Impact of Ball Burnishing Process on Residual stress distribution in Aluminium 2024 Alloy using Experimental and Numerical Simulation

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Abstract: Deep ball burnishing is surface enhancement process is specifically used to induce compressive residual stress in material sub surface. In this investigation deep ball burnishing surface treatment process was carried out on the periphery of Al 2024 alloy and induced beneficial compressive residual stress was determined by X-Ray Diffraction method. In this work explicit module of the FE-Code ABAQUS-6.17 was used to model the ball burnishing process and analysis is carried out to determine the residual stresses in Aluminium 2024 Alloy by changing instantaneously process variables like burnishing passes and pressure. Comparison was made among experimental and results obtained from FEA, it was observed that there is well agreement between the FE Results and experimental results. Also the results revealed the impact of deep ball burnishing process parameters on distribution of beneficial compressive residual stress.

Keywords : Ball burnishing, Residual stress, Finite element analysis.

1. Introduction
The cyclic loads are the prime reason for failure of aero engine components. The aeroengine parts manufactured mainly fails due to the cyclic loads as they are instantaneously subjected to HCF and LCF. Lack of mirror surface finish of the part would increase the rate of crack initiation, propagation and gradually leads to the failure of component. In commercial practice many surface coating and surface treatment processes are available to enhance surface integrity properties of engineering components like laser shock peening, deep rolling. Burnishing which helps to avoid the fatigue failure of engine components. Aviles R et al.[1] investigated the effect of deep ball burnishing on fatigue life of mechanical components with and without surface treatment. In this work deep ball burnishing surface treatment is employed to improve the surface integrity parameters that are needed to enhance its fatigue life. Rolling process makes the component surface smoother with out producing chip and with less amount of cold work. The integral process rolling variables like pressure, force, speed, feed, types of lubricant also affects the treatment effectiveness. Loh N[2] conducted exhaustive literature work related to the process variable parameters affecting the surface integrity of components in turn increase the fatigue life. Harish et al.[3] conducted the comparative study of influence of deep ball and roller burnishing treatment on surface integral properties mainly its impact on induced residual stresses of Aluminium 2024 Alloy. It was found that ball burningish process was effective in improving the hardness while roller burnishing process was effective in surface roughness. Beres et al.[4] numerically investigated the residual stress distribution results of low plasticity burningish process. Harish et al [5]analysed the impact of ball burnishing on surface properties of Aluminium 2024 Alloy. It was found that ball burningish process has a great impact on the surface enhancement of material.
2. Selection of Test Specimen

In this investigation the deep burnishing process is carried out on Aluminium alloy 2024. Al 2024 alloy is an most widely used element in aero engine component manufacturing industry due to its resistance to fatigue failure and its valuable strength to weight ratio. The main constituent of Al 2024 alloy is Cu (4.95%). Ultimate tensile strength and yield strength was found to be 469 Mpa, 441 Mpa respectively. Details of Material properties of Al 2024 alloy was given in below Table 1.

| Elements | Al (Wt %) | Cu | Cr | Mg | Mn | Si |
|----------|-----------|----|----|----|----|----|
|          | 94.7      | 4.9| 0.1| 1.8| 0.9| 0.5|

Table1 Material properties used for simulating Aluminium 2024 Alloy

3. Experimentation

The deep rolling burnished tool consists of tungsten carbide steel ball, helical spring, hydrostatic bearing seat. The steel ball is pressed against the specimen with hydraulic pressure supplied by hydraulic unit of pressure of maximum capacity 20MPa. The deep rolling tool is fixed in the tool post of conventional lathe machine. Seven equal spaces were machined on the specimen. Later Specimen was placed in between supporting chucks of lathe. Then with the help of burnishing tool, ball is pressed over specimen. Deep rolling process was carried out at different section by varying overturns and pressure to understand the effectiveness of burnishing treatment. Burnishing Process is carried out under the different pressure at different sections. In this investigation treatment is carried out using the variable pressure 10MPa, 15MPa and 20MPa respectively. The maximum overturns carried out at specimen surface is 3. After the completion of surface treatment the beneficial compressive stress is measured by X-Ray diffraction method.

