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Failure Analysis of Grey Cast Iron Camshaft By Mode of Fracture

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Abstract:-The failure analysis is a special field of study for mechanical engineers. Many studies have been carried out on the automotive failure analysis. Camshafts made of grey cast iron a is a shaft having some semi-oval protrusions which are designed to control the open and close intervals of the inlet and exhaust poppet valves in the gasoline and diesel engines. Rotation of the cam causes its profile to slide against the smooth flat closed end of a cylindrical member known as a follower. The cam profile has a follower lift or valve opening side and a corresponding follower fall or valve closing side.
Microstructural observation revealed an intergranular network of carbides and intergranular micro cracks present in the carburized layer and a banded structure consisting of ferrite and pearlite in the core.
Literature study shows that the failure is occurred as a sudden fracture at very close to journal location, where there is a stress concentration. As a result of the analyses, the main reason of the fracture is determined as a casting defect. As the failure was related to a material production problem it is likely to affect more than one vehicle. The stress analysis of the camshaft is carried out for the determination of the stress concentration level at the fracture region by the finite element method. Von Misses stress distribution (MPa) on the camshaft at the most critical loading condition. The highest stress concentration occurs at the cracked location. The SIFs at the crack tip (node 958) are $K_I = 23.71$ MPa √mm.

Keywords: - Camshaft, Failure analysis, Fracture, Linear elastic fracture mechanics, Stress concentration, SIF

I. INTODUCTION

The economic value of the work capacity in the automotive sector is estimated as 1.6 billion Euros and this figure shows that the automotive sector is the 6th economic sector worldwide. The sector has an interrelationship with more than 300 different fields.
On the other hand, the failure analysis is a special field of study for materials and mechanical engineers. Many studies have been carried out on the automotive failure analysis.
Cams are designed to control the open and close intervals of the inlet and exhaust poppet valves. The radial cam used for this purpose consists of a circular disc having a semi-oval triangular protrusion. Rotation of the cam causes its profile to slide against the smooth flat closed end of a cylindrical member known as a follower.
Fatigue failure in components usually initiates at stress concentrations: geometric features such as holes, grooves and corners, and despite some local plasticity, high-cycle fatigue behavior is essentially a linear elastic problem.

Figure 1.1 Typical view of camshaft

The camshaft manufacturing uses the special grey cast iron in alloy with Cr, Mo, V, Ni, Cu, nodular cast iron, high-quality carbon steel slightly alloyed with Cr, Mn, Si and sometimes Ni.

II. GREY CAST IRON CAMSHAFT

Camshafts made of grey cast iron and camshaft is a shaft having some semi-oval protrusions which are designed to control the open and close intervals of the inlet and exhaust poppet valves in the gasoline and diesel engines.

Cams are designed to control the open and close intervals of the inlet and exhaust poppet valves. Rotation of the cam causes its profile to slide against the smooth flat closed end of a cylindrical member known as a follower. The cam profile has a follower lift or valve opening side and a corresponding follower fall or valve closing side. Both the lift and fall sides of the profile can be divided in to three phases which are; the cam ramp, the cam flank and, the cam nose.

With the four-stroke cycle engine, the cycle of events of the inlet and exhaust valve opening and closing is performed by the camshaft in one revolution, but the piston strokes (induction, compression, power, and exhaust) are completed in two crankshaft revolutions. Consequently, for the camshaft timing cycle to be in phase with the crankshaft angular movement, the camshaft has to turn at half crankshaft speed, that is, a 2:1 speed ratio.

Material properties of the Grey cast Iron camshaft

Table 1 Composition of grey cast iron camshaft (% weight)

C	Si	Mn	Ni	Cu	Cr	P	S
3.3	1.8	1.5	0.07	0.2	0.05	0.03	0.09

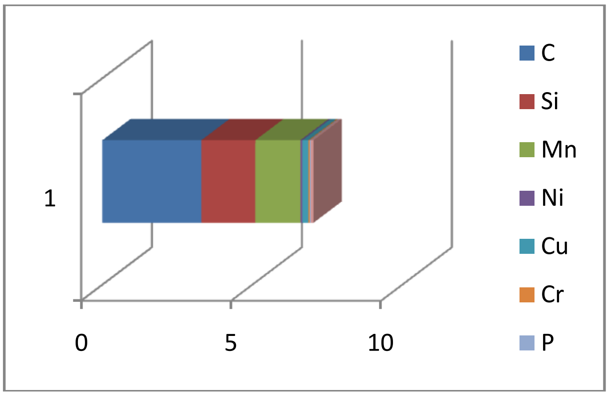


Figure 1.2 Chemical composition of Grey cast iron camshaft graph

Table 2 Mechanical properties of grey cast iron

Young's modulus	170 GPa
Poisson's ratio	0.29
Yield stress	202 MPa
Ultimate strength	249 MPa

