Breakdown investigation of Diesel Engine Camshaft of Front End Loader

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Abstract. The cause of a diesel engine camshaft failure of BEML BL40 loader diesel engine confirming BS6D140-1. A fractured sample of camshaft was collected from the BCCL Sinidih workshop. For identification of material used in the camshaft, chemical composition and hardness value were determined using a spectrometer and Brinell hardness tester. Phase composition was confirmed with the help of an optical microscope. For mechanical properties and behavior of fracture of material used tensile testing was done conforming ASTM-E08 standard specimen and experimental value of ultimate tensile strength determined. The analytical analysis is done by analytical design. The stress analysis of the camshaft is carried out for the determination of the stress concentration level at the fracture area by FEM (finite element method) by using ANSYS work bench 14. Fractography analysis of fractured surface is done by SEM, the SEM photographs show an intergranular fracture, and also it indicates grain boundaries were embrittled. The results presented in paper intend to focus on the potential process of crack initiation to catastrophic that may help to think of improved design and manufacturing procedure for the same type of failure.

1. Introduction

Engine and its constituents are the birthplaces of uppermost of the failure taking place in automotive [2]. Numerous studies have been approved on the automotive failure investigation. Heyes[2] has shown that the generally failed parts are from the engine and its constituents between the automotive failures. This is tracked by the drivetrain failure. Between the studies on the engine component failures, Wang et al. [3] examined the forecast of fatigue failure in a camshaft using the crack–modeling method. They confirmed that the crack –modeling method, which envisages fatigue limit of stress concentration using a fracture mechanics approach, was able to the forecast the behavior of an automotive camshaft component in two dissimilar design instances under torsion and bending loading. As we all know prevention is better than cure. Failure analysis is accurately fit in this. Each product or process has modes of failure. Failure analysis is the superlative tactic to conclude the cause of failure. an analysis of forthcoming failures helps designers focus and understand the influence of likely process or product risks and failures. To find out the cause of failure there are different ways of failure analysis. The key role of the camshaft in an engine is closed and opens the valve. Camshaft design outcome in valves being closed and opened at the controlled rate of speed as well as at perfect time in relation to piston position. Typically camshaft has two lobes per cylinder, one to drive the exhaust
valve and other one drive to intake valve. The camshafts are commonly produced by forging or casting. The cast camshaft is prepared from SG iron.

In this paper, failure analysis of a camshaft which belongs to diesel engine is carried out figure 1. The investigated camshaft is fractured after a very short time of usage of the loader. Failure investigation is performed with the help of different experiments, which comprise fractography, mechanical testing, chemical analysis, metallography, and nonlinear finite element analysis (FEM) using ANSYS software. Fractography is performed with the help of SEM (scanning electron microscope). Different high-resolution images are taken from SEM and their morphology is conferred to conclude the crack generation and type of failure. Chemical analysis is executed with the assistance of spectrometer. This analysis contributes the chemical composition of camshaft material, Metallography investigation is executed with the help of metallographic microscope after polishing and etching of sample. Mechanical testing includes hardness test and tensile test. Nonlinear finite element method is used to find out stress attentiveness/concentration and deformation in the failed region of camshaft under the static load condition. The failure is happened as an unexpected fracture at very close to cam location where there is a stress concentration.

2. Experimental Analysis
2.1 Chemical properties
The chemical composition of any material has a great significance as it defines the potential mechanical property of the material. Camshaft collected from the workshop that's why its composition is known. To analyze the motive of failure it's very significant to know about the property of the material, which cannot potential without knowing the elemental composition of the material. Chemical analysis of the fractured camshaft material was carried out using a spectrometer. The chemical composition of the material is given in table 2.1.1.

2.2 Microstructure analysis
The surface of a metallographic specimen is prepared by numerous processes of grinding, polishing, and etching. Before grinding, molding of material is done on the automatic mounting press. After grounding, Phase compositions were confirmed with the help of an optical microscope. As the mold is ready so to proceed further etching becomes an integral part of the process. Etching is the heart and soul of microstructure analysis and it is clearly proved from the fact that without former the latter can’t come into existence. Etching is done with 2% Nital solution. It is basically 2 % nitric
acid solution with ethyl alcohol. Without proper etching, the image can't be taken by a microscope. The process involves three steps:
The first step is the creation of etching solution. By weight, 2% nitric acid (HNO3) is mixed with ethyl alcohol solution. Solution left for 5 minutes to formulate. The second step is the polished sample is deepen into a solution for 2 to 3 minutes and then taken out. The third step is sample is dried speedily after taken out from etching solution. After etching sample is used for microscopic analysis. The microstructure image of the sample is shown in figure2.2.1.

