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Comparison of hub inner shaft design options for orbital forming process by Finite Element Method and subsequently effect on preload of Generation-3 wheel hub bearing.

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Abstract: *Presently orbital forming is done to assemble Generation-3 wheel hub bearings where hub inner shaft end is plastically formed to lock small inner. Orbital forming process is very critical in terms of controlling preload in a Generation-3 wheel hub bearing and hence provides a maintenance free design. In this study, comparison and simulation has been done among three hub inner shaft design options (i) without relief curve & step (ii) with relief curve & step (iii) only with step, by using commercial finite element software ABAQUS 6.12.1 EXPLICIT module. Pre-stress, radial & axial plastic deformation of small inner was found after simulating orbital forming and compared for above stated three design options.*
Keywords: *Orbital forming, Generation-3 wheel hub bearing, Dynamic analysis, FEM,*

I. Introduction

Earlier, a nut was used for fastening and retaining small inner on hub inner shaft of a generation-3 wheel hub bearing. Now in present day, Orbital forming is a new methodology to delimit the nut and make the assembly simple (eliminate threading operation on hub inner shaft) [1]. Orbital forming is a technology used in many wheel hub assemblies with some key advantages like preload the bearing permanently in manufacturing process which increase the stability of the bearing hence providing a maintenance free design. The deformed section of hub inner shaft is also called as flange, caulking portion, shaft clinching etc. [2, 3].