Chemical analysis of the grey cast iron camshaft material was carried out using a spectrometer. The chemical composition of the material is given in Table 1. Chemical composition shows that the material is a grey cast iron with carbon 3.3%. This material has good fluidity and castability, excellent machinability, and good wear resistance.

The average hardness of the cross-section is obtained as 20 HRC while the average surface hardness values of heat treated regions are obtained as 45 HRC. The mechanical properties for the Grey cast iron having similar chemical composition and microstructure are given approximately as 202 MPa for yield strength and 249 MPa for ultimate strength.

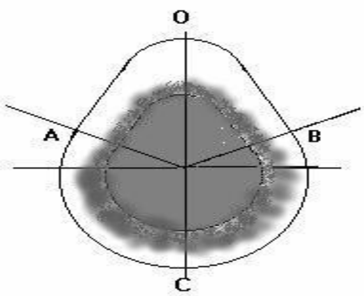


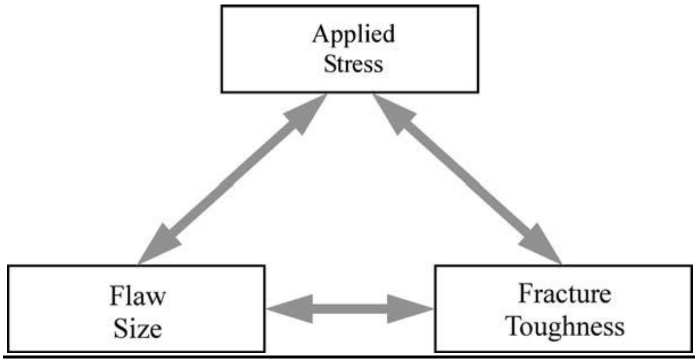
Figure 1.3 Cam cut view of camshaft

III. FRACTURE MECHANICS

Through the ages the application of the material in engineering design as posed difficult problem to mankind. The unsatisfactory 38behavior of the structures build from this materials and their unexpected failure become a matter of great concern. The failure all welded design even at low stresses made its investigation even more prudent. It was proved beyond doubt that stress concentrations around the pre existing flaws were the major reason for crack appearance and their ultimate failure.

Fracture mechanics approach to design

- The fracture mechanics approach.



Study of crack pattern

Cracks in structures, if existed in materials would grow with time due to application of repeated load or due to combination of load and environmental attack. Longer the crack higher the stress concentration induced in it. The rate of stress propagation will increase with time

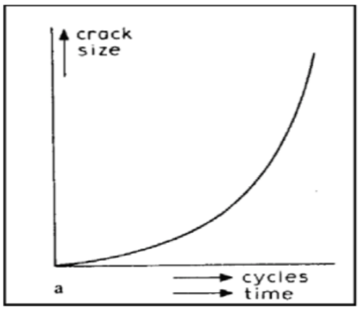


Figure 1.4 Crack pattern

Residual strength of structure will reduce progressively with increasing size of the crack. After a certain time the residual strength will become so low that it cannot withstand accidental high load. At this point in can be said that the strength of the structure has reduced to extent that it can be declared as a failure.
In such cases where accidental high load doesn't occur the crack will continue to grow until residual strength so low that the fracture occurs under normal service load.

Fracture Mechanics Terminology

Crack surface displacement modes:
Mode I - opening mode
Mode II - edge-sliding mode
Mode III - tearing mode
Where: I, II, III are subscripted on G, K fracture mechanics terms, as applicable

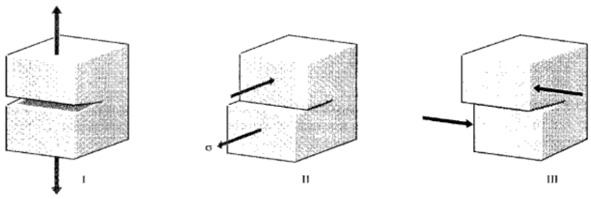


Figure 1.5 Fracture modes.

