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Optimized Heat Treatment of Bearing Cup Using Taguchi Method

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ABSTRACT

According to the vehicle‘s driving type power transmission system has different constructive features which can be front wheel drive, rear wheel drive or four wheel drive. In rear wheel drive system, system include elements such as clutch, transmission system, propeller shaft, joints, differential, drive shafts and wheels. Each element has many different construction and design properties depending on the brands of vehicles. Motion is transmit from gear box to differential by carden shaft also called drive shaft. After critical analysis of the drive shaft assembly the problem identified. During assembly operation bearing cup assembly was get cracked in universal joint assembly. Hence it was decided to eliminate this highest rejection of bearing cup failure in drive shaft assembly with cost effective solution. This paper will mention the methodology used for finalizing the solution to this problem by means of the FEA analysis supported by taguchi method of design of experiment. Various Heat Treatment processes are compared and it was found that Carbonitriding process is the optimum solution which will reduce the failure of bearing cup as well as reduce the overall manufacturing cost.

Keywords— **Carden Shaft, Carbonitriding, Drive shaft, FEA, Heat treatment.**

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I. 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 cardan 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.

Element of Power Transmission System: The movement of vehicles can be provided by transferring the torque produced by engines to wheels after some modification. The transfer and modification system of vehicles is called as power transmission system and has different constructive features according to the vehicle‘s driving type which can be front wheel drive, rear wheel drive or four wheel drive. The 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. The carden shaft also called drive shaft is used to transmit motion from gear box to differential. The universal joint consists of two forged-steel yokes or forks joined to the two shafts being coupled and situated at an angle to each other. Friction due to rubbing between the journal and the yoke bores is minimized by incorporating needle-roller bearings between the hardened journals and hardened bearing caps pressed into the yoke bores.

I. LITERATURE SURVEY

Bayrakceken.et.al. [2006] did failure analysis of an automobile differential pinion shaft which reveals that the fracture has taken place at a region having a high stress concentration by a fatigue procedure under a combined bending, torsion and axial stresses having highly reversible nature. The crack of the fracture is initiated probably at a material defect region at the critical location [2]. Makevet et.al.[2002] in their paper present a case study in failure analysis of a final drive transmission in an off-road vehicle. The failure involved a satellite gear mounting shaft that departed from the differential assembly as a result of fracturing of a retaining pin. An investigation of the mechanical condition of various transmission components, consisting primarily of visual (macroscopic) inspection, geometrical investigation and analysis of mechanical loads, led to the assignment of two principal causes of failure. Firstly, it was established that the retaining pins installed in the assembly were shorter than required, allowing them to shift in their guide holes and assume a single-shear position. Secondly, in this position they were loaded to failure in shear by abnormally high frictional forces acting at the shaft/satellite interface. These loads were attributed to severe usage and handling of the vehicle [3]. Asi [2006] studied the failure analysis of a rear axle shaft used in an automobile which had been involved in an accident. The axle shaft was found to break into two pieces. The investigation was carried out in order to establish whether the failure was the cause or a consequence of the accident. An evaluation of the failed axle shaft was undertaken to assess its integrity that included a visual examination, photo documentation, chemical analysis, micro-hardness measurement, tensile testing, and metallographic examination. The failure zones were examined with the help of a scanning electron microscope equipped with EDX facility. Results indicate that the axle shaft fractured in reversed bending fatigue as a result of improper welding. Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and higher specific strength of composite materials. In their work Lee et al.[2004] one-piece automotive hybrid aluminum/composite drive shaft was developed with a new manufacturing method, in which a carbon fiber epoxy composite layer was co-cured on the inner surface of an aluminum tube rather than wrapping on the outer surface to prevent the composite layer from being damaged by external impact and absorption of moisture. The optimal stacking sequence of the composite layer was determined considering the thermal residual stresses of interface between the aluminum tube and the composite layer calculated by finite element analysis. Press fitting method for the joining of the aluminum/composite tube and steel yokes was devised to improve reliability and to reduce manufacturing cost, compared to other joining methods such as adhesively bonded, bolted or riveted and welded joints. Protrusion shapes on the inner surface of steel yoke were created to increase the torque capability of the press fitted joint. From experimental results, it was found that the developed one-piece automotive hybrid aluminum/composite drive shaft had 75% mass reduction, 160% increase in torque capability compared with a conventional two-piece steel drive shaft. It also had 9390 rpm of natural frequency which was higher than the design specification of 9200 rpm [4],[5]. In his study Mutasher et.al.[2009] studied a hybrid aluminum/composite is an advanced composite material that consists of aluminum tube wound onto layers of composite material. The result from this combination is a hybrid shaft that has a higher torque transmission capability, a higher fundamental natural bending frequency and less noise and vibration. This paper investigates the maximum torsion capacity of the hybrid aluminum/composite shaft for different winding angle, number of layers and stacking sequences. The hybrid shaft consists of aluminum tube wound outside by E-glass and 22 carbon fibers/epoxy composite. The finite element method has been used to analyze the hybrid shaft under static torsion. ANSYS finite element software was used to perform the numerical analysis for the hybrid shaft. Full scale hybrid specimen was analyzed. Elasto-plastic properties were used for aluminum tube and linear elastic for composite materials. The results show that the static torque capacity is significantly affected by changing the winding angle, stacking sequences and number of layers. The maximum static torsion capacity of aluminum tube wound outside by six layers of carbon fiber/epoxy composite at winding angle of 45° was 295 N m. Good agreement was obtained between the finite element predictions and experimental results [6].

