Optimization of Roller Burnishing Process on Inconel 625 Material using Taguchi Approach & ANSYS

Aditya Kolapkar[1] Bhavesh Sheth[2] Deven Rahane[3] Vikrant Shilimkar[4] Vishwajeet Loni[5]
[1,2,3,4,5]B.E. Student
[1,2,3,4,5]Department of Mechanical Engineering
[1,2,3,4,5]Zcoer Pune University

Abstract— Surface quality affect product performance like assembly fit, aesthetic appeal, luster, corrosion properties, etc... Burnishing is a cold forming process, in which the metal near a machined surface is displaced from protrusions to fill the depressions. In roller burnishing, a hard roller is pressed against a rotating cylindrical work piece and parallel to the axis of the work piece. In the present work, various experiments are conducted to investigate the effect of burnishing on surface hardness and surface roughness of Inconel 625 specimens and applying Taguchi method for optimization. The results show that improvements in the surface roughness and increases in surface hardness were achieved by the application of roller burnishing .This process can be effectively used in many fields such as Aerospace Industries, Automobiles Manufacturing sector, Production of Machine tools, Hydraulic cylinders, etc.

Key words: Inconel 625 Material, Taguchi Approach

I. INTRODUCTION

Surface finish is required to avoid friction losses, good corrosion resistant property and high fatigue life. Conventional machining process leaves surface irregularities, which causes additional cost of finishing operations. Burnishing is a cold working process in which plastic deformation occurs by applying a pressure through a ball or roller on metallic surfaces .In the burnishing process, the pressure generated by the rollers exceeds the yield point of the softer piece part surface at the point of contact, resulting a small plastic deformation of the surface structure of the piece part. All machined surfaces consist of a series of peaks and valleys of irregular height and spacing. The plastic deformation created by roller burnishing displaces the material from the peaks by means of cold work under pressure into the valleys. The result is a mirror-like finish with a tough, work hardened, wear and corrosion resistant surface. It is a finishing and strengthening process. Improvements in fatigue resistance, yield and tensile strength can be achieved by the application of this process.

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. A burnishing tool develops a finished surface on turned or bored metal surface by performing a continuous planetary rotation of hardened rolls. The rotation of the rolls increases the yield point of the soft portion of the metal surface at the point of contact. The material in the peaks gets plastic deformation and it is filled up in the valleys.

In today's manufacturing industry, special attention is given to dimensional accuracy and surface finish. Thus, measuring and characterizing the surface roughness can be considered as the predictor of the machining performance. Burnishing is a process that leads to an accurate change in the surface roughness of the work piece by a minor amount of plastic deformation. In burnishing process, the metal on the surface of the work piece is redistributed without material loss. Besides producing a good surface finish, the burnishing process has additional advantages such as securing increased hardness, corrosion resistance and fatigue life as result of the produced compressive residual stress.

II. PROBLEM STATEMENT

To study the effect of roller burnishing process on properties of Inconel 625. Which is primarily used for gas turbine and compressor blade material subjected to high pressure and high temperature?

Some studies showed that roller burnishing results into highly improved fatigue life, surface finish, micro hardness, Corrosion resistance. However, the effects of roller burnishing on surface integrity of INCONEL 625 have not been well documented.

In this research, the major objective based on experimental analysis aims to:

1) Investigate the influence of roller burnishing parameters on surface integrity, such as surface roughness, micro hardness, and microstructure.
2) Obtain the optimum parameters for surface roughness.
3) Chapter 2 Literature reviews shows that effects of burnishing on surface integrity such as surface roughness, hardness, and residual stress.
4) Chapter 4 provides the descriptions of the experimental procedures including design of experiment for roller burnishing process for INCONEL 625. Surface roughness, micro hardness, and micro structure are considered as the surface integrity factors. Experimental results and discussions on the surface integrity resulting from burnishing process.
5) In chapter 5 results obtained after burnishing process such as Ra & Hardness values are listed.
6) Chapter 6 provides a summary of conclusions are made from this work as well as recommendation for future work.

III. METHODOLOGY

A. *Selection of Material:*

Inconel Alloy 625 (UNS designation N06625), also known as AMS 599, is a nickel-based super alloy that possesses high strength properties and resistance to elevated temperatures. It also demonstrates remarkable protection against corrosion and oxidation. Its ability to withstand high stress and a wide range of temperatures, both in and out of water, as well as being able to resist corrosion while being exposed to highly acidic environments makes it a fitting choice for nuclear and marine applications.

Inconel 625 was developed in the 1960's with the purpose of creating a material that could be used for steam-line piping. Some modifications were made to its original composition that has enabled it to be even more creep-resistant and weldable. Because of this, the uses of Inconel 625 have expanded into a wide range of industries such as the chemical processing industry, and for marine and nuclear applications to make pumps and valves and other high pressure equipment. Because of the metal's high Niobium (Nb) levels as well as its proposed exposure to harsh environments and high temperatures, there was concern about the weld ability of Inconel 625. Studies were therefore conducted to test the metal's weldability, tensile strength and creep resistance, and Inconel 625 was found to be an ideal choice for welding.

