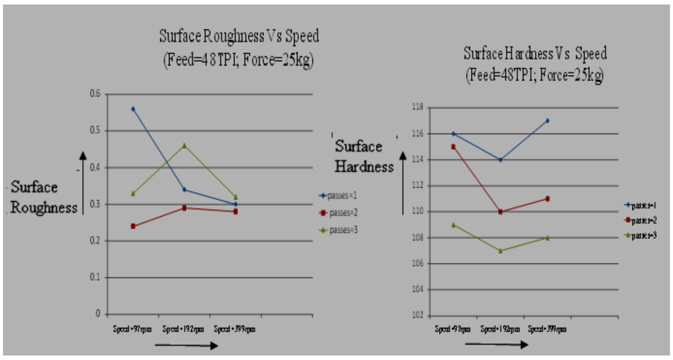
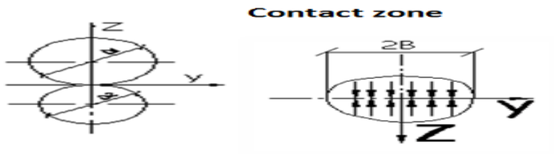


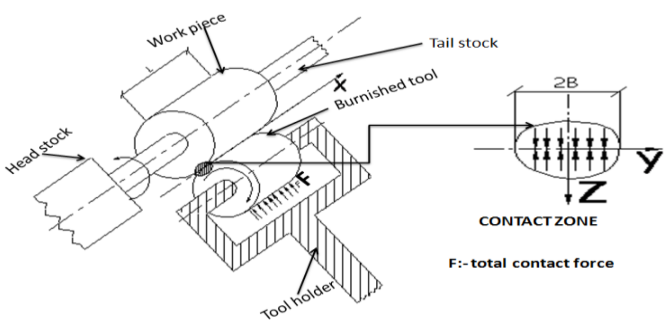
Fig. Speed Vs Surface Roughness and Surface Hardness by keeping force, feed are constant

Theoretical Analysis And Computation

Hertz Theory

Contact mechanics is foundational to the field of mechanical engineering; it provides necessary information for the safe and energy efficient design of technical systems. Hertz a contact stress refers to the localized stresses that develop as two curved surfaces come in contact and deform slightly under the imposed loads. This amount of deformation is dependent on the modulus of elasticity of the material in contact. It gives the contact stress as a function of the normal contact force, the radii of curvature of both bodies and the modulus of elasticity of both bodies. In gears and bearings in operation, these contact stresses are cyclic in nature and over time lead to sub-surface fatigue cracks. Hertzian contact stress forms the foundation for the equations for load bearing capabilities in bearings, gears, and any other bodies where two surfaces are in contact. The motion of a single body in space is described by the governing equations of continuum mechanics. The approach used in contact mechanics is to restrict the motion of two or more bodies in space by additional constraints. Hertzian contact stress, is a description of the stress within mating parts. In general, the Hertzian contact stress usually refers to the stress close to the area of contact between two spheres of different radii.





Boresi Method

Two semicircular disks made of elastic material are pressed together by forces P. The two bodies are initially in contact at a single point. The principal radii of curvature of the surface of the upper solid at the point of contact are R_1 and R'_1.Likewise R_2 and R'_2 are the principal radii of curvature of the surface

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of the lower solid at the point of contact . The intersection of the planes in which the radii R_1 and R_2 lie from an angle α. The line of action of load P lies along the axis that passes through the centers of curvature of the solids and through the point of contact. Hence, the line of action force P is perpendicular to a plane that is tangent to both solids at the point of contact. The problem is to determine a relation between the load P and the maximum compressive stress on this small area of contact and to determine the principal stresses at any point in either body on the line of action of the load, designated as the Z axis. The principal stresses σ_{xx} ,σ_{yy} and σ_{zz} acting on a small cube at a point on the axis . The maximum shear stress at the point is $\tau_{max} = 1/2(\sigma_{zz}-\sigma_{yy})$, where σ_{zz} and σ_{yy} are the maximum and minimum principal stresses at the point.

Finite Element Analysis On Burnishing

Significance Of Finite Element Analysis

Finite element analysis makes it possible to evaluate a detailed and complex structure in a computer, during the planning of structure. The demonstration in the computer of adequate strength of structure and possibility of improving the design during planning can justify the cost of analysis work.FEA has also been known to increase the rating of structures that were significantly over designed.

In the absence of FEA (or the numerical analysis), development of structures must be based on hand calculations only. For complex structures, the simplifying assumptions required to make any calculations possible can lead to a conservative and heavy design. Significant changes in design involve risk. Designs will require prototypes to be built and field tested. The field tests may involve expensive strain gauging to evaluate strength and deformation.

With Finite element Analysis, the weight of a design can be minimized and there can be a reduction in number of prototypes built. Field-Testing will be used to establish loading on structures, which can be used to do future design improvements via Finite element analysis

Ansys – 11 as a Finite Element Analysis Tool.

ANSYS is general-purpose software ,which can be used for almost any type of finite element analysis in virtually any industry like automobiles, aerospace, railways, electronics, power generation ,power transmission and biomedical to mention just a few. General purpose refers to the fact that the software can be used in all disciplines of engineering- structural, mechanical, electrical, electronic, electromagnetic, thermal, fluid and biomedical.

ANSYS program can be either in the interactive mode or batch mode. Interactive mode, as its name implies, is where designer constantly interacts with the computer when the command is issued and the ANSYS program processes it and indicates what it does. In case of mistakes, corrective action can right away be taken. Interactive mode allows the designer to use convenient features such as graphics display, on-line help, the menu system, and graphics picking.