2.3 Hardness Analysis
To carry on the study of hardness Brinell test is used. The Brinell hardness test is an indentation hardness test that can deliver beneficial information about metallic materials. The experiment executed for Brinell hardness test with 10 mm indenter, load application of 750 kg. Four points are used for this test. The diameter of indenter impression and BHN at all four points are exemplified in the table.

| Test point | Dia. of indenter impression (d) in mm | BHN |
|------------|---------------------------------------|-----|
| 1          | 1.9                                   | 292 |
| 2          | 1.87                                  | 296 |
| 3          | 1.875                                 | 298 |
| 4          | 1.88                                  | 295 |
| Mean       | 1.88125                               | 295 |

2.4 Tensile Testing
For mechanical properties of the material used tensile testing was done conforming ASTM-E08 standard specimen and experimental value of ultimate tensile strength determined is 480MPa. Tensile tests are executed at room temperature using five standard samples taken out from the camshaft. A specimen of tensile testing and drawing of tensile specimen conforming ASTM-E08M standard, the tensile test specimen is obtained from camshaft beam area using wire electrode cutting. A specimen of tensile testing and Drawing of tensile specimen conforming ASTM-E08M standard shown in figure 2.4.1.
The tensile test is performed on the universal testing machine keeping the strain rate $10^{-3}$ Result obtained is shown with the help of graph between engineering stress and strain. Ultimate tensile strength acquired is about 480 Mpa. Resultant Graph is shown in figure 2.4.2. The result of the tensile test is listed in table 2.4.1, which is used for the FEM analysis.
Table 2.4.1. Material properties of camshaft

| Property            | Value          |
|---------------------|----------------|
| Density             | 7850 kg/m³     |
| Young's modulus     | 1.7 x 10^5 MPa |
| Poisson's ratio     | 0.3            |
| Ultimate tensile stress | 480 MPa     |
| Tensile strength    | 480 MPa        |

Figure 2.4.1 Specimen of tensile testing and Drawing of tensile specimen conforming ASTM-E08M standard

2.5 Finite element analysis
The stress investigation of the camshaft is carried out for the determination of the stress concentration level at the fracture area via FEM. The commercial finite element code, ANSYS 14.0 is used for analysis. Before FEA analysis the model of camshaft model is developed in CAD software CATIA V5 R18. The camshaft modal is made with exact geometry, measuring the dimension of camshaft sample obtained from the workshop. Micro meter, Vernier caliper, and ruler are used for this.

2.5.1 FEA Procedure in ANSYS
ANSYS is one of best existing FEM software to for analysis. While analyzing the camshaft modeled in three dimensions. The Ansys workbench interface is shown in figure 2.5.1. The procedure of analysis is as follow:
a) **Specify material property:**
Material property is specified under engineering data tab; ANSYS provides a wide range of material property under its material library. We can select required material from there or options are also available for entry of new material along with their properties. Material property provided for the analysis is tabulated in table 2.4.1. As camshaft made up of Spheroidal graphite iron.

b) **Import the model:**

c) **Meshing:** In general, design analysis tools are demanding with respect to the geometric integrity. During the CAD modeling development, these integrity necessities may not be met and may even go unnoticed. Examples of integrity errors include small gaps, overlaps or overhangs which can easily be overlooked from the CAD point of view. However, they can be very problematic for the mesh. So before meshing the geometry clean-up is done, i.e., parts that have very small features with respect to the overall model dimensions and do not play a considerable role in the simulation results can be avoided or suppressed. Mesh generation is an important miracle in FEM analysis. It should be appropriate and uniformly distributed all over the parts which are under analysis. Without appropriate meshing, results can't be appropriate. Whatever be the result of FEM analysis obtained are nodal results, means that result we get at a node. The meshing of the camshaft is through with element type tetrahedron which is the default. For ANSYS WORKBENCH. Element size is kept as 3mm. meshing detail of camshaft is shown in table 2.5.2. The number of Nodes is 367134. This image is taken by mechanical APDL. After proper meshing, setup for analysis is done.

d) **Setup for Analysis:** Here static stress analysis is performed. Static stress analysis is enhanced way to catch the stress concentration area and deformation. The setup for analysis is shown in figure 2.5.2.

