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An Optimized Heat Treatment for Bearing Cup Using FEA Analysis

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Abstract

In automobile field there are number of manufacturing facilities system has different constructive features according to the vehicle's driving type which can be front wheel drive, rear wheel drive or four wheel drive. In rear wheel drive system, elements of the system include clutch, transmission system, propeller shaft, joints, differential, drive shafts and wheels. Each element has many different designs and construction properties depending on the brands of vehicles. Drive shaft is used to transmit motion from gear box to differential. The problem identified after critical analysis of the drive shaft assembly. In that bearing cup assembly was getting cracked during assembly operation in universal joint assembly. This was highest rejection, hence it was decided to eliminate bearing cup failure in drive shaft assembly with cost effective solution. It will highlight the methodology adopted for finalizing the solution to this problem by means of the FEA analysis supported by logical reasoning. Various Heat Treatment processes are compared and it was found that the optimum solution which will reduce the failure of bearing cup as well as reduce the overall manufacturing cost.

Key Words: *FEA, drive shaft.*

1. Introduction

The automobile is a typical industrial product that involves a variety of materials and technologies. The present societal needs necessitate that metallic materials are ideally suited for applications in heavily stressed components that require high durability. The degree of functionality and component performance is strongly tied to the effectiveness of the processing technology deployed for a given application.

A propeller shaft or carden shaft is a mechanical component for transmitting torque and rotation usually used to connect other components of a drive train that cannot be connected directly because of distance or the need to allow for relative movement between them. The universal joint is used to transfer drive (power) from one shaft to another when they are inclined (non collinear) to each other.

1.1 Bearing Cup Assembly with drive shaft

Fig. 1.1 shows exploded view of bearing up with drive shaft assembly. Major parts involved are end yoke, journal, needle rollers, bearing cup, spline shaft, sleeve, tube, etc Bearing cups are assembled with needle rollers and are used as bearing in universal joint kit. The product quality requirement includes high wear resistance at surface and toughness at core. During assembly of the bearing in end yoke the bearing cup failure occurred.

This problem is defined in 4W 1H as below.

What- Bearing cup failure of UJ kit assembly.

When- While assembling the UJ Kit.

Where-Inside the plant on assembly line.

Which-This failure is on 1000 series of UJ assembly of drive shaft.

How- Average PPM for this failure is around 4000.