Common fracture mechanics terms:
K - Stress intensity factor
K_I - mode I stress intensity factor
K_{II} - mode II stress intensity factor
K_{III} - mode III stress intensity factor
K_{Ic} - mode I critical stress intensity factor; plane strain fracture toughness; fracture toughness
K_c - often used to designate mode I plane stress fracture toughness (not universally accepted)

IV. MATERIAL AND MANUFACTURING PROCESS

The major camshaft material competitors currently used in industry are cast iron. Comparison of the performance of these materials with respect to static, cyclic, and impact loading are of great interest to the automotive industry.
Camshaft are manufactured in foundries by preparing molten metal from mild steel ,pig iron, internal generations and alloying elements Si Mn Cu Cr etc.

V. 2 D FRCTURE ANALYSIS OF THE CAMSHAFT

Stress singularities in 2D bodies with cracks

In this Section we introduce the universal asymptotic behavior of stress and displacement fields around crack fronts in linear elastic materials. The sharp geometry of the cracks in the vicinity of the front points leads to singular stress fields. Such solutions appear to violate the assumption upon which linear elasticity theory is grounded and accommodations are required for the description of the local behavior. New concepts, like intensity factors for stresses, will be introduced and employed for the formulation of crack propagation criteria.

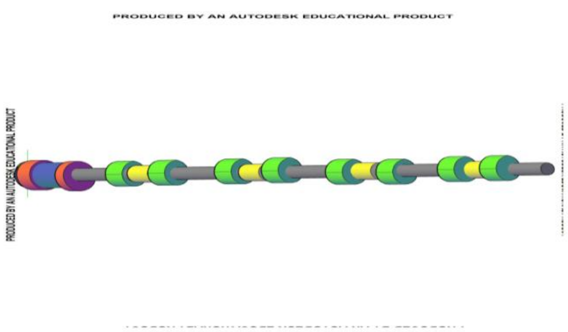


Figure 1.6 Autocad created model of camshaft

Analytical Approach

Problem Description Consider a cam surface in tension with a central crack as shown in Figure. The cam surface is made of grey cast iron with Young's modulus E = 170 GPa and Poisson's ratio υ = 0.29. Let b = 11.6 mm, length = 36 mm a = 0.2 mm,σ = 202 MPa. Determine the stress intensity factors (SIFs).

Assumptions and Approach
- Linear elastic fracture mechanics (LEFM).
- Plane strain problem.
- Crack is 2D

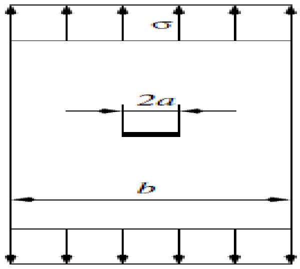


Figure 1.7 Through-thickness crack.