IV. DESIGN OF EXPERIMENT

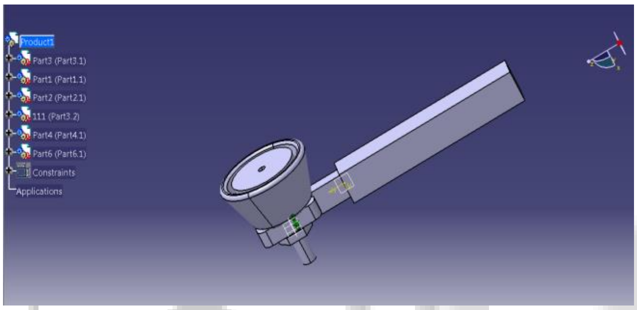


Fig. 1: Representing the 3D assembled model of Roller Burnishing Tool

Fig. 2: Roller Burnishing Tool

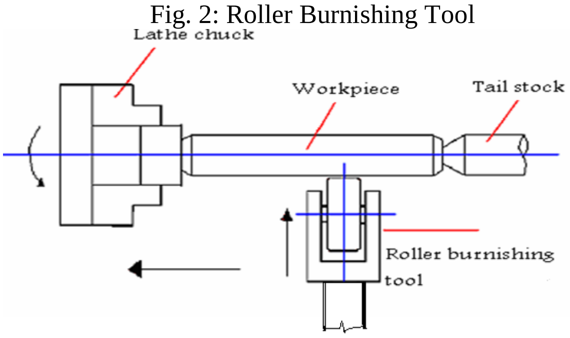


Fig. 3: Experimental setup for Burnishing Process

Following are the steps which were carried out for conducting the experiment:

Step1: Purchase of material (Inconel 625)

STEP2: After Finalizing The Material To Carry Out Our Experiment We Approached" Om Steel Pune "For The Purchase Of Material.

Step3: Verification Of Genuineness Of Material After Purchasing The Material We Tested The Material For Its Genuineness In Om Meta Lab Services Following Was The Lab Report.

Step4: Turning Process On Material To Achieve 20 Mm Diameter The Purchased Material Was 22 Mm In Diameter .So As To Generate The Roughness Values Which Mostly Occur In Machining Process We Performed Turning Operation On The Material .Due To This We Get Better Scope For Studying The Effect Of Burnishing Because In Actual Practice , All The Parts Are Machined To Achieve The Required Shape And Size And Due To These Machining Processes Finishing Processes Are Required To Improve The Surface Properties Of Material .

Fig. 4: Turning of Inconel 625

Step5: Division Of Single Bar Into Patches For Experimentation After Turning, We Divided A Single Bar Into Equally Sized 10 Patches So As To Vary The Burnishing Parameters For Each Patch. It Gives Us Wider Data Base For Studying The Effect Of Burnishing On Each Patch As Surface Roughness And Hardness Values Vary From Patch To Patch.

Step6: Recording The Readings Of Surface Roughness And Hardness Of The Patches After Dividing The Rod Into Patches We Recorded The Values Of Roughness And Hardness For Each Patch And Stored It For Analysis .It Helps For Comparative Study Of The Results Which Will Be Obtained After Burnishing.

Step7: Carrying out Burnishing on Lathe machine after recording roughness and hardness values for each patch, we carried out Burnishing process on lathe machine .We varied parameters like Speed of spindle, Depth of Cut, No. of passes for each patch using Taguchi Approach.

Fig. 5: Burnishing of Inconel 625

Step8: Recording Values of surface roughness and hardness after burnishing After Burnishing we again recorded values of roughness and hardness .We compared these values with values obtained before burnishing.

Step9: Conclusion of Experiment We can conclude that for Inconel 625 optimum values of parameters can get by varying speed, Depth of cut and Number of Passes.

V. OPTIMIZATION TECHNIQUE: TAGUCHI APPROACH

A. *Introduction*

every experimenter has to plan and conduct experiments to obtain enough and relevant data so that he can infer the science behind the observed phenomenon.

Performing a series of experiments each of which gives some understanding. This requires making measurements after every experiment so that analysis of observed data will allow him to decide what to do next - "Which parameters should be varied and by how much". Many a times such series does not progress much as negative results may discourage or will not allow a selection of parameters which ought to be changed in the next experiment. Therefore, such experimentation usually ends well before the numbers of experiments reach a double digit! The data is insufficient to draw any significant conclusions and the main problem (of understanding the science) still remains unsolved.