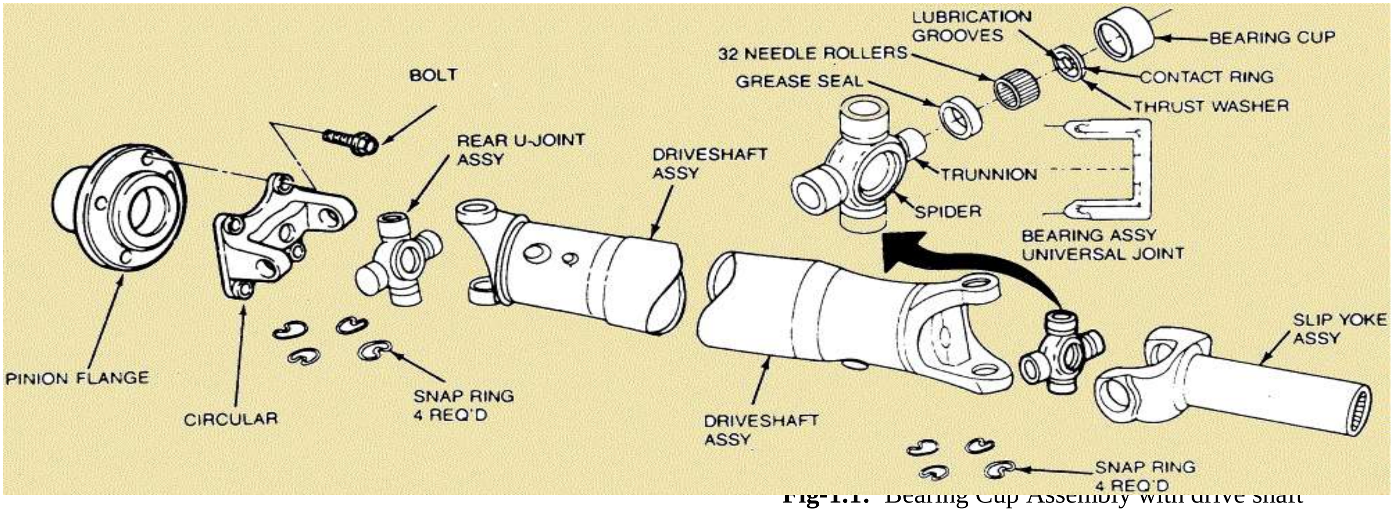

Fig-1.1: Bearing Cup Assembly with drive shaft

2. Literature Survey

Funatani et. al. [2004] presented various heat treatments and surface technology which satisfy customer needs and environmental norms. Heat treatment and surface modification are the key technologies available today to enhance the effective use of materials, to achieve the desired properties of the components used in the automotive industries, to save energy and conserve natural and surface modification technologies including future technological possibilities of relevance to the automotive industry are also reviewed [7].Ulutan et. al [2010] studied effect of different surface treatment methods on the friction and wear behaviour of AISI 4140 steel in this study sample surfaces of AISI 4140 steel were treated by quenching, carburizing, boronizing and plasma transferred arc (PTA) modification. The microstructural characteristics of surface treated steel samples were examined by optical microscopy and scanning electron microscopy (SEM). The mechanical properties of the samples including the surface roughness, micro hardness, and abrasive and adhesive wear characteristics were also evaluated. Wear tests were applied by using a block-on-disc configuration under dry sliding conditions. The wear behavior and friction characteristics of the samples were determined as a function of sliding distance. Each sample group was compared with the other sample groups. It was observed that the carburized samples demonstrated the lowest weight losses; however, PTA-treated samples demonstrated the lowest coefficient of friction in comparison to the other sample groups at the same sliding distance [8].

2.1 Methodology for Analysis

Following are different steps are used

Step1: Select the Theme.
- Step 2: Justify the choice.
- Step 3: Understand the current situation.
- Step 4: Select Targets.
- Step 5: Analysis.
- Step 6: Implement corrective measures.
- Step 7: Confirm the Effects.
- Step 8: Standardize.
- Step 9: Summarize & Plan future actions.

2.2 Performance Requirement of Material

Owing to the nature of performance of UJ kit in propeller shaft, following properties are needed in UJ cross and bearing cup.

i) Wear resistance.
ii) Impact toughness.
iii) Fatigue life.

Wear resistance – As the parts are moving in tandem with each other the surface needs to wear resistant. The wear resistance property is directly proportional to hardness and hence high hardness is a requisite (58 to 64 HRC).
Impact toughness- The bearing is subjected to impact loads due to movement of propeller shaft and hence the core needs to be tough and not brittle (Hardness – 25 to 40 HRC). To achieve these dual properties with single material is not possible and hence surface treatment is necessary to achieve wear resistant surface and tough core.

3 Heat Treatments

3.1 Carburization

Carburization is simply defined as the addition of carbon to the surface of low carbon steel at temperature generally between 850-950 degree Celsius. Carburization is the most widely used method of surface hardening. It consist of enrichment of surface layers of low carbon / mild steel (c less than equal to 0.30%) with carbon up to 0.8 % to1% by this way the good wear and fatigue resistance is superimposed on a tough low carbon steel core. usually have base-carbon contents of about 0.2%, with the carbon content of the carburized layer generally being controlled at between 0.8 and 1% C. However, surface carbon is often limited to 0.9% because too high a carbon content can result in retained austenite and brittle martensite.

3.2 Nitriding

Nitriding is a surface-hardening heat treatment that introduces nitrogen into the surface of steel at a temperature range (500 to 600°C) while it is in the ferrite condition. Thus, nitriding is similar to carburizing in that surface composition is altered, but different in that nitrogen is added into ferrite instead of austenite. Because nitriding does not involve heating into the austenite phase field and a subsequent quench to form martensite, nitriding can be accomplished with a minimum of distortion and with excellent dimensional control. In this process pure ammonia dissociates by the reaction $NH3 = 3H + N$ The atomic nitrogen thus formed diffuses into the steel. In addition to providing outstanding wear resistance , the nitride layer increases the corrosion resistance of steel in moist atmosphere. Practically only alloy steels are subjected to nitriding.