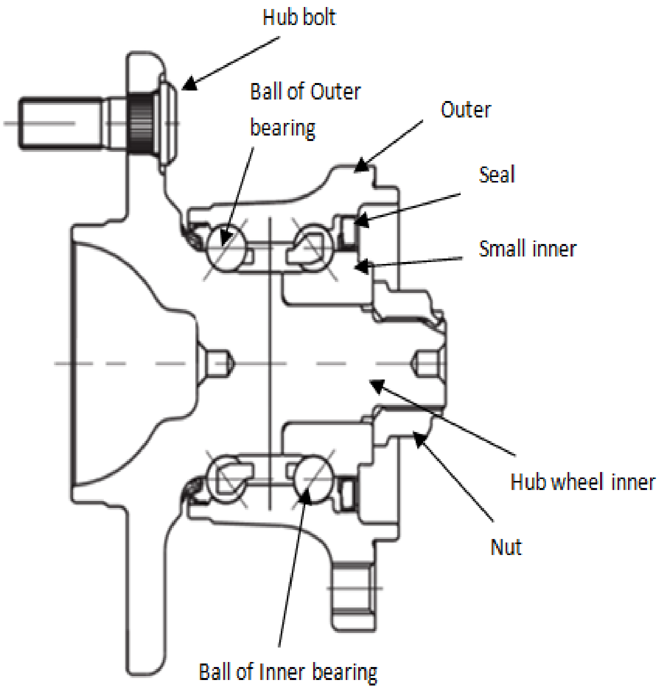


Figure 1: GEN-3 bearing with nut

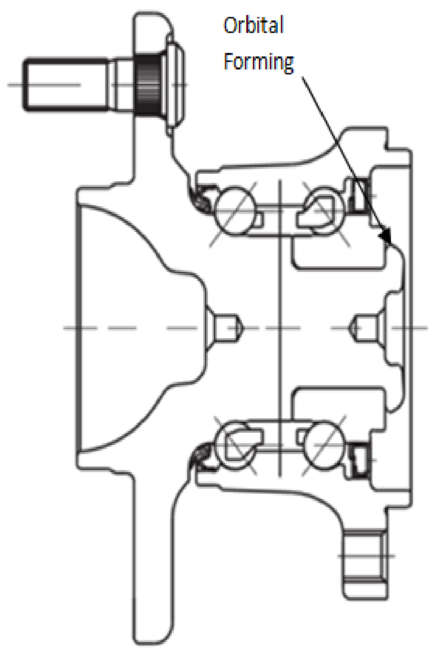
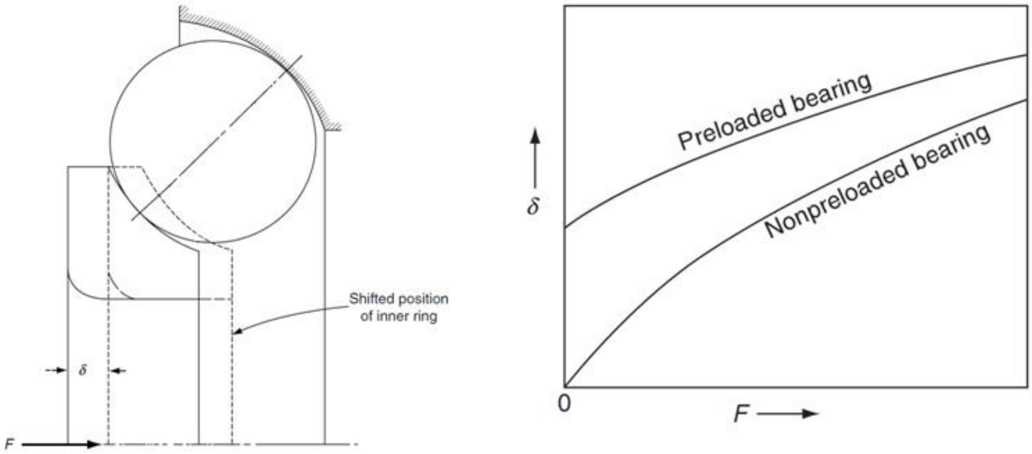


Figure 2: GEN-3 bearing with orbital forming

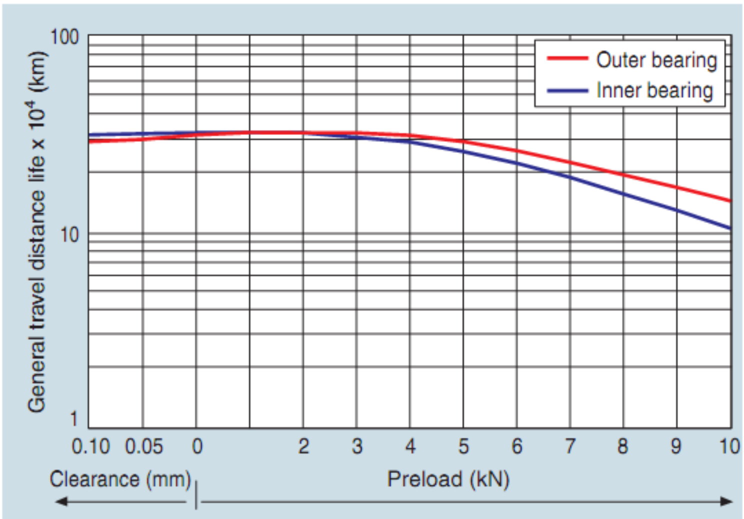
Preload is an axial interference between balls and raceways of hub outer, hub inner and small inner such that there is no measurable axial shaft movement when a small axial force is applied – in both directions, while oscillating or rotating the hub inner shaft [4].

A typical curve of ball bearing deflection vs. load is shown in Graph 1. It can be seen from Graph 1 that as the load is increased uniformly, the rate of deflection increase declines. Hence, it would be advantageous with regard to minimizing bearing deflection under load to operate above the knee of the load–deflection curve [6].



Graph 1: load vs. deflection curve

The value of preload is very essential part of bearing. The figure shown the relationship between bearing preload and fatigue life of generation 3 bearing. The generation 3 bearing has two rows of balls. The row which is near to the wheel is outer bearing and row which near to the flange is called inner bearing. At zero clearance the life of bearing is lower than the preload condition. At higher preload also cause the decrease the bearing fatigue life. So therefore optimum preload is selected for higher bearing life [9]. Further orbital forming becomes critical operation since it is done near to inner bearing and deformation caused in small inner ring will cause change in preload.