A well planned set of experiments, in which all parameters of interest are varied over a specified range, is a much better approach to obtain systematic data. Mathematically speaking, such a complete set of experiments ought to give desired results. Usually the number of experiments and resources (materials and time) required are prohibitively large. Often the experimenter decides to perform a subset of the complete set of experiments to save on time and money! However, it does not easily lend itself to understanding of science behind the phenomenon. The analysis is not very easy (though it may be easy for the mathematician/statistician) and thus effects of various parameters on the observed data are not readily apparent. In many cases, particularly those in which some optimization is required, the method does not point to the BEST settings of parameters. A classic example illustrating the drawback of design of experiments is found in the planning of a world cup event, say football. While all matches are well arranged with respect to the different teams and different venues on different dates and yet the planning does not care about the result of any match (win or lose)!!!! Obviously, such a strategy is not desirable for conducting scientific experiments (except for co-ordinating various institutions, committees, people, equipment, materials etc.).

B. *Taguchi Method:*

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings "of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

VI. STATIC PROBLEM (BATCH PROCESS OPTIMIZATION)

There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems;

A. *Smaller-The-Better:*

$n = -10\ Log_{10}$ [mean of sum of squares of measured data]

This is usually the chosen S/N ratio for all undesirable characteristics like "defects "etc. for which the ideal value is zero. Also, when an ideal value is finite and its maximum or minimum value is defined (like maximum purity is 100% or maximum Tc is 92K or minimum time for making a telephone connection is 1 sec) then the difference between measured data and ideal value is expected to be as small as possible. The generic form of S/N ratio then becomes,

$n = -10\ Log_{10}$ [mean of sum of squares of {measured - ideal}]

B. *Larger-The-Better:*

$n = -10\ Log_{10}$ [mean of sum squares of reciprocal of measured data]

This case has been converted to SMALLER-THE-BETTER by taking the reciprocals of measured data and then taking the S/N ratio as in the smaller-the-better case.

C. *Nominal-The-Best:*

$$n = 10\ Log_{10} \frac{\text{Square of mean}}{\text{variance}}$$

This case arises when a specified value is MOST desired, meaning that neither a smaller nor a larger value is desirable.

Examples are;

1) Most parts in mechanical fittings have dimensions which are nominal-the-best type.
2) Ratios of chemicals or mixtures are nominally the best type.
3) e.g. Aqua regia 1:3 of HNO3: HCL Ratio of Sulphur, KNO3 and Carbon in gun powder
4) Thickness should be uniform in deposition /growth /plating /etching...

VII. 8-STEPS IN TAGUCHI METHODOLOGY

Taguchi method is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment, and facilities. These improvements are aimed at improving the desired characteristics and simultaneously reducing the number of defects by studying the key variables controlling the process and optimizing the procedures or design to yield the best results.

The method is applicable over a wide range of engineering fields that include processes that manufacture raw materials, sub systems, products for professional and consumer markets. In fact, the method can be applied to any process be it engineering fabrication, computer-aided-design, banking and service sectors etc. Taguchi method is useful for 'tuning' a given process for 'best' results. Taguchi proposed a standard 8-step procedure for applying his method for optimizing any process.

A. 8-STEPS:

Step-1: Identify the Main Function Side Effects
Step-2:Identify the noise factors,
testing conditions, and quality characteristics
Step-3: identify the objective function to be optimized
Step-4: identify the control factors and their levels
Step-5: select the orthogonal array matrix experiment
Step-6: Conduct the matrix experiment
Step7:Analyze the data;predict the optimum levels and perfo rmance
Step-8:Perform the verification experiment
and plan the future action

VIII. RESULTS & DISCUSSIONS

A. Surface Roughness (Ra):

Surface roughness often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. Roughness is typically considered to be the high-frequency, short-wavelength component of a measured surface. However, in practice it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose.Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces .Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion. Although a high roughness value is often undesirable, it can be difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application.

Ra is the arithmetic average of the absolute values of the profile height deviations from the mean line, recorded within the evaluation length. Simply put, Ra is the average of a set of individual measurements of a surfaces peaks and valleys. Reveal the Ra formula for more insight.