Objective- The main objective of this paper is to solve the problem of bearing cup failure in drive shaft assembly in universal joint assembly during assembly of bearing cup in universal joint which needs to be eliminated with cost effective solution. For that above described heat treatment processes are analyzed and compared with each other.

II. METHODOLOGY FOR ANALYSIS

As this problem is chronic concerns and high severity concern, systematic concern resolution process is adopted to analyze the problem and find out cost effective solution.

- Step1: Study all the Heat treatment processes
- Step 2: Study the effect of Surface treatment methods
- Step 3: Analyze each method
- Step 4: Compare the results of each method
- Step 5: Selection best possible solution

A. Optimization of Carburizing Process Variables

The successful operation of the gas carburizing process depends on the control of three principal variables.

- Temperature.
- Time.
- Atmospheric composition.

Other variables that affect the amount of carbon transferred to parts include the degree of atmosphere circulation and the alloy content of the parts.

 Temperature. The maximum rate at which carbon can be added to steel is limited by the rate of diffusion of carbon in austenite. This diffusion rate increases greatly with increasing temperature; the rate of carbon addition at 925°C (1700°F) is about 40% greater than that at 870°C (1600 °F).The temperature most commonly used for carburizing is 925°C (1700°F). This temperature permits a reasonably rapid carburizing rate without excessive rapid deterioration of furnace equipment, particularly the alloy trays and fixtures. The carburizing temperature is sometimes raised to 955°C (1750°F) or 980°C (1800°F) to shorten the time of carburizing for parts requiring deep cases. Conversely, shallow case carburizing is frequently done at lower temperatures because case depth can be controlled more accurately with the slower rate of carburizing obtained at lower temperatures [20].

 Time: The effect of time and temperature on total case depth is shown in it can be seen that case depth increases with respect to time. In addition to the time at the carburizing temperature, several hours may be required to bring large work pieces or heavy loads of smaller parts to operating temperature [20].

To optimize parameters of different surface treatment processes design of experiments was conducted. DOE is a test in which purposeful changes are made to certain parameters of system so that one may observe and quantify the changes in output. Our purpose of DOE is to optimize the carburizing process parameters. For achieving case depth between 0.8 to 1.1 mm. Full factorial DOE was conducted to optimum process parameters of carburizing. DOE obtains information in most efficient way, uses statistical techniques for planning, design, data collection, analysis and interpretation. Minitab software is used. for DOE. Fig 7.2 shows DOE planning sheet which explains the objective of DOE, factors to be studied. In this DOE there are two factors: temperature and time and their lower and upper range is 915ºc to 925ºc and 8 to 9 hours respectively. Number of replicates are 2. First step is to design experiments for DOE which can be done with help of Minitab software. After giving lower and higher range of two factors software gives us number of experiments to be conducted, temperature and processing time and run order to carry the experiments. For this study since factors are two eight experiments need to be conducted. After conducting experiments results were captured in term of case depth and feed in Minitab. Table 7.1 shows details of experiments and case depth achieved for experiments conducted. 48 **Design Of Experiment for Carburizing process.**

Problem and objectives of the experiment

Objective :

To optimize the process parameters of Carburizing process to achieve case depth of 0.8 to 1.1 mm

Factors to be studied

Factors to be studied

Factors	**Code**	**Level 1**	**Level 2**	**Unit**
temperature	T	915	925	Deg. C
time	Te	8	9	Hrs
response				
Item	Unit	Measuring Device		
Case depth	mm	Micro hardness tester		