The ANSYS menu system is organized into logical groupings of related topics. The three main groupings of related topics are –main commands, Utility commands, and reference. Each grouping is organized in a tree structure general topics are encountered at the top of the tree, and as the user proceeds down a particular branch, specific topics are located at the lower levels.

The Main command tree is where one spends most of his time; the tree main branches of main command are PREPROCESSOR, SOLUTION, and POST PROCESSOR.

Advantages Of Fem:

- This method can be efficiently applied to cater irregular geometry.
- It can take care of any type of boundary conditions
- Material anisotropy and in homogeneity can be treated without much difficulty
- Optimization of design can be done with ease.

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Disadvantages Of Fem:

- To solve the problem the approximations used do not provide accurate results.
- Stress value may vary from fine mesh to average mesh analysis.

Analysis Of Contact Model Without Surface Roughness Peaks

Force (N)	Displacement	Von Misses Stress	Von Misses Elastic Strain
50	0.463e-03	94.434	0.606e-3
100	0.917e-3	188.799	0.001209
250	0.003143	190.098	0.001247

Table: Results of Mild Steel Contact model without peaks.

Ansys results on Aluminum Contact Model without peaks:

Force (N)	Displacement	Von Misses Stress	Von Misses Elastic Strain	Von misses Plastic Strain
50	0.001233	97.466	0.001591	0.001233
100	0.00254	139.319	0.001858	0.001302
250	0.616e-3	48.743	0.795e-3	0.616e-3
500	0.001233	97.466	0.001591	0.001233

Table Results of Aluminum Contact model without peaks

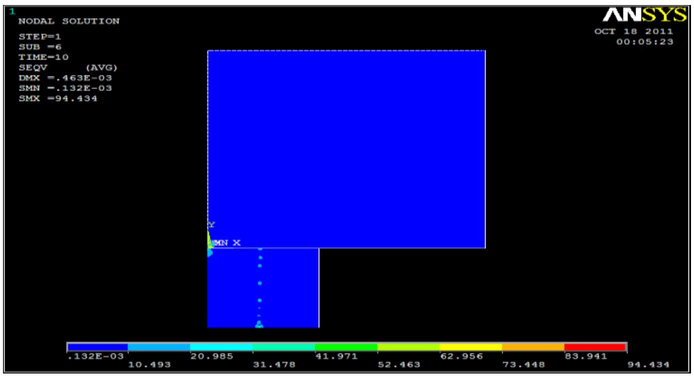

Fig: Mild Steel Von misses stress obtained for force 50N.

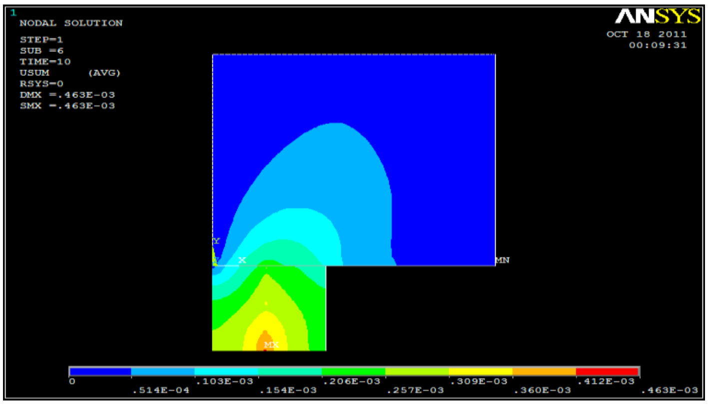

Fig:Mild Steel Displacement obtained for force 50N.