3.3 Carbonitriding

Carbonitriding is a modified form of gas carburizing, at a temperature range between 750 – 9000C.The modification consists of introducing ammonia into the gas carburizing atmosphere to add nitrogen to the carburized case as it is being produced. Nascent nitrogen forms at the work surface by the dissociation of ammonia in the furnace atmosphere; the nitrogen diffuses into the steel simultaneously with carbon. Typically, carbonitriding is carried out at a lower temperature and for a shorter time than is gas carburizing, producing a shallower case than is usual in production carburizing. In its effects on steel, carbonitriding is similar to liquid cyaniding. Because of problems in disposing of cyanide-bearing wastes, carbonitriding is often preferred over liquid cyaniding. In terms of case characteristics, carbonitriding differs from carburizing and nitriding in that carburized cases normally do not contain nitrogen, and nitrided cases contain nitrogen primarily, whereas carbonitrided cases contain both.

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4. Experimentation Plan

It is decided to evaluate carbonitriding, nitriding and existing heat treatment process carburizing.
For this following tests were planned

i. Hardness gradient study of selected processes
ii. Wear test of selected processes.
iii. Push out force of selected processes.

4.1 Tools and Test Rigs

Following tools and test rigs were used during experimentations.
i) Vickers Hardness Testing machine.
ii) Wear test rig.
iii) Load test rig.

4.2 Following are the good properties of bearing cup

For desired properties of bearing cup requires fine martensite microstructure, having hardness between 58-62 RC, wear rate of surface 1 x 10-5 to 7 x 10-5 µm is required and push out force required in between 800-1000kg

4.3 To obtain these properties we have the following heat treatment & then we check in which heat treatment we get the desired properties and comparing with this FEA analysis.

Table 1

Sr No	Types of Heat Treatments	Hardness	Wear rate	Push out force
01	Without heat treatment	20-22RC	$1.25 X 10^{-2}$to $3.2 X 10^{-2}$µm	105 kg
02	Carburizing	58-62RC	$1.48 X 10^{-5}$ to $6.99 X 10^{-5}$ µm	285 kg
03	Nitriding	30RC	$1.33 X 10^{-5}$ to $2.84 X 10^{-5}$ µm	885 kg
04	Carbonitriding	58-62RC	$4.39 X 10^{-5}$ to $5.51 X 10^{-5}$ µm	1015kg

5 Bearing Cup analysis using Ansys

5.1Background:

All the three methods of heat treatment are analyzed for better life of the Universal Joint. As discussed above we concluded that major failure in bearing cup is due to the assembly process. During Assembling of the cup in the respective yoke impact load is applied on it. This causes sudden rise in stress level in the cup. This can be analyzed by doing some FEA analysis.

5.2Pre-processing:

5.2.1Modelling:

The 3-D model of cup was modelled in Pro/ENGINEER software as shown in fig5.1 and then imported in HyperMesh software.

Fig-5.1 Pro-E Model of Bearing Cup

5.2.2Meshing:

Meshing was done in Hyper Mesh. The bearing cup being a solid component, hence 3d meshing was required. To mesh this component the cup was first meshed with 2d mesh and then converted to 3d. For meshing the following steps were carried out.

a) Meshing in 2d:

Bearing cup is imported in HyperMesh and 2D meshing is done. To create quality meshing surface of the spring is divided in to number of surfaces as shown in Fig. 9.2. After dividing the surface component collector is created to apply 2D meshing. Then 2D meshing is created using quad4 shell elements and having an element size of 2.

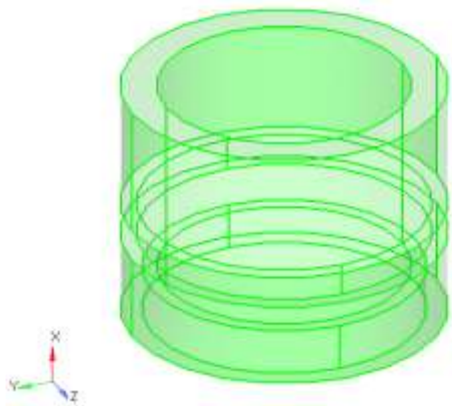

Fig-5.2: Bearing cup Surface refining for 2D meshing

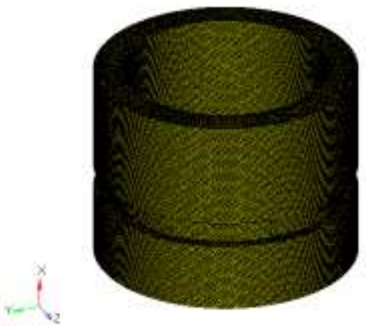

Fig-5.3: 2D Meshing of Bearing cup

b) Convert to 3d mesh:

The bearing cup which was previously meshed by quad 2D elements then were meshed by tetra 10 elements. Then after quad meshing of 2D elements were deleted.