Graph 2: bearing fatigue life vs. Preload condition

The Orbital forming process is a large deformation contact forming process by an automated machine. A typical machine set up is shown in Figure 3 (i). The tool used for forming is called Peen as shown in Figure 3 (ii). In the practical experiment of orbital forming the tool is tilted by an angle 3˚~ 6˚and rotating at 500 ~ 700 RPM for 5~7 sec as shown in Figure 3 (iii). The contact area between hub inner shaft and Peen tool changes continuously during process. The force is acting on the small area of the work piece therefore the friction is low [2]. When friction is low, the metal can flow much easier in radial direction. The metal flow and the tool stress is generally depend on the axial feed speed, the RPM of spindle. The purpose of this study was to simulate actual practical conditions during orbital forming. The effect of different Hub inner shaft design options were investigated in order to generate desirable product specification after orbital forming. The analysis zone is shown in Figure 3 (iv). Actual pictures of Generation-3 bearing is shown for before and after orbital forming in Figure 3 (v). The common process of orbital forming process is explained in figure 4.

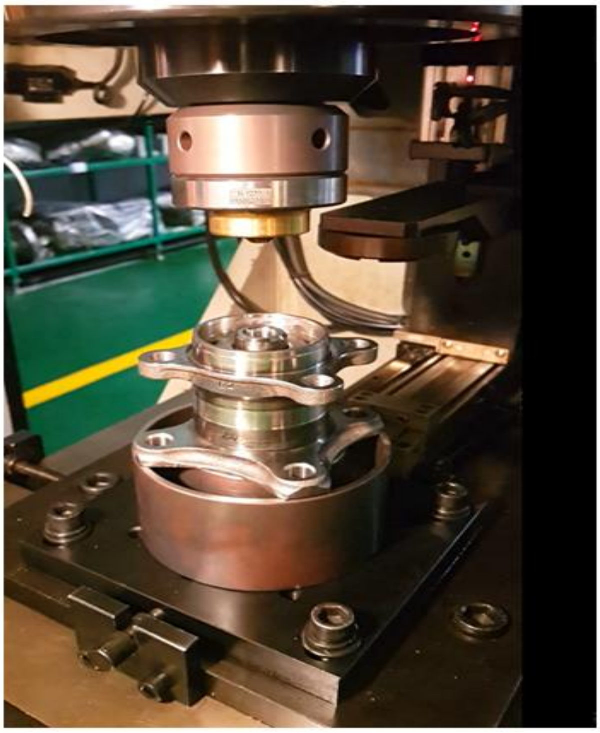


Figure 3 (i): orbital forming setup

Figure 3 (ii): orbital forming Peen tool

Figure 3 (iii): orbital forming setup

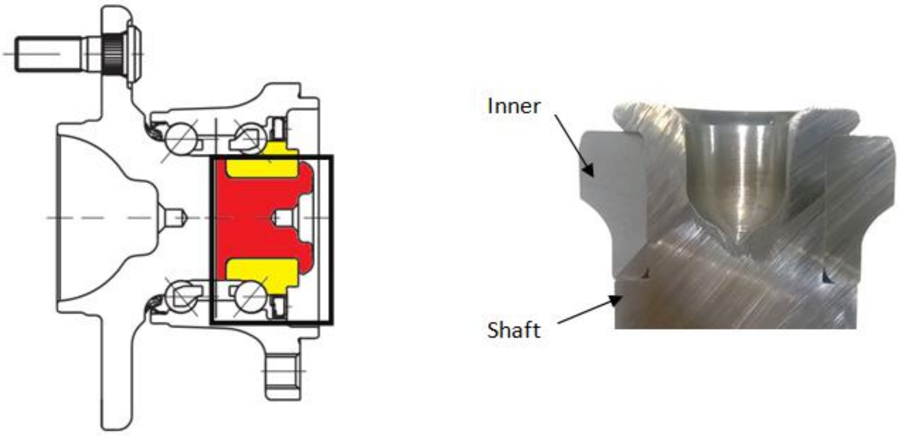


Figure 3 (iv): Analysis Zone of Generation-3 bearing

Figure 3 (v): Generation-3 bearing before and after orbital forming process

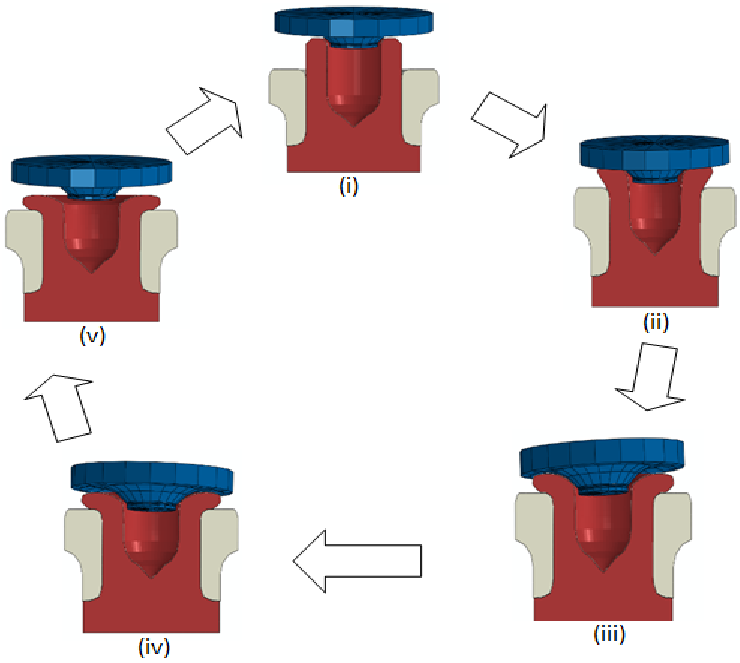