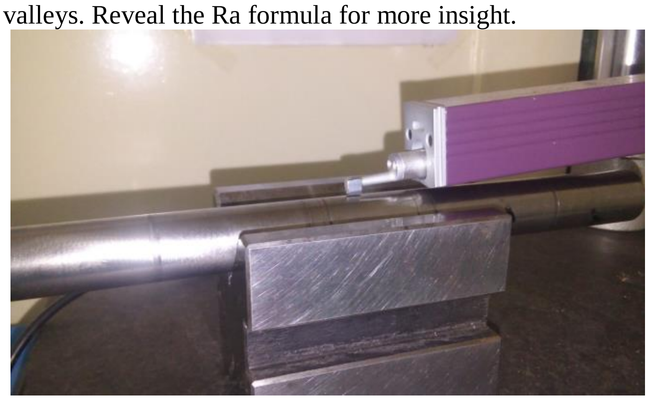


Fig. 6: Mitutoyo Surface Roughness Tester

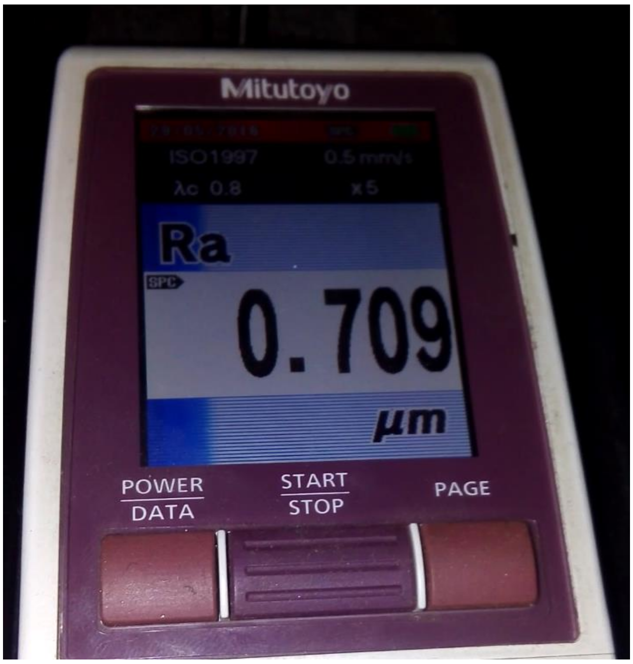


Fig. 7: Optimum Value obtained by Mitutoyo Surface Tester after Burnishing

B. Surface Hardness Rockwell HRC:

The Rockwell scale is a hardness scale based on indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. There are different scales, denoted by a single letter, that use different loads or indenters. The result is a dimensionless number noted as HRA, HRB, HRC, etc., where the last letter is the respective Rockwell scale.

When testing metals, indentation hardness correlates linearly with tensile strength. This important relation permits economically important nondestructive testing of bulk metal deliveries with lightweight, even portable equipment, such as hand-held Rockwell hardness testers.

C. Analysis of Variance (ANOVA):

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences among group means and their associated procedures (such as "variation" among and between groups), developed by statistician and evolutionary biologist Ronald Fisher.

ANOVAs are useful for comparing (testing) three or more means (groups or variables) for statistical significance. It is conceptually similar to multiple two-sample t-tests, but is less conservative (results in less type I error) and is therefore suited to a wide range of practical problems. The calculations of ANOVA can be characterized as computing a number of means and variances, dividing two variances and comparing the ratio to a handbook value to determine statistical significance. Calculating a treatment effect is then trivial, "the effect of any treatment is estimated by taking the difference between the mean of the observations which receive the treatment and the general mean.