4. Finite Element Modelling

The ABAQUS 6.17 is used to simulate burnishing process to investigate residual stresses in various depth. The numerical simulation was carried out using two variables i.e burnishing pass and burnishing pressure. The 3D finite element mesh for modelling of the deep ball burnishing process as shown in figure below. The simulation has been carried out by assuming tungsten carbide ball as a rigid and rectangular Al 2024 alloy as deformable. In this analysis the used boundary conditions are rotation and linear displacement for rigid ball and plate is completely constrained in all the directions. In this analysis work piece was meshed using C3D8R elements. Figure 2 shows the meshing strategy of the rectangular specimen. The burnishing process is followed as according to the burnishing pattern.
5. Numerical Results and its Validation.

After the numerical simulation of deep rolling process, induced residual stresses in longitudinal and transverse direction as shown in below figure 3 and 4. Longitudinal and transverse residual stresses are computed by varying process parameters such as overturns and deep rolling pressure are shown in the figure 6,7 and 8. The experimental results obtained in [3] is validated with numerical simulation results. It was observed that experimental results are deviating by numerical results only by 9%.
Validation of results:

The experimental results obtained in [3] is validated with numerical simulation results. It was observed that experimental results are deviating by numerical results only by 9%. To verify the accuracy of the numerical simulation of ball burnishing process, the residual stress profile comparison made and it is shown in figure 5. The stress distribution for the rolling variables in longitudinal direction was shown in figures 6, 7, 8 and 9.

![Figure 5 validation of results](image)

![Fig.6 stress distribution for pressure 10 MPa](image)

![Fig. 7 stress distribution for pressure 15 MPa](image)
6. Conclusion:

A comprehensive 3D finite explicit dynamic analysis was conducted to simulate the ball burnishing process. Based on obtained residual stress distribution from FE method and experimental method the following conclusions are drawn.

- It was found that experimental results shows well agreement with the numerical results. The results revealed that increase in overlap of the rolling tracks largely increases the magnitude of the residual stress created in target plate.
- Numerical results revealed that the overlapping effect has a greater impact on residual stress distribution in the given material.
- It is also found that burnishing passes also major impact on the residual stress distribution in Aluminium 2024 Alloy.
- It may also be observed that the depth of residual stress was improved by increasing the burnishing pressure.

References

[1] R. Avilés, J. Albizuri, A. Rodríguez, and L. N. López de Lacalle, “On the fatigue strength of ball burnished mechanical elements,” *Mechanisms and Machine Science*, vol. 17, pp. 365–373, 2014, doi: 10.1007/978-94-007-7485-8_45.

[2] N. H. Loh and S. C. Tam, “Effects of ball burnishing parameters on surface finish A literature survey and discussion,” 1988.

[3] Harish and D. Shivalingappa, “The influence of ball and roller burnishing process parameters on surface integrity of Al 2024 alloy,” *Materials Today: Proceedings*, vol. 27, pp. 1337–1340, 2020, doi: 10.1016/j.matpr.2020.02.614.

[4] W. Beres, J. Li, and P. Patnaik, “GT2004-53925 NUMERICAL SIMULATION OF THE LOW PLASTICITY BURNISHING PROCESS FOR FATIGUE PROPERTY ENHANCEMENT,” 2004. [Online]. Available: http://www.asme.org/about-asme/terms-of-use.

[5] Harish, D. Shivalingappa, P. Vishnu, and Sampath Kumaran, “Impact of Ball burnishing process parameters on surface Integrity of an Aluminium 2024 Alloy,” in *IOP Conference Series: Materials Science and Engineering*, Jun. 2018, vol. 376, no. 1, doi: 10.1088/1757-899X/376/1/012099.