Figure 4 : (i) Initial condition, (ii) Peen Tool just touches hub inner with given feed rate, (iii) Peen Tool presses the hub inner to form a flange up to desired height, (iv) Idle revolution for fine finishing, (v) detach Peen Tool

The explicit FEM can be used for this analysis because it does not require iterative calculation.
In results radial & axial plastic deformation (permanent deformation) and stresses on small inner after orbital forming is computed for observing effect on preload of bearing.

II. Finite element method

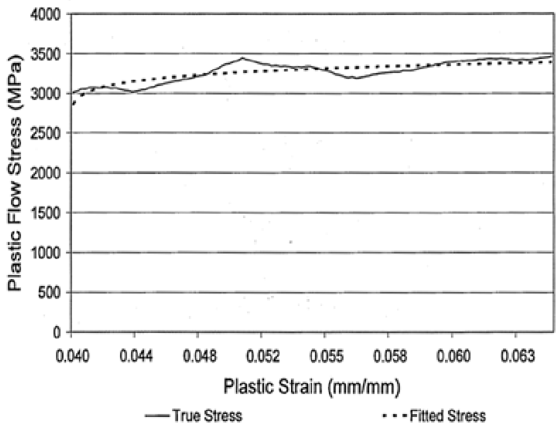
To simulate orbital forming process in explicit FEA, three parts (Small inner, hub inner & Peen tool) were modeled in 3D-modeling software (Creo Elements/Pro 5.0). Then parts were imported in FEA software (Abaqus 6.12.1). Material properties were taken as follows:

Material properties	
Density	7.8 kg/m3
Elastic properties	
Small inner:	
Young modulus	210000MPa
Poisson ratio	0.3
Hub inner	
Young modulus	207000MPa
Poisson ratio	0.27
Peen Tool	Rigid Body

Table1: material properties of small inner and hub inner

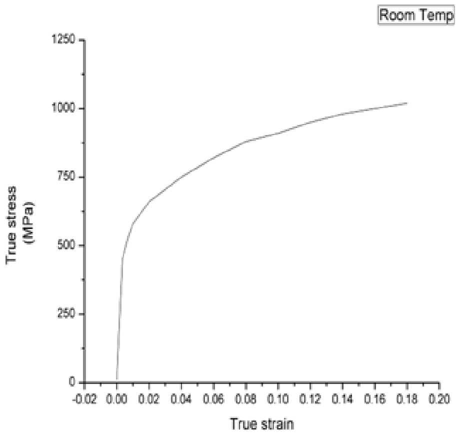
Plastic properties:-

For small inner:



Graph 3: Plastic property of small inner at room temperature (RT) [5]

For hub wheel inner



Graph 4: Plastic property of hub wheel inner at room temperature [8]

For simulation of orbital forming process the tilted angle of tool was taken 5˚, revolution of tool was taken 600 RPM and the time of completion of orbital process was taken 5 sec. the study was done for three hub inner shaft design options (i) without relief curve & step (ii) with relief curve & step (iii) only with step.