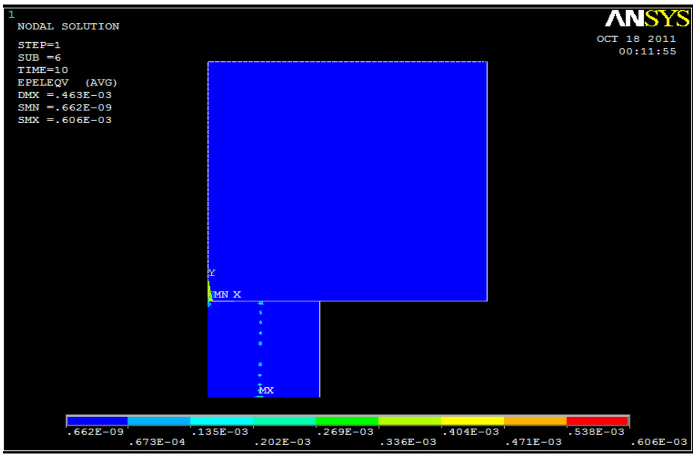

Fig: Mild Steel Von Misses Elastic strain obtained for force 50N

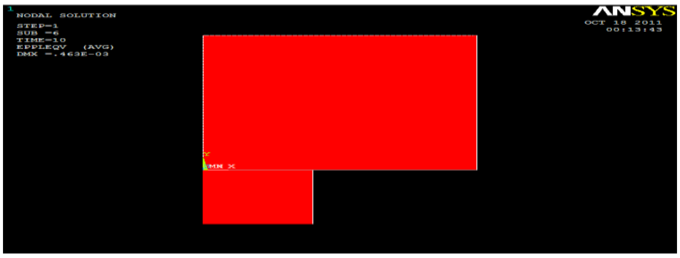

Fig: Mild steel Von Misses Plastic strain obtained for force 50N

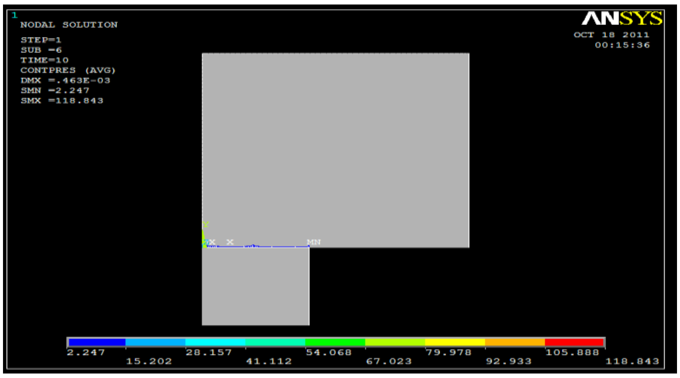

Fig: Mild steel Contact Stress obtained for force 50N

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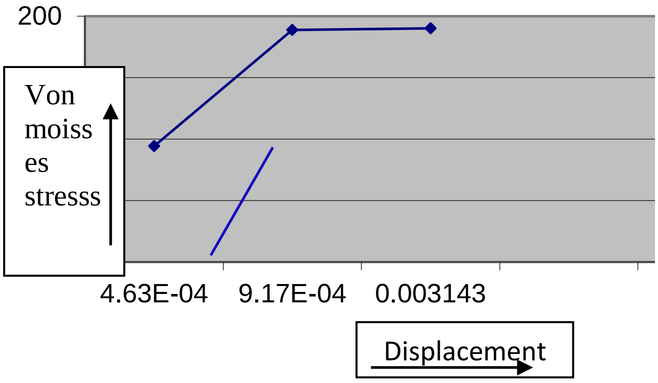

Fig: Von misses stress Vs Displacement for Mild Steel

ANALYSIS OF 3D CONTACT MODEL

Sl.No.	Force	Displacement	Von misses Stress	Elastic Strain	Plastic Strain
1	50	0.001395	163.387	0.817 e-3	-
2	250	0.007371	190.247	0.925 e-3	0.0075
3	500	0.017489	190.386	0.959 e-3	0.043165

Table Results of Mild Steel 3D Contact model

Sl.No.	Force	Displacement	Von misses Stress	Elastic Strain	Plastic Strain
1	50	0.003146	100.01	0.001334	0.478e-3
2	250	0.018183	100.775	0.001344	0.019674
3	500	0.04861	101.68	0.001356	0.04222

Table Results of Aluminum 3D Contact model

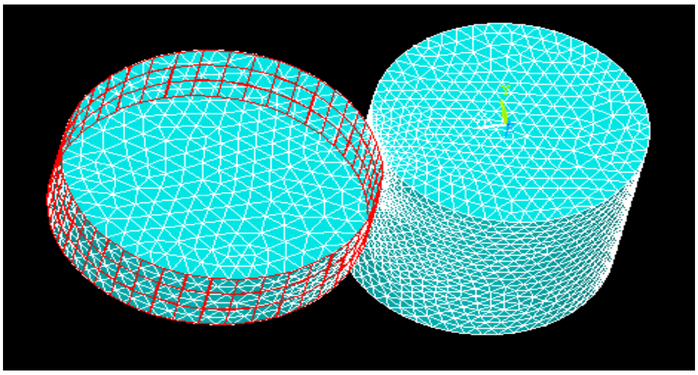

Fig: loading Diagram for 3D contact Model.