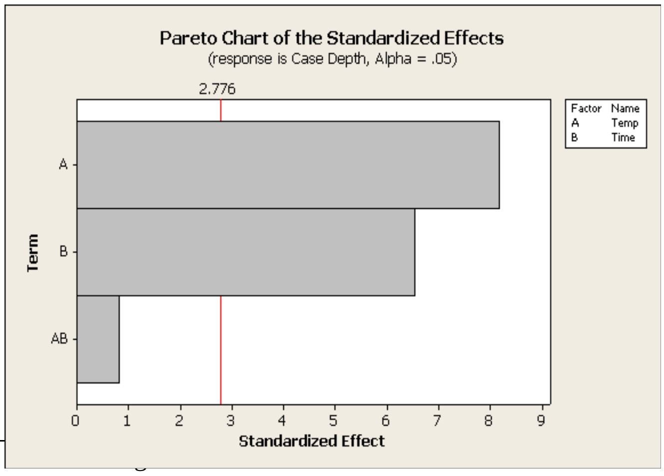
Local Control required for

Local Control required for:

Sl. No.	Factor	At level
1	Carbon %	0.18%
2	CN Drip	1.5 LPH
No. of replicate Design Selected Full factorial 22	2	

Std Order	**Run Order**	**Center Pt**	**Block**	**Temp (°c)**	**Time Hrs.**	**Case Depth (mm)**
5	1	1	1	915	8	0.75
2	2	1	1	925	8	1.1
1	3	1	1	915	8	0.8
4	4	1	1	925	9	1.2
6	5	1	1	925	8	1
8	6	1	1	925	9	1.25
3	7	1	1	915	9	1

Analysis step 2: Identify Improvement Factors**.** In design of experiments second step is identifying improvement factors. Fig.1 shows Pareto chart which indicates factors to right side of red line i.e. time and interaction of time and temperature are significant. Fig.2 shows effect chart which shows that both effects are positive as the points are on right side of the normal line.



Hrs

Fig.1 Pareto chart of standardized effect-carburizing process

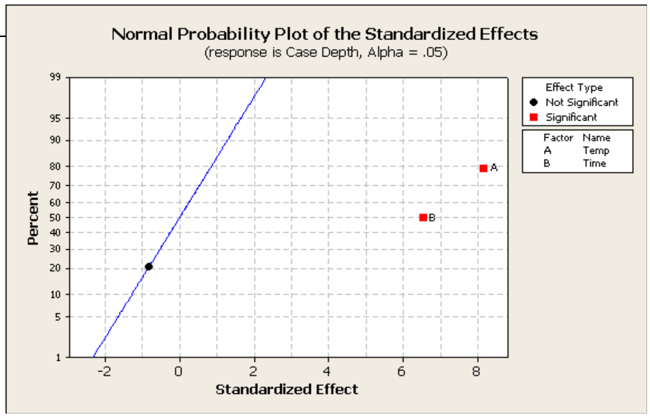


Fig.2 Pareto chart of standardized effect-carburizing process

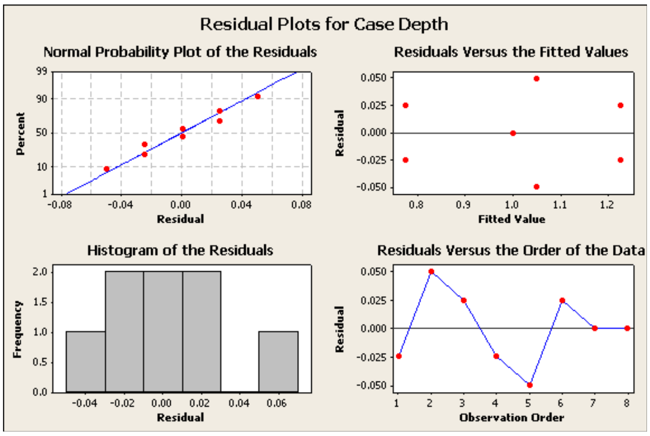


Fig.3 Residual plots for case depth.

Find the Best Setting: Interaction plot is plotted to understand the effect of both factors and to see if both factors have any interactions or not as two line are intersecting. As shown in Fig. There is interaction in two factor, same effects are positives

Conclusion: Both the factors have positive effect.

B. Optimization of Carbonitriding Process Variables

The successful operation of the gas carbonitriding process depends on the control of principal variables.

- Temperature.
- Time.

Other variables that affect the amount of carbon transferred to parts include the degree of atmosphere circulation and the alloy content of the parts.

• *Effect of Time and Temperature.*

Based on a survey of industrial practice, shows case depths for different combinations of total furnace treating time and temperature which will give idea for selecting temperature and time range.

Check Goodness of Model : To confirm no funneling of data model is checked for goodness. Various chart as shown in Fig residual plot for case depth are plotted which shows there is no funneling and data is normal which concludes that model is good.