III. Design of tool used in orbital forming process

Fig. 5 is shown the tool design which is used in orbital forming process. The tool is same for all design iteration of relief curve. The tool has been tilted by an angle of 5˚.some segment of tool always touch with the work piece. For analysis purpose the tool supposed to be rigid body (no deformation and total load transfer to work piece).

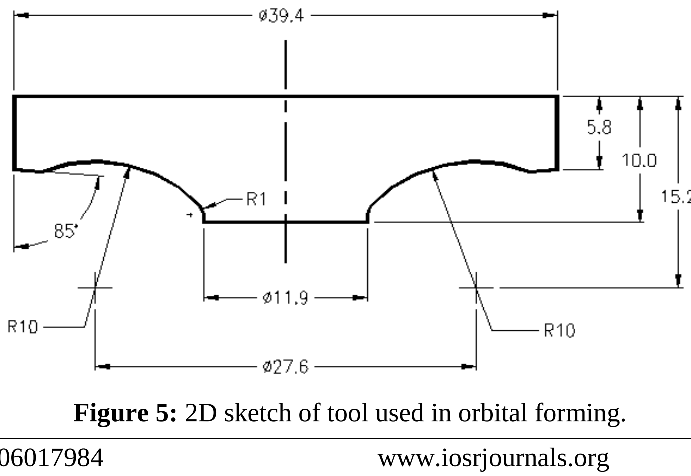


Figure 5: 2D sketch of tool used in orbital forming.

IV. Design of shaft and inner in orbital forming process

As shown in figure 6 is a design of shaft and inner .this design is same for all iteration except the relief curve on the shaft. For the first iteration of orbital forming no relief curve is provided on shaft. Simulation was done on the shaft which is shown in figure 6 (a).the second iteration was done on the relief curve of radius 3mm with the depth of 0.2mm.(figure 6(b)).the third iteration was done on the relief curve which has actually stepped cut of 0.25 mm (figure 6(c))