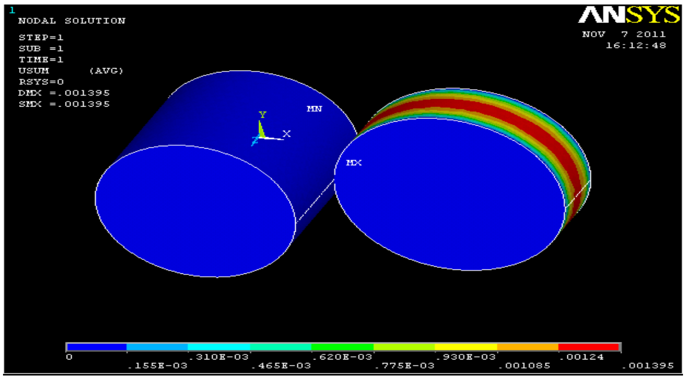

Fig: Mild Steel Displacement obtained for 50N

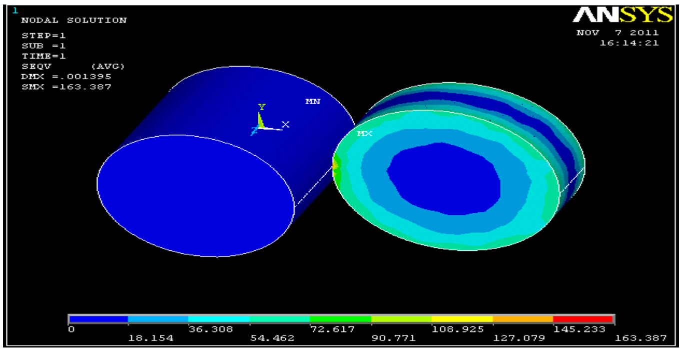

Fig:Von Misses Stress obtained for 50N

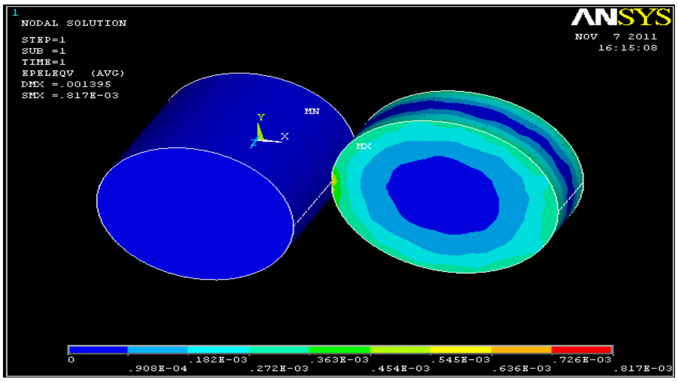

Fig: Von Misses Elastic strain obtained for 50N

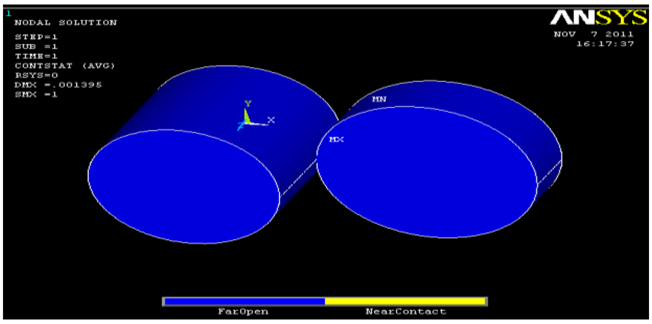

Fig: Contact Status for 50N

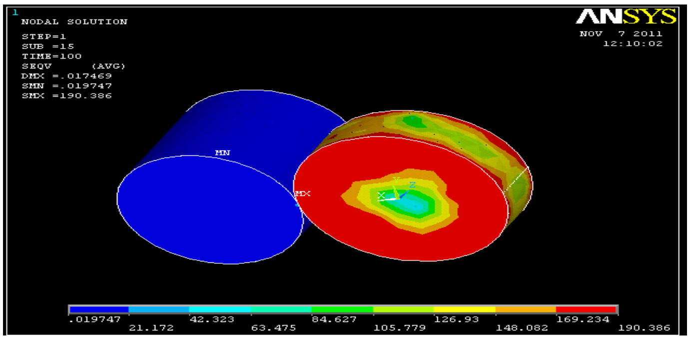

Fig: Von Misses Stress for 3D Contact Model of 500N

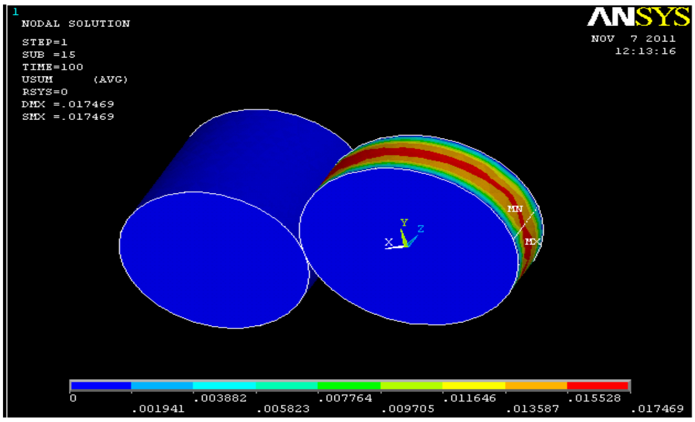

Fig: Displacement for 3D Contact Model of 500N

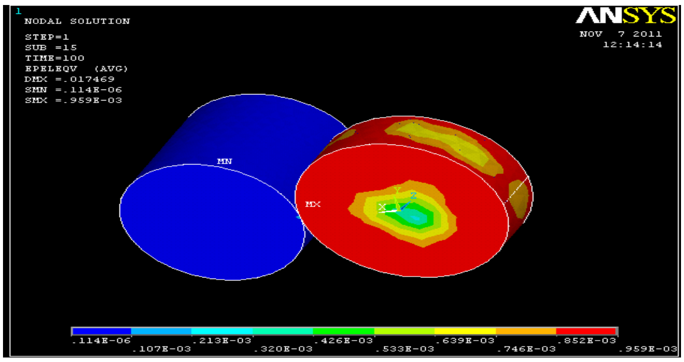

Fig: Von misses elastic strain for 3D Contact Model of 500N

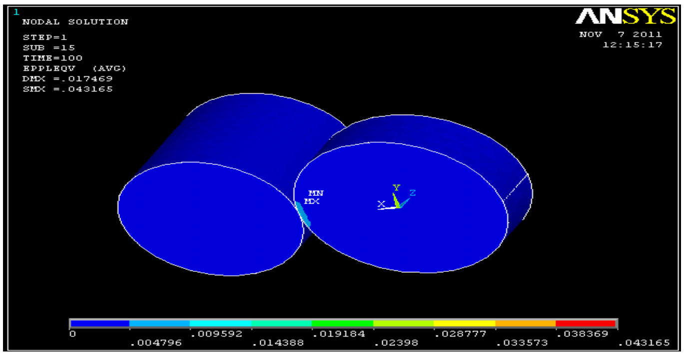

Fig: Von Misses Plastic strain for 3D Contact Model of 500N

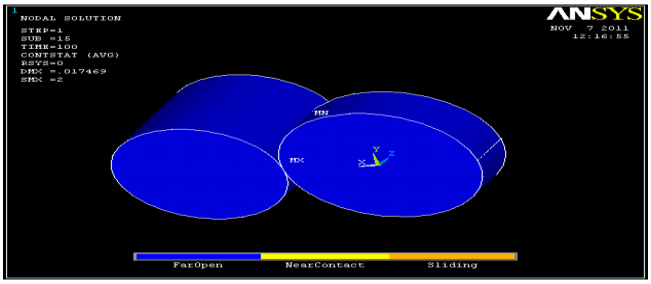

Fig: Contact status for 3D Contact Model of 500N