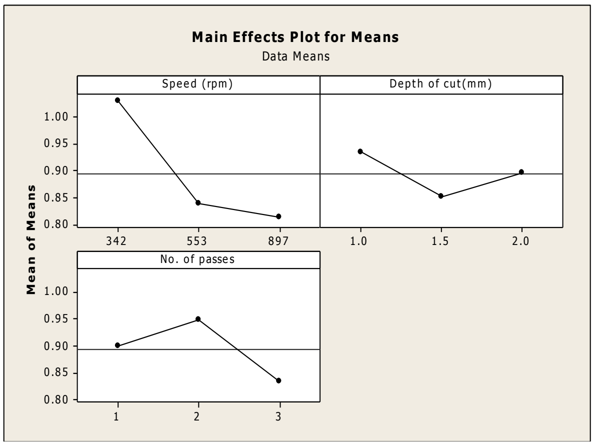


Fig. 8: Mean of Mean Vs Speed, No. of Passes, Depth of Cut

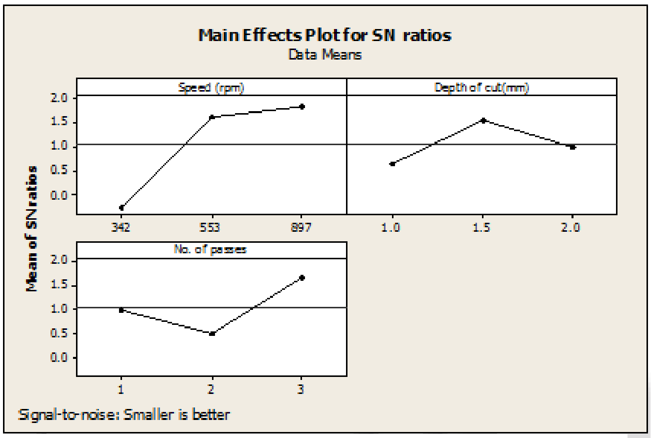
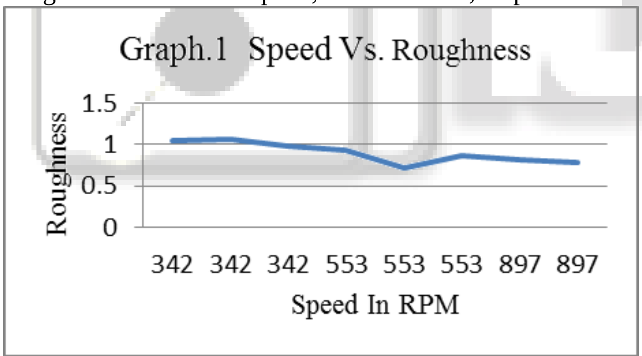
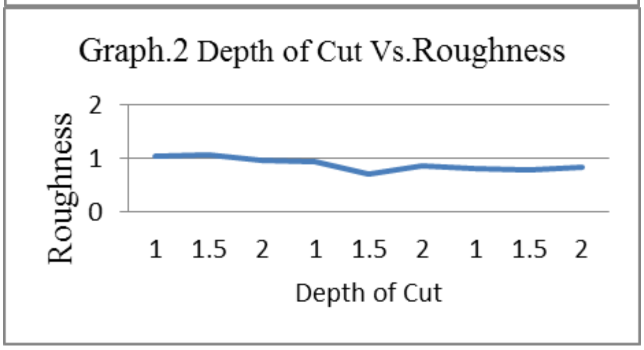
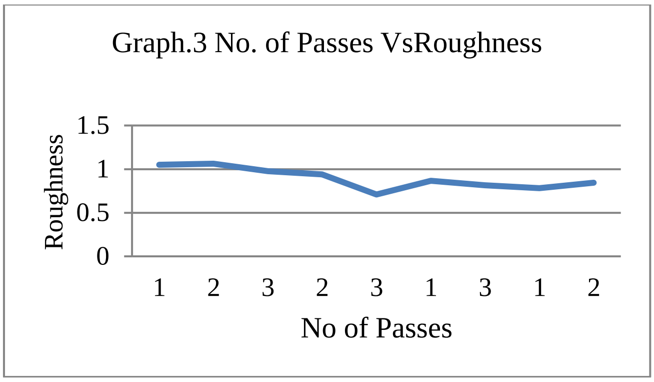


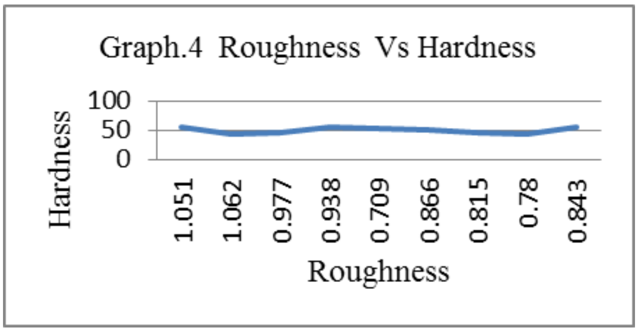
Fig. 9: S/N Ratio vs. Speed, No. of Passes, Depth of Cut



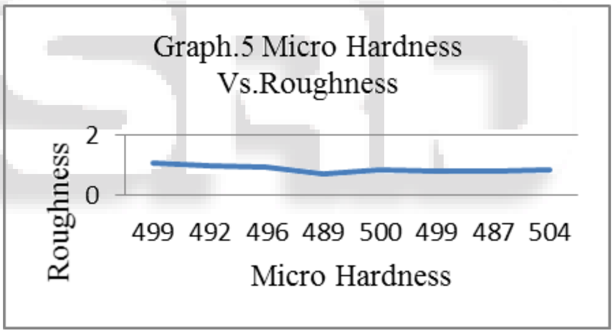




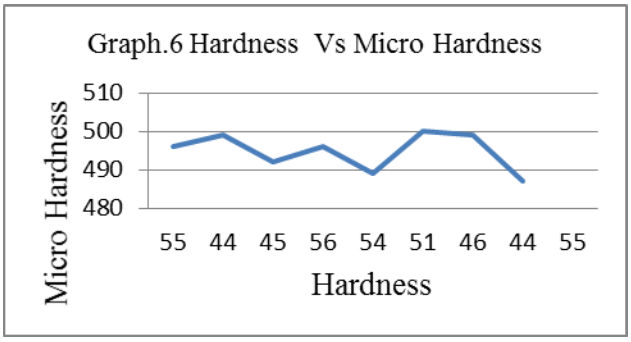
From above graphs, we can see that roughness value decreases when speed is 553, Depth of cut is1.5 mm and No. of Passes is 3.



From above graph, we can see that, maximum hardness observed is 57 HRC and minimum roughness value is .7 microns.



From above graph, we can see that, only at one point i.e. when microhardness value is 489 HV roughness value is minimumi.e. 0.7 microns



From above graph, we can see that nature of graph is very unstable. Thus a suitable parameter is required to be selected to achieve a particular result.