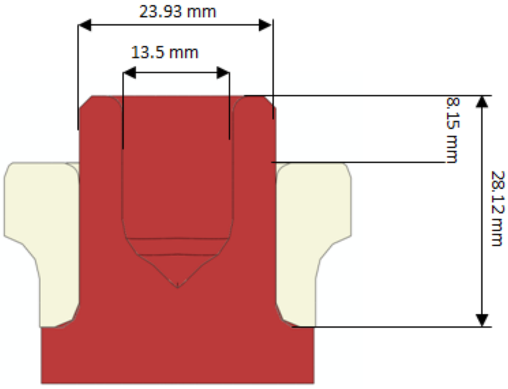


Figure 6 (a) without relief curve & step

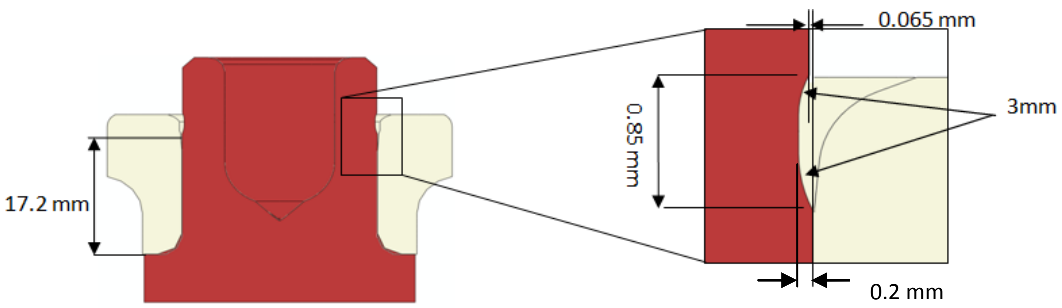


Figure 6 (b) *with* relief curve & step

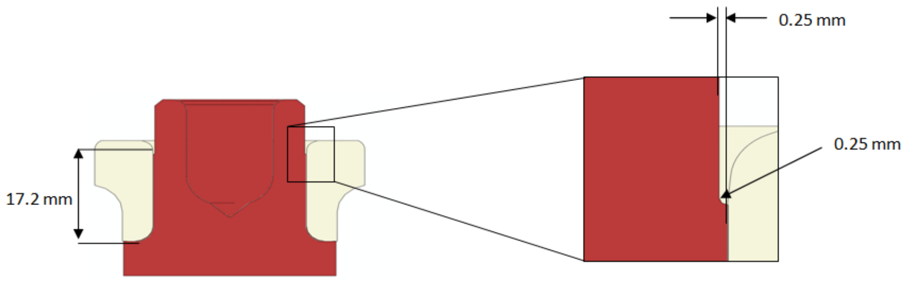


Figure 6 (c) only with step

V. FEA Results and Discursion

a. Iteration 1: No relief curve

Figure 7 (a) Before orbital forming

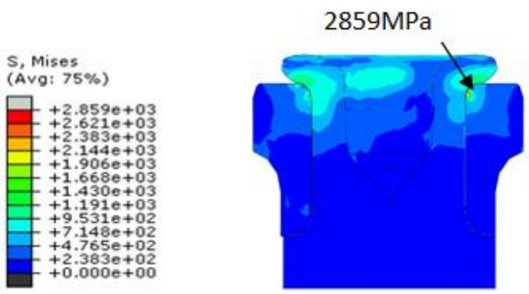


Figure 7 (b) After orbital forming

In the first iteration the shaft has no relief curve. After performing orbital forming process the stress has come across 2859 MPa at the top inside corner point of inner. During this operation the load is continuously transfer to the inner and some deformation has come in inner which is elastic as well as plastic. After withdrawal the tool from work piece elastic deformation is remove but the plastic deformation occur. The plastic deformation is measured from two depth of inner 1.5mm and 2.25mm from the top of inner surface. Initial diameter of inner is 42.225mm after orbital forming the elastic deformation are 21 µm at the depth of 1.5mm and 13 µm at the depth of 2.25 mm and the axial plastic deformation of small inner is 26 µm.

b. Iteration 2: With relief curve of radius 2mm with the depth of 0.2mm.

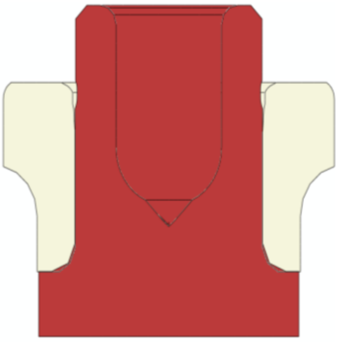


Figure 8 (a) Before orbital forming

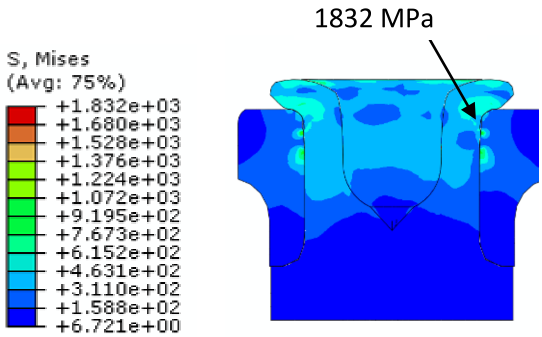


Figure 8 (b) After orbital forming

The second iteration was done on the relief curve of radius 2mm with the depth of 0.2mm. After performing orbital forming process the stress has come across 1832 MPa at the top inside corner point of inner with is low as compare to previous test (no relief curve). During this operation the load is continuously transfer to the inner and some deformation has come in inner which is elastic as well as plastic. After withdrawal the tool from work piece elastic deformation is remove but the plastic deformation occur. The plastic deformation is measured from two depth of inner 1.5mm and 2.25mm from the top of inner surface. Initial diameter of inner as same for all test(42.225mm) after orbital forming the elastic deformation are 5 µm at the depth of 1.5mm and 2 µm at the depth of 2.25 mm. and the axial plastic deformation of small inner is 18 µm.

c. Iteration 3: Relief curve (stepped cut of 0.25 mm).