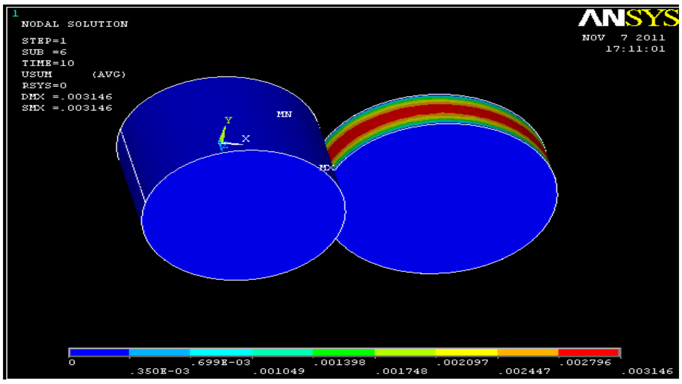

Fig: Aluminum Displacements for 3D Contact Model of 50N

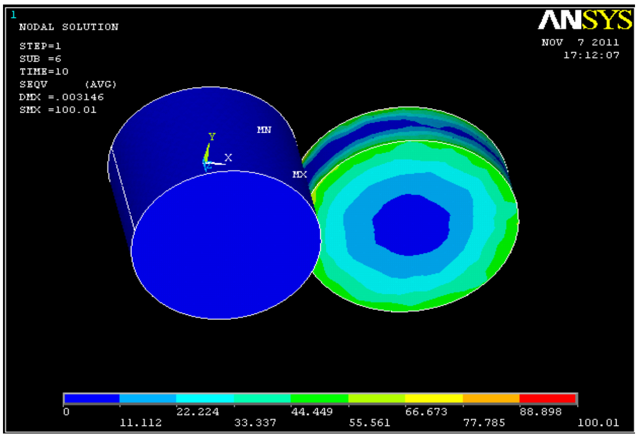

Fig: Aluminum Von misses Stress for 3D Contact Model of 50N

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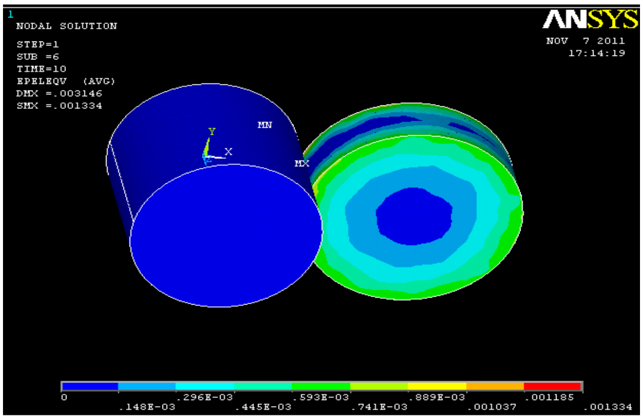

Fig: Aluminum Von misses Elastic Strain for 3D Contact Model of 50N

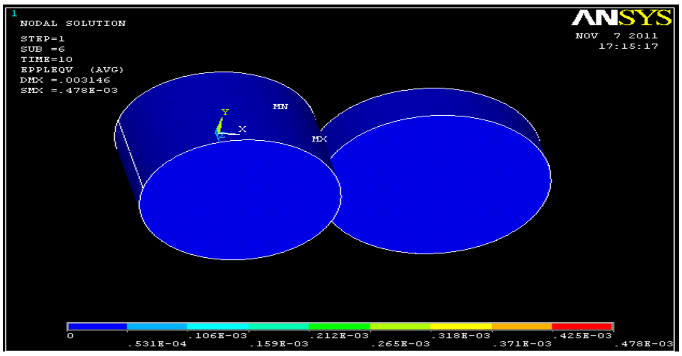

Fig: Aluminum Von misses Plastic Strain for 3D Contact Model of 50N

Analysis of Contact Model with Surface Roughness Peaks.

Maximum numbers of Surface Roughness Peaks are in Contact with Tool.

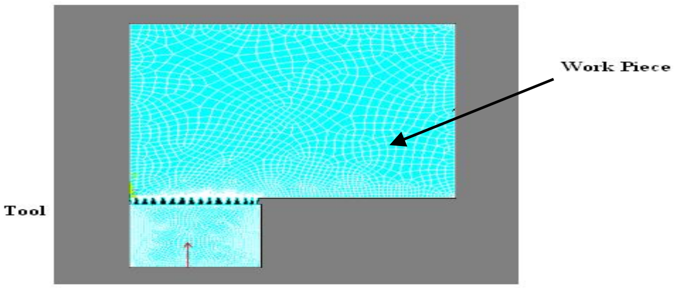

Fig: loading Diagram of Contact Model with surface roughness Peaks

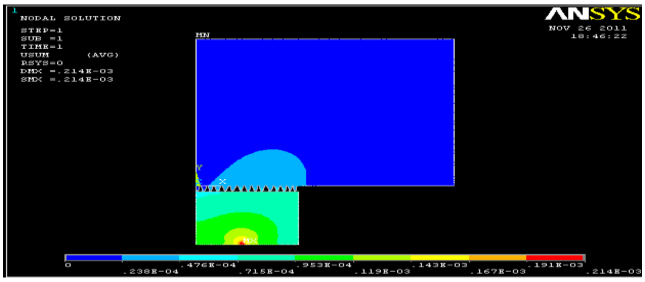

Fig: Mild steel Displacement obtained for 100N force.