D. Finite Element Analysis:

The numerical determination of stresses in bodies by the finite element method is well known and has been applied to many problems of elasticity, plasticity, creep visco elasticity and vibrations. While it is difficult to apply this method to surfaces which involve microscopic asperities (except when one utilizes the complex multi-scale approach), an attempt is made in the present work to utilize asperities of larger size to examine the resulting stresses. Thus, the analyses are carried out in four different ways of representing the contact zone, namely, Contact without surface roughness peaks in 2D representation, 3D contact without surface roughness Peaks and contact with surface roughness peaks.

The analysis is carried out by using the code, ANSYS Rel 16.0. The boundary Conditions are as follows. As Work piece is fixed in chuck and live centre at ends, displacement is zero in UX direction. The load is applied on bottom surface of contact model. The contact between the roller and the work piece is created using contact elements. Three loading passes are used in these analyses as per experimental data. For this purpose, the data obtained after each pass are taken as initial state of the work piece and the analysis proceeded further.

Assumptions:

1) Material is homogeneous
2) All displacement, stress and strain values are taken in to static consideration.
3) Beam is cantilever.
4) in static analysis we consider one end is fixed (All DOF = 0) and other end is free on which load is applied (FY =100/150/200 N).
5) Burnishing process is usually dynamic in nature but due to some limitation we did it in static analysis.
6) For static consideration we only took one peak on which we applied load.

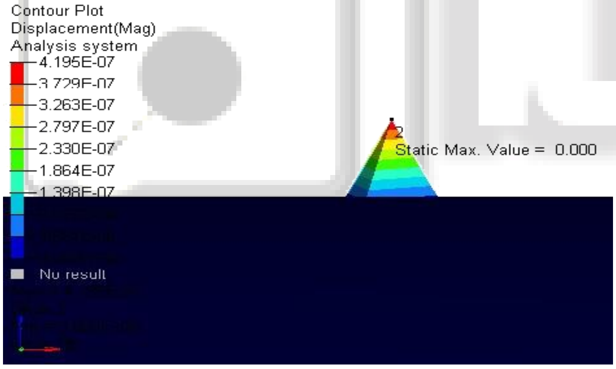


Fig. 10: Formation of Peak on Cylindrical Surface and Nodal displacement for 200N

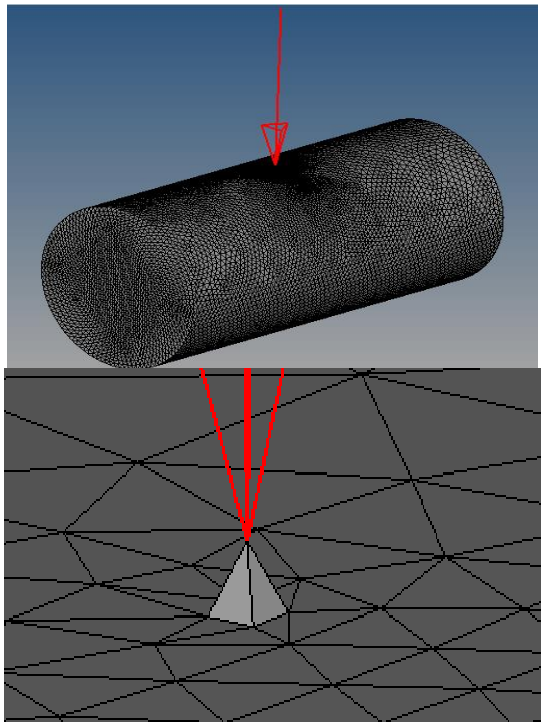


Fig. 11: Formation of peak on cylindrical surface with mesh with applied load 200N