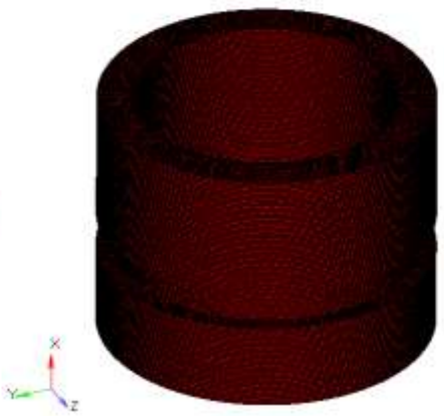

Fig-5.4: Meshed model of Bearing cup

c) Connections:

The bolt connections were modeled by rigid elements as shown in fig9.5. This gives same effect as that of the cup being hammered in the yoke.

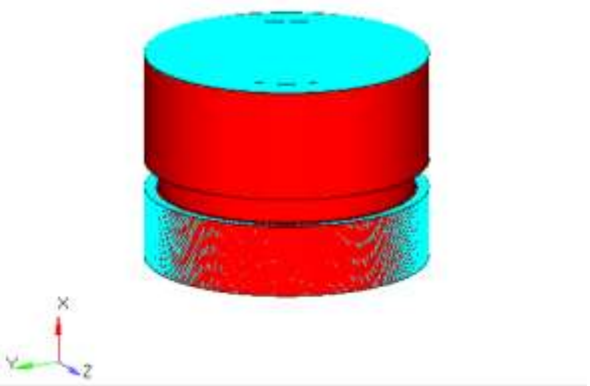

Fig-5.5: connection by rigid elements

5.2.3Boundary conditions:

The nodes which are constrained are shown in the figure below:

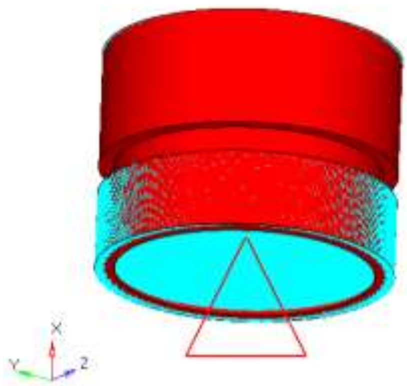

Fig-5.6: Boundary conditions applied on the bearing cup

5.2.4Loading for Static calculations:

Load case: Vertical Load = 1000N. The vertical loads were applied on the spring centre.

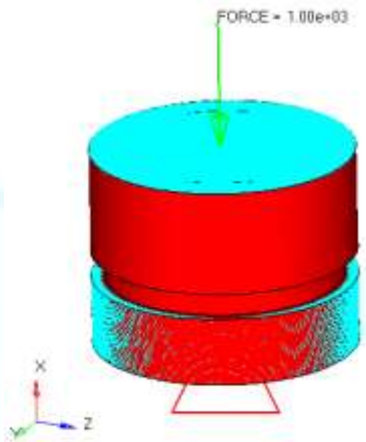

Fig-5.7: Load case

Bearing cup was constraint as per above and 1000 N in Vertical was applied on the cup face as shown above.

5.3 Solution:

After performing above pre-processing steps analysis was started. The static analysis was done in radios solver.

5.4 Post Processing:

After the solution was achieved the results and the stress plot and deflection plot were viewed and judged for the safety conditions.

The results are as follows:

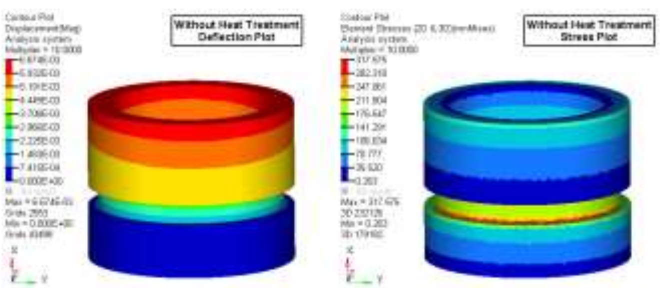

Fig-5.8: Deflection and Stress Plot (Cup without Heat Treatment)