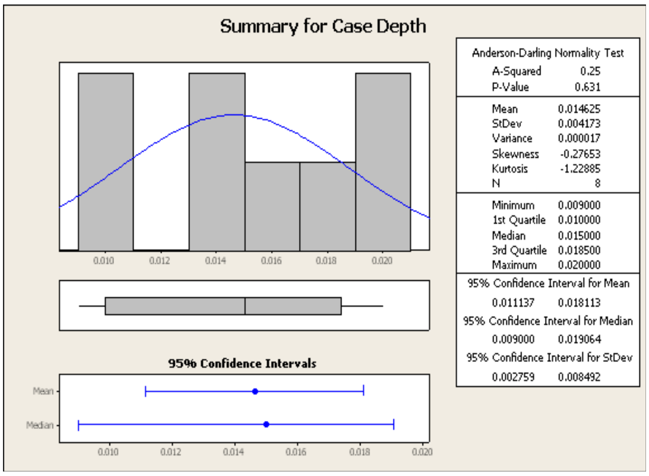
Find the Best Setting: Interaction plot is plotted to understand the effect of both factors and to see if both factors have any interactions or not as two line are intersecting. As shown there is interaction in two factors; same effects are positive.

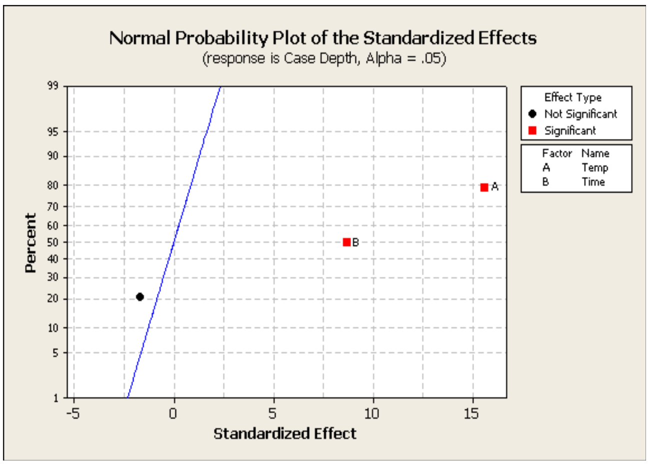
Conclusion: Interaction observed, both the factors have positive effect.

Fig.4 Interaction plot for case depth

C. Optimization of Nitriding Process Variables

Depth of case depends on time and temperature. The average nitriding cycle is 24 hours, although total cycle time may vary between 4 and 72 hours. To stabilize core hardness, it is recommended hat all parts to be tempered at a temperature at least 28°C (50 °F) higher than the nitriding temperature before they are immersed in the nitriding bath. Fig.5. shows variation of case depth with respect to time for SAE 4140 steel which will give some idea about temperature and time range required for nitriding.





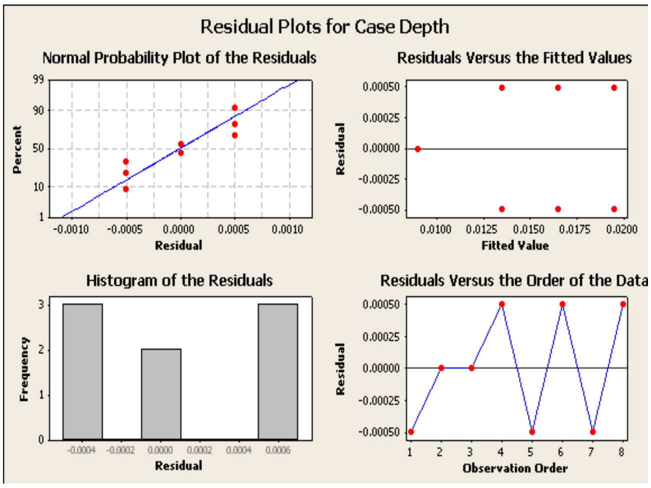


Fig.5 Residual Plots for case depth nitriding process

Find the Best Setting: Interaction plot is plotted to understand the effect of both factors and to see if both factors have any interactions or not as two line are intersecting. As shown in Fig.5 there is interaction in two factor same effects are positives

Conclusion: Interaction observed, both the factors have positive effect.

III. CONCLUSIONS

In this study failure analysis of bearing cup was carried out. Bearing cup assembly was produced from SAE1117 low carbon carburizing steel and was surface treated by carburizing, hardening and tempering processes. Cause and effect diagram was made to find out root cause of the failure. 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 chemical analysis, microstructure study, 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 martensite structures which gives 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. Float value was within acceptable limit.

2. Carbonitriding and hardening processes show good results to achieve martensite structures which gives 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 achived by carburizing and hardening (0.8 to 1.1mm). Push out force was high as compared carburized and hardened samples 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. Case microstructure was fine tempered martensite. Push out force for nitride 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.

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