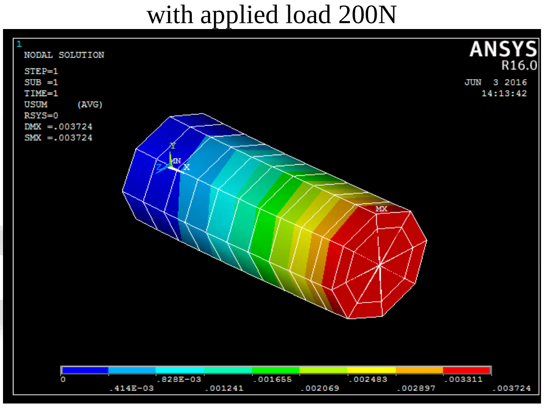


Fig. 12: Nodal Displacement for 100 N

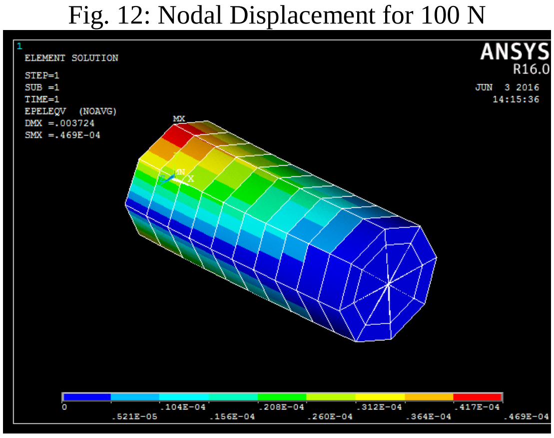


Fig. 13: Von Misses Elastic Strain for 100 N

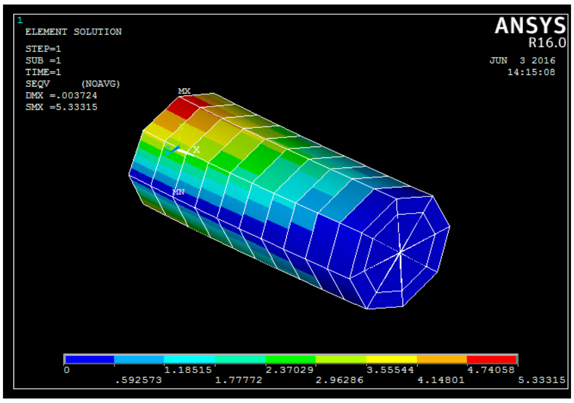


Fig. 14: Von Misses Stress for 100N

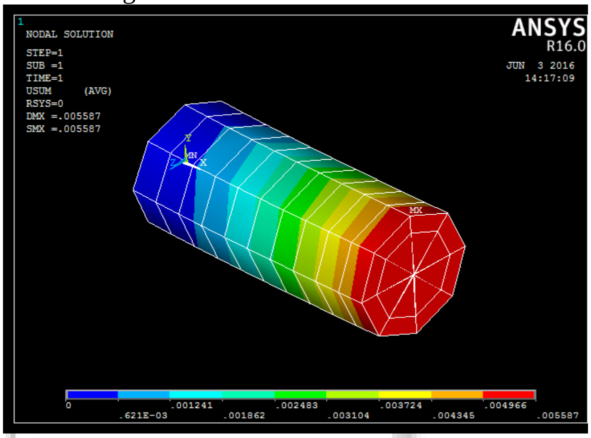


Fig. 15: Nodal Displacement for 150 N

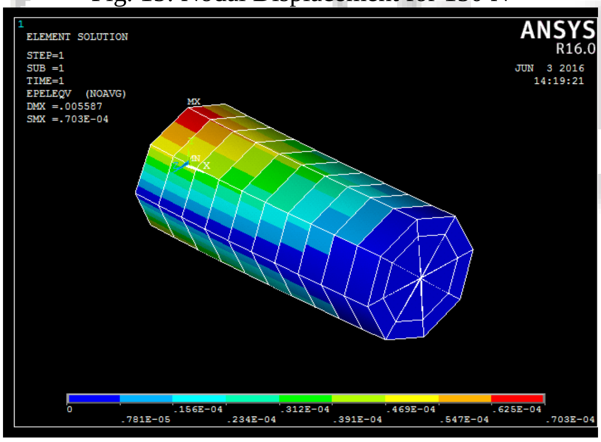


Fig. 16: Von Misses Elastic Strain for 150 N

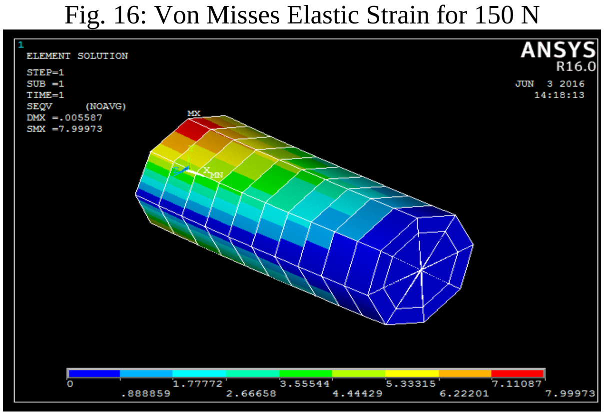


Fig. 17: Von Misses Stress for 150N

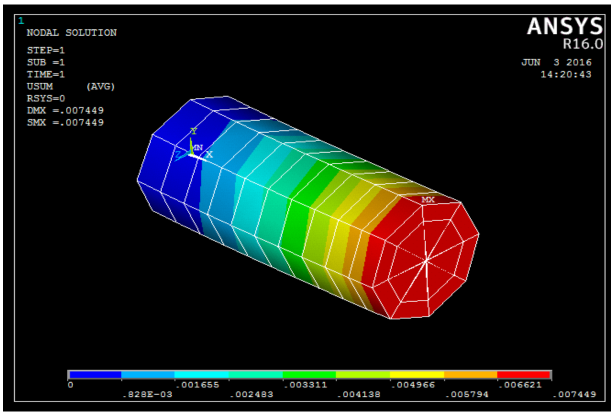


Fig. 18: Nodal Displacement for 200 N

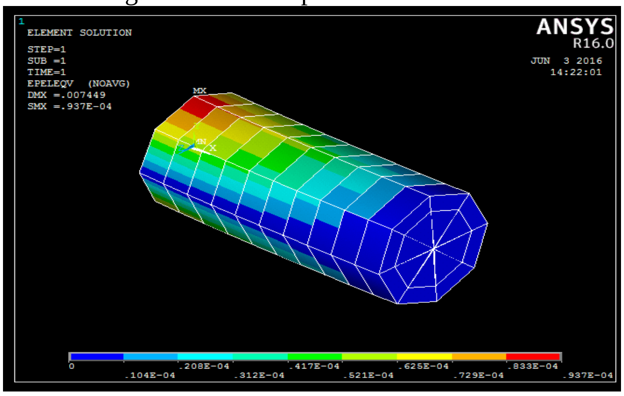


Fig. 19: Von Misses Elastic Strain for 200 N

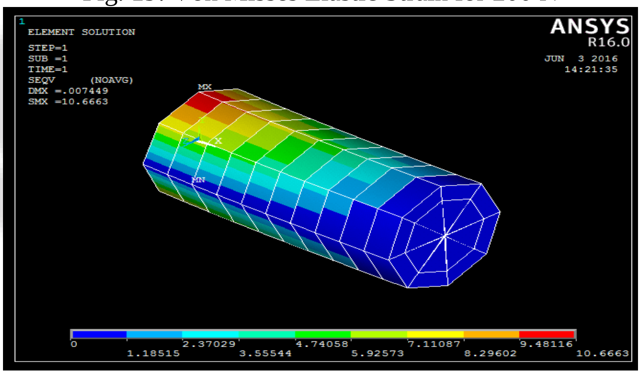


Fig. 20: Von Misses Stress for 200N

IX. Conclusions

The burnishing process leads to a smoother surface on which significant effects of process parameters that include no. of passes, depth of cut, and speed are obtained.

From above experiment we conclude that:

1) Surface finish achieve by roller burnishing process upto 0.709 µm for inconel 625 at speed 553 rpm , no. of passes 3 and depth of cut 1.5 mm.
2) We observed that the micro hardness of material is improved upto 504 HV for speed 897rpm, no. of passes 2 and depth of cut 1 mm.
3) From the experimental results we got improved hardness values upto 56 HRC by roller burnishing process.
4) From figure 5.4.2 and figure 5.4.3 we observed that microstructure of inconel 625 is comparatively improved and refine grain structure is obtained at 200X optical zoom.
5) Effect of depth of cut: Maximum surface finish is achieved at higher depth of cut of 1.5 mm shown in graph 5.5.4 as depth of cut increases roughness is decreases.

6) Effect of speed: Maximum surface finish is achieved at 553rpm. It is found that as speed increases than optimum value of roughness start increasing as shown in graph 5.5.3.