e) **Solution:** up to now problematic formulation is done. Now it should be solved. For this analysis, we need three thing stress, strain, and deformation, with the help of these three things we can find out the failure region and their reasons. So the problem is solved for all these as discussed earlier in this section. ANSYS solver is used for this solution which is the default for this system and results are determined.

f) **Results:** results obtained here are shown with the help of ANSYS plot of the image. Deformation, stress and strain analysis is shown in the figure. Maximum deformation is seen in the cam lobe portion. The red portion of the figure 2.5.3 showing the maximum Stress. Maximum stress is found on the shaft. Results are tabulated in, as can be seen, the highest stresses occur at the fractured section and at the beginning location of the fracture as shown with an arrow in the fractured section.

| Part       | No of elements | No of node | Element type |
|------------|----------------|------------|--------------|
| Camshaft   | 258217         | 367134     | Tetrahedron  |

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Figure 2.4.2 Graph between stress and strain

Figure 2.5.2 Force application

Figure 2.5.3 Stress plot of camshaft
2.6 Fractography: Fractography is the study of the fracture surfaces of materials. One of the objectives of fractographic examination is to determine the cause of failure by studying the physical appearance of a fractured surface. Different types of crack growth (e.g. fatigue, stress corrosion cracking, and hydrogen embrittlement) produce characteristic features on the surface, which can be used to assistance, detect the failure mode. After visual inspection sample for microanalysis is prepared from camshaft sample. Samples are obtained by wire electrode cutting. SEM observation performed in central research facility center of Indian school of mines, Dhanbad. Before SEM observation the fractured surface sample is cleaned by acetone and dried quickly. A different image of crack initiation, striation marks, and morphology at different magnification is taken by SEM. Some of the images are shown and discussed below.

3. Result: On the behalf of chemical composition and Brinell hardness test we search material from the material properties data handbook the material properties of the chemical composition and Brinell hardness number is found in the range of that the material is Cast Spheroidal Graphite Iron which grade was EN–GJ-S-700–2. Spheroidal graphite iron is achieved by making small ladle additions of a modifier such as magnesium or cerium to liquid metal. Unlike flaky graphite in gray cast iron, Spheroidal graphite does not weaken the matrix significantly for this reason; the mechanical properties of SG iron are greater to gray iron. For mechanical properties of the material used tensile testing was done conforming ASTM-E08 standard specimen and experimental value of ultimate tensile strength determined is 480MPa. Through the analytical design, we calculated the value force exerted by the cam on the roller in a direction normal to the contact surface (Gravitational and Frictional effect are neglected) are approximately 63147 N. The maximum stress found by FEM is 235.66MPa which is less than the ultimate tensile strength of the material (480MPa).SEM images show Fracture surface (Figure2.6.1.) show an intergranular fracture, also it indicates grain boundary were embrittled.
4. Conclusions:
1. A fractured sample of camshaft was collected from the BCCL Sinidih workshop.
2. For identification of material used in the camshaft, chemical composition and hardness value were determined using a spectrometer and Brinell hardness tester. Phase composition was confirmed with the help of an optical microscope.
3. For mechanical properties of the material used tensile testing was done conforming ASTM-E08 standard specimen and experimental value of ultimate tensile strength determined is 480MPa.
4. Analytical analysis is done by analytical design, by analytical design we calculated the value of F=the force exerted by the cam on the roller in a direction normal to the contact surface (Gravitational and Frictional effect are neglected) are approximately 63147 N. The stress analysis of the camshaft is carried out for the determination of the stress concentration level at the fracture area by FEM (finite element method) by using Ansys work bench 14. The maximum stress found by FEM is 235.66MPa which is less than the ultimate tensile strength of the material (480MPa). Hence there is no design fault in the Diesel Engine Camshaft.
5. Fractography analysis of fractured surface is done by SEM, the SEM photographs show an intergranular fracture, and also it indicates grain boundaries were embrittled. This could be hydrogen embrittlement which might have occurred because of pickling/phosphatizing and improper baking of the cam shaft.
6. On the behalf of this analysis, my recommendation for the manufacturer is Temperature and time of the baking process should be strictly maintained so that the hydrogen introduced into the material during pickling/phosphatizing is completely removed thereby preventing hydrogen embrittlement of the cam shaft. The results presented here intend to focus on the potential process of crack initiation to catastrophic that may help to think of improved design and manufacturing procedure for the same type of failure.
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