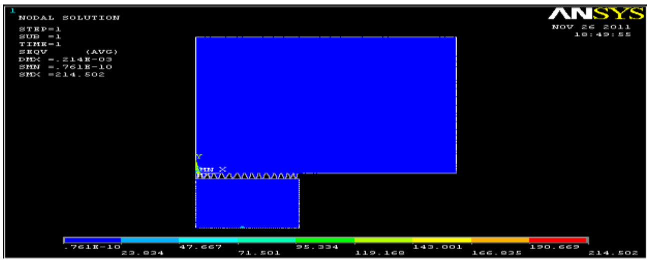

Fig: Von misses Stress for 100N Force.

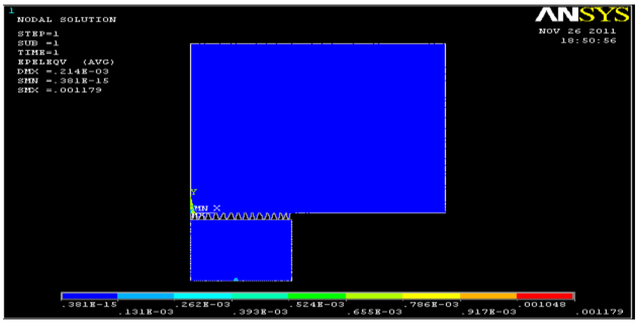

Fig: Von misses Elastic Strain for 100N Force

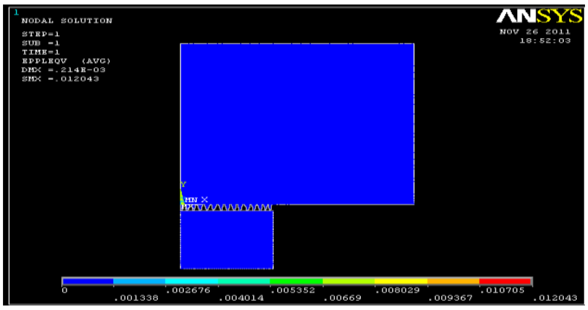

Fig: Von misses Plastic Strain for 100N Force

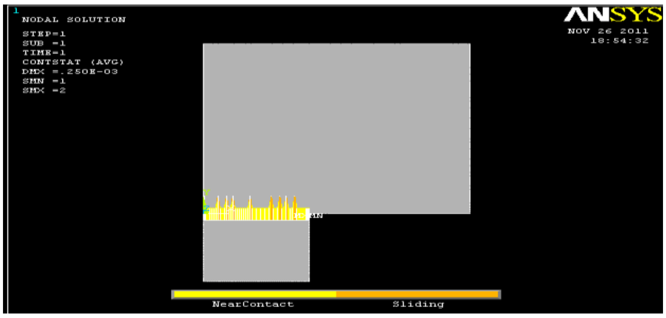

Fig: Contact Status for 100N Force

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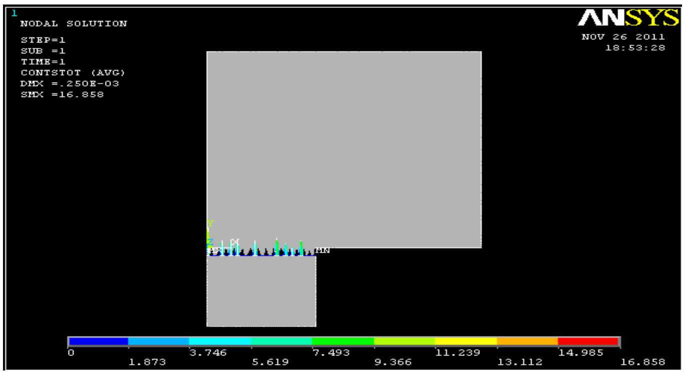

Fig: Contact Stress for 100N Force

Analysis Of Work Piece Having Maximum Surface Roughness Peaks.

Maximum Number of Surface Roughness Peaks is 38Nos.

Sl.No.	Load	Displacement	Von misses Stress	Elastic Strain
1	50	0.296e-03	8.025	0.422e-04
2	250	0.592e-03	16.05	0.844e-04
3	500	0.971e-03	26.322	0.138e-03
4	1000	0.002367	64.201	0.338e-03
5	1500	0.002959	80.251	0.422e-03

Table: Result of Mild Steel analyses for 38No.Surface roughness Peaks

Sl. No.	Load	Displacement	Von misses Stress	Elastic Strain
1	50	0.801e-03	8.018	0.113e-03
2	250	0.001603	16.035	0.227e-03
3	500	0.002805	28.06	0.397e-03
4	1000	0.005611	56.133	0.798e-03
5	1500	0.008017	80.174	0.001141