7) Effect of number of passes: Number of passes is also important factor. It is found that at one number of pass burnishing gives better microhardness. As number of passes increases roughness start increasing.

REFERENCES

[1] P. S. Kamble, V. S. Jadhav "Experimental study of Roller burnishing process on plain carrier of planetary type gear box", International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol.2, Issue.5, Sep-Oct. 2012 pp-3379-3383 ISSN: 2249-6645
[2] S. Thamizhmanii, B. Saparudin, S. Hasan"A study of multi-roller burnishing on non-ferrous metals", Journal of Achievements in Materials and Manufacturing Engineering, Volume 22 Issue 2 June 2007
[3] Saeed Saki Entezami and Masoud Farahnakian "Manufacturing a Burnishing Tool and Experimental Study of Effective Parameters on Burnishing Treatment process Of External Surfaces", Indian J.Sci.Res.3 (1): 110-114, 2014, ISSN: 0976-2876 (Print) ISSN: 2250-0138 (Online)
[4] Prof. Ghodake A. P., Prof. Rakhade R.D., Prof. Maheshwari A.S." Effect of Burnishing Process on Behavior of Engineering Materials- A Review", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684 Volume 5, Issue 5 (Mar. - Apr. 2013), PP 09-20www.iosrjournals.org
[5] Paul S. Prevéy , Ravi A. Ravindranath , Michael Shepard , Timothy Gabb" Case Studies of Fatigue Life Improvement Using Low Plasticity Burnishing in Gas Turbine Engine Applications ", Proceedings of ASME Turbo Expo 2003June 16–19, 2003, Atlanta, Georgia, USA
[6] Ashish Deshmukh, Prof.Dr.R.N.Patil" Analysis and Optimization of Roller Burnishing Process on Cylindrical Surface micro Hardness of Aluminum Alloy ", International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization) Vol. 4, Issue 7, July 2015, ISSN (Online) : 2319-8753 ISSN (Print) : 2347-6710
[7] Igor Yu. Smolin Viktor P. Kuznetsov Andrey I. Dmitriev" Numerical analysis of the stress-strain state of the steel superficial layer under Nano structuring burnishing "Proceedings of XLII International Summer School–Conference APM 2014