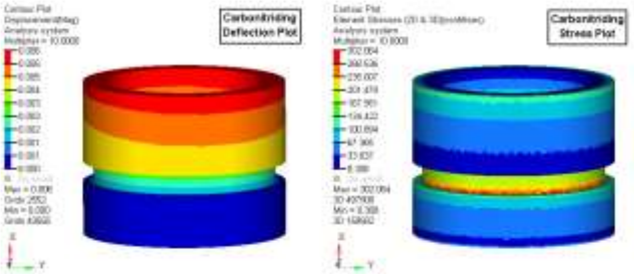

Fig-5.9: Deflection and Stress Plot (Cup without Carbonitriding)

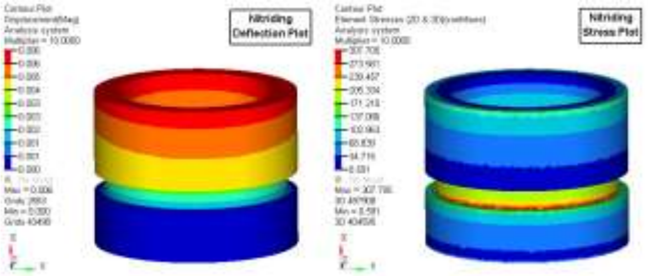

Fig-5.10: Deflection and Stress Plot (Cup withoutNitriding)

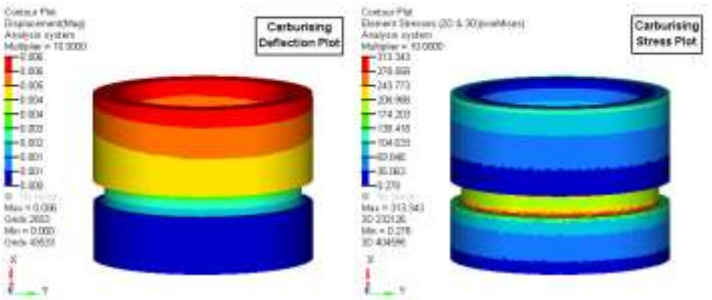

Fig-5.11: Deflection and Stress Plot (Cup without Carburizing)

6 Result

As per experimentation following results are obtained

i. In bearing cup without heat treatment we found stress value 317.575MPa and hardness value @ 20-22RC
ii. In carburizing the stress value found 313.343MPa and hardness value @ 58-62RC
iii. In nitriding the stress value found 307.705MPa and hardness value @ 30RC
iv. In carbonitriding the stress value found 302.064MPa and hardness value @ 58-62RC

7 Conclusion

In this study failure analysis of bearing cup was carried out. Bearing cup assembly was produced from SAE1117 low carbon carburizing steel. Analysis revealed that bearing cup was failing due to through hardening at groove, as wall thickness was less in this area which results into brittle failure during assembling process. Alternate heat treatment processes like carbonitriding and nitriding were tested on various tests like hardness measurement, endurance test & push out load tests. From results and discussion following conclusions can be drawn.

1. Carburizing and hardening processes achieve good results to achieve good wear resistance. Hardness achieved at surface was within range of 58-62 RC. Case depth achieved was high, 0.8 -1.1mm. However this causes through hardening at groove area of bearing cup hence push out force was less in case of carburized and hardened samples as compare to other samples which was average 285Kg. Specific wear rate was less in the range of 1.48X 10-5 to 6.99 X 10-5. Endurance test found satisfactory for wear and fatigue.
2. Carbonitriding and hardening processes show good results give good wear resistance. Hardness achieved at surface was within range of 58-62 RC; case depth achieved was less (0.3-.045mm) as compared to that achieved by carburizing and hardening (0.8 to 1.1mm). Push out force was high as compared a carburized and hardened sample which was average 885 kg. Specific wear rate was in the range of 4.39 X 10 -5 to 5.51 X 10 -5. Endurance test also found satisfactory; float value was within acceptable limit giving an alternative process to carburized and hardened samples.
3. Nitriding process achieves good surface hardness @ 566 Hv1. However case depth achieved is less than 10 microns. Core hardness was 30 RC. Push out force for nitrided bearing cup was average 1015Kg. Specific wear rate was in the range of 1.33 X 10 -5 to 2.84 X 10 -5. Float value was beyond acceptable limit in endurance test which was not satisfactory; hence nitriding sample failed in endurance test.
4. Carbonitriding can replace carburizing process in bearing cup assembly surface treatment process hence it implemented as solution.
5. Carbonitriding process as heat treatment process for bearing cup assembly has given good results over earlier process of surface hardening.
6. Carbonitriding is effective surface hardening process in components where wear and torsional fatigue is required but chances of through hardening due to component design cannot be avoided.

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