Table: Result of Aluminum analysis for 38No.Surface roughness Peaks

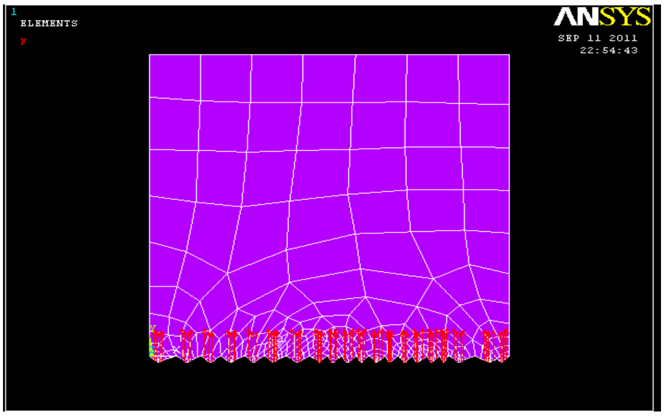

Fig Loading Diagram of Mild steel and Aluminum

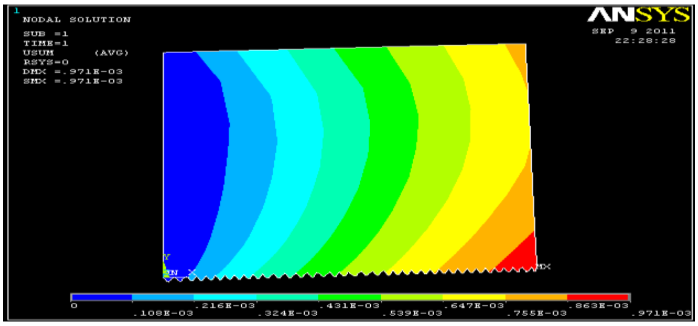

Fig: Mild steel Displacement obtained for 500N Force

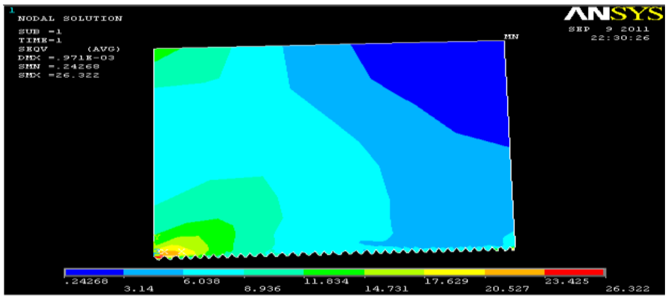

Fig: Von Misses Stress obtained for 500N force

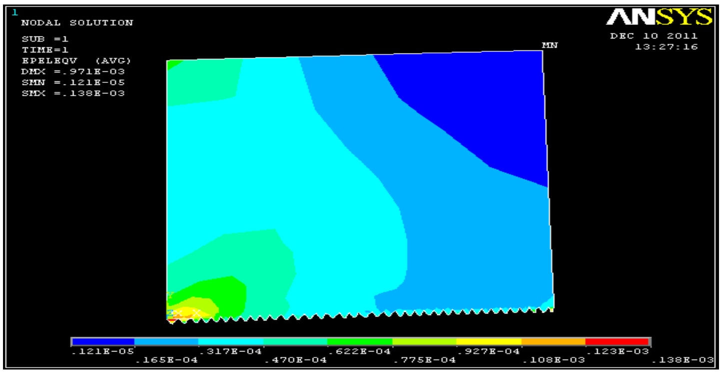

Fig: Von Misses Elastic strain obtained for 500N force

Number of Surface Roughness Peaks is 20Nos.

Sl.No.	Load	Displacement	Von misses Stress	Elastic Strain
1	50	0.160e-03	4.696	0.237e-04
2	250	0.795e-03	30.39	0.152e-03
3	500	0.992e-03	29.369	0.148e-03
4	1000	0.001994	58.763	0.296e-03
5	1500	0.003182	94.195	0.475e-03

Table: Result of Mild Steel analysis for 20 Surface Roughness Peaks

Sl.No.	Load	Displacement	Von Misses Stress	Elastic strain
1	50	0.432e-03	4.73	0.637e-04
2	250	0.002129	23.37	0.315e-03
3	500	0.003008	32.982	0.444e-03
4	1000	0.005383	59.058	0.795e-03
5	1500	0.008622	94.753	0.001271

Table: Result of Aluminum analysis for 20 surface roughness Peaks

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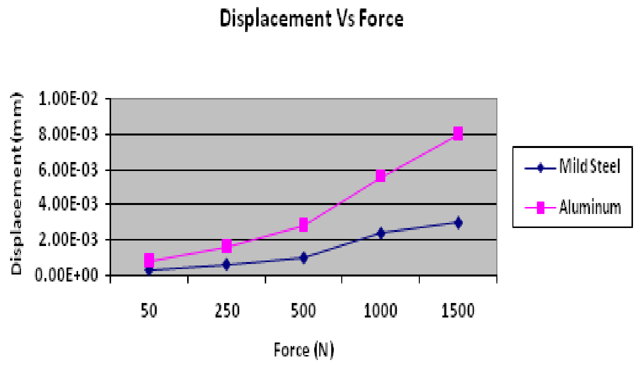

Fig: Comparison of Mild steel and Aluminum for 38 Surface Roughness Peaks

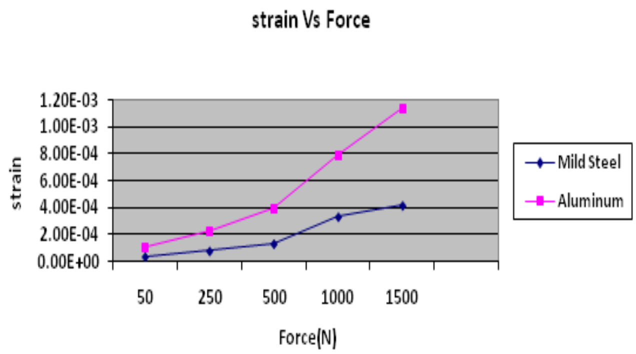

Fig: Comparison Strain and Force for Mild Steel, Aluminum 38 Surface Roughness Peaks