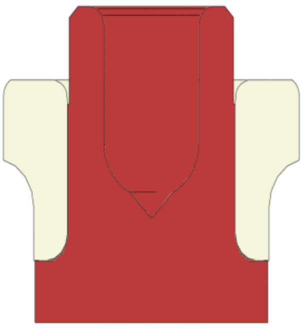


Figure 9 (a) Before orbital forming

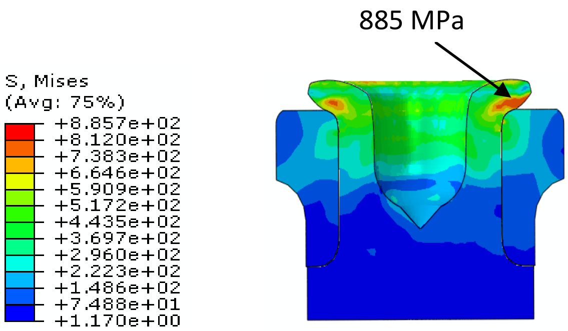
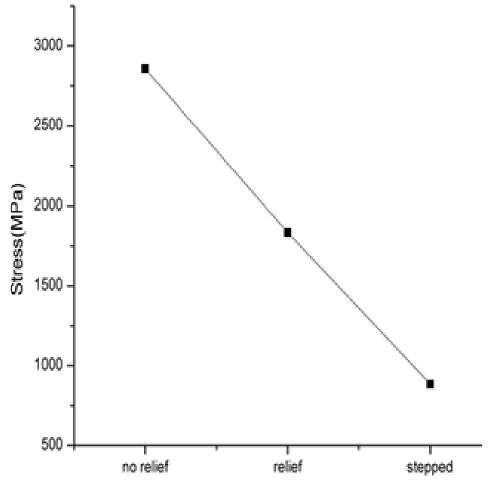


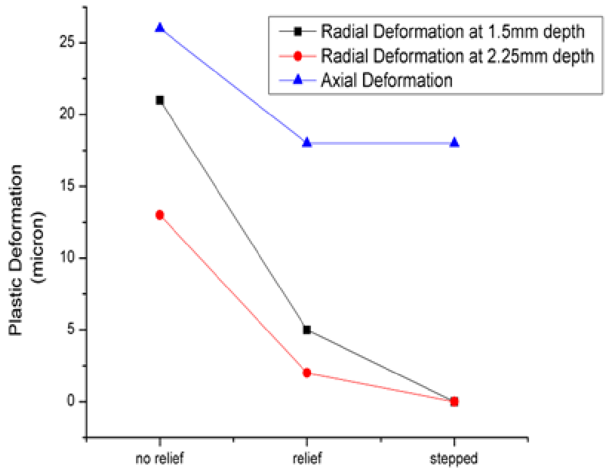
Figure 9 (b) After orbital forming

The third iteration was done on the relief curve (stepped cut of 0.25 mm). After performing orbital forming process the stress has come across 550 MPa at the top inside corner point of inner with is low as compare to previous two test. During this operation the load is continuously transfer to the inner and some deformation has come in inner which is only elastic because the stress value after orbital forming within elastic limit (for steel 900MPa). After withdrawal the tool from work piece elastic deformation is remove. The stress after orbital forming is in elastic limit so there is no plastic deformation and the axial plastic deformation of small inner is 18 µm.

Comparison of FEM results for different design of inner wheel hub



Graph 5: Stress in small inner after orbital forming process.



Graph 6: Plastic deformation in small inner after orbital forming

V. Conclusions

In this study, finite element method simulation of different relief curve on shaft in orbital forming process were conducted using ABAQUS 6.12.1. It is concluded that the shaft has high stress after orbital forming process that high stress on the shaft and inner is cause for plastic deformation. The design of inner track is very sensitive design parameter because bearing performance is depend on the track of inner and outer so the relief curve is done the commendable work by reduce the stress in inner and highly dissolve the plastic deformation. In this study two relief curve is used. In first relief curve (radius 3mm with the depth of 0.2mm) stress and plastic deformation of inner is reduced as compare to no relief curve iteration. In the second relief curve (stepped cut of 0.25 mm) stress is coming within the limit and no plastic deformation.

This study illustrated that the relief curve is important in orbital forming process and optimizing the stress by using the relief curve.

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