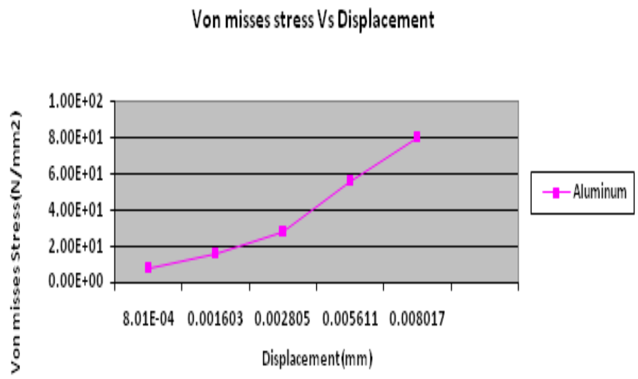

Fig. Analysis of Aluminum having 20 Surface Roughness Peaks

In both the cases as force and displacement increases Stress, Strain increases.

Discussion of Results

Comparison of Contact Stress Analysis.

Theories as described in section are compared with Ansys Contact Models of Mild Steel.

Contact Models are:
Model 1: Contact without Surface Roughness Peaks.
Model 2: 3D Contact without Surface Roughness Peaks.

Model 3: Contact with Surface Roughness Peaks

Model 4: Work Pieces (Mild steel and Aluminum) analysis

Sl.no.	Force	Hertz	Single asperity	Boresi	Von Misses stress
1	50	106	107.868	78.41	94.434
2	250	234.64	241.21	173.56	190.098
3	500	315	323.605	233.13	94.434

Table: Comparison of Contact Stress with Contact Model 1.

Sl.no.	Force	Hertz	Single asperity	Boresi	Von Misses stress
1	50	106	107.868	78.41	163.387
2	250	234.64	241.21	173.56	190.247
3	500	315	323.605	233.13	190.386

Table: Comparison of Contact Stress with Contact Model 2.

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Sl.no.	Force	Hertz	Single asperity	Boresi	Von Misses stress
1	50	106	107.868	78.41	109.312
2	250	234.64	241.21	173.56	-
3	500	315	323.605	233.13	-

Table: Comparison of Contact Stress with Contact Model 3.

Sl.no.	Force	Hertz	Single asperity	Boresi	Von Misses stress
1	50	106	107.868	78.41	8.025
2	250	234.64	241.21	173.56	16.05
3	500	315	323.605	233.13	26.322

Table: Comparison of Contact Stress with Contact Model 4.

The Results Obtained indicates that Hertz Theory yields similar results to FEM Model. The Discrepancies in comparison of results are due to reasons:

- Approximate Materials Properties used in simulation since text book values are different from Practice.
- The Contact analysis Prove to about 10 to 15% variation in results.

Conclusion

On the basis of Extensive Numerical and Experimental Investigations of the Present work, the Following conclusions:

1) The Results Shows that improvement in Surface Roughness and increase in Surface Hardness are achieved by application of Roller burnishing for Mild steel and Aluminum Work pieces.

2) The surface roughness decreases with increase in feed, burnishing speed, force and number of passes, to a certain limit, and then it starts to increase with the increase of each of the above-mentioned burnishing parameters. Burnishing parameter values are: Feed 48tpi, Speed 399rpm, Force 250N and Passes 3 for Mild Steel. Burnishing parameter values are: Feed 32tpi, Speed 399rpm, Force 250N and Passes 3 for Aluminum.

3) The surface Hardness decreases with increase in feed, burnishing speed, force and number of passes, to a certain limit, and then it starts to increase with the increase of each of the above-mentioned burnishing parameters. For Example Optimum values are: Feed 32tpi, Speed 399rpm, Force 50N and Passes 3 for Mild Steel and Feed 48tpi, Speed 399rpm, Force 500N and Passes 3 for Aluminum.

4) Regression analysis yields that Surface Hardness depends on decreasing order of factors like Feed, Force, Passes and Speed for Mild Steel and Surface Roughness depends on decreasing order of factors like Speed, Passes, Feed and Force for Mild Steel.

5) Regression analysis yields that Surface Hardness and surface Roughness depends on increasing order of factors like Passes, Speed, Feed and Force for Mild Steel and Aluminum.

6) As Force increases Stress increases up to certain limit and decreases due to Work Hardening Effect, Loss of ductility of material.

7) All Models are Compared Theoretically and Experimentally the results Obtained indicates that Hertz Theory yields similar results to FEM Model.

8) The Discrepancies In comparison of results are due to reasons:

- Approximate Materials Properties used in simulation since text book values are different from Practice.
- The Contact analysis Prove to about 10 to 15% variation in results.

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Future Scope

- Investigations are making use of different size of rollers is used to conduct tests on the components.
- Investigations on the effect force, feed, Speed and Passes to determine the optimal burnishing parameters on corrosion resistance, since surface roughness has great influence on corrosion resistance.
- Dynamic analysis can be performed for different Contact Models subjected to various Loads, especially FEM analysis.
- Different Modern Statistical approaches like Taugchi Technique, Genetic Algorithm and ANOVAs can be performed to Optimize Parameters like Speed, Feed, Force and Number of Passes.
- Contact Stress analysis can be performed on different materials like Copper and Titanium etc.

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