Mode-I - Stress Intensity Factor is given by

$K_I = C\sigma \sqrt{(\pi a)}$

$C = (1-0.1\eta^2 + 0.96\eta 4) \ [1/\cos(\pi\eta)]^{1/2}$

$\eta = a/b$

By putting above values and calculation we get $K_I = 23.71$ N/mm^2

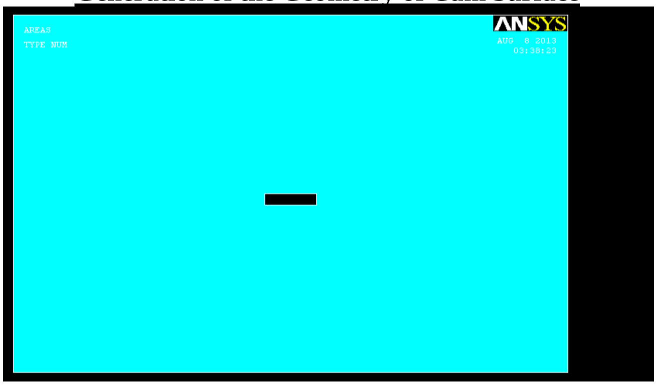
VI. FINITE ELEMENT ANALYSIS

Finite Element Modelling Assumptions

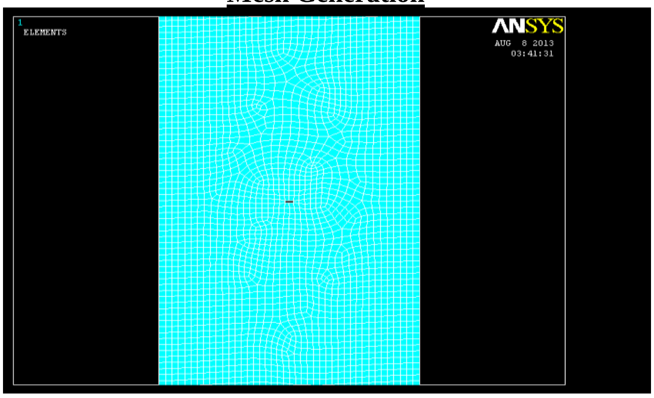
- Linear elastic fracture mechanics (LEFM).
- Plane strain problem.

Approach Since the LEFM assumption is used, the SIFs at a crack tip may be computed using the ANSYS's KCALC command. The analysis used fit of the nodal displacements in the vicinity of the crack tip. Due to the symmetry of the problem (cam), only one cam surface model is analysed.

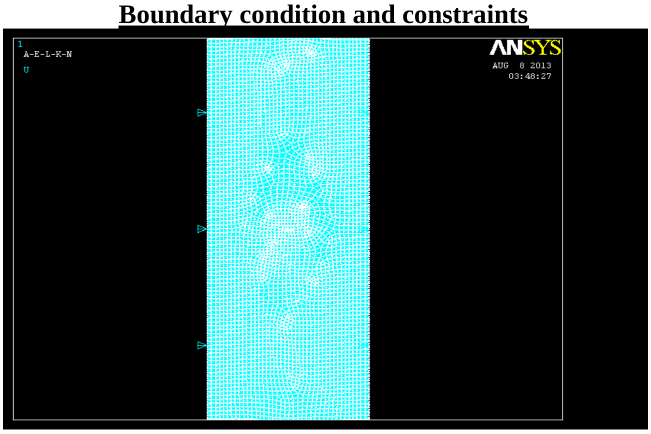
Generation of the Geometry of Cam Surface



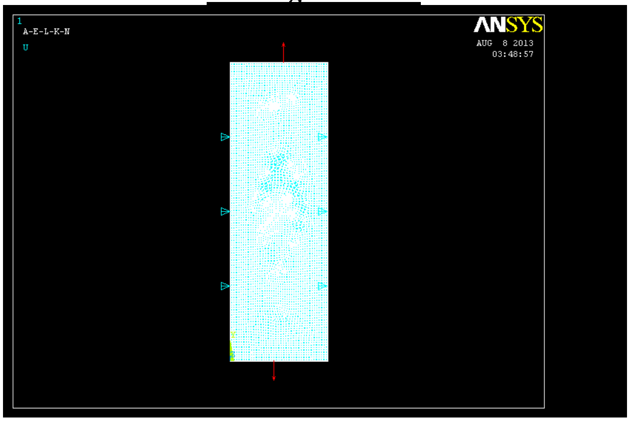
Mesh Generation



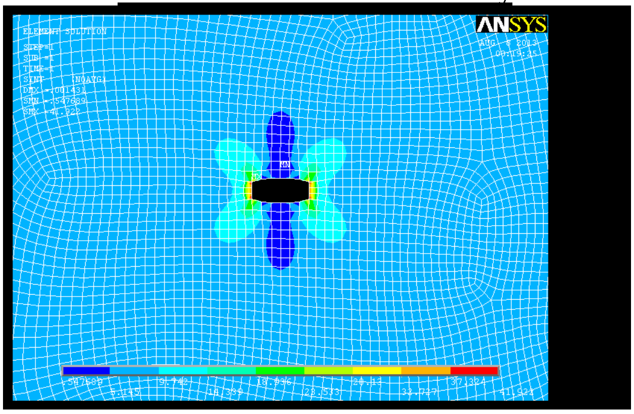
Boundary condition and constraints



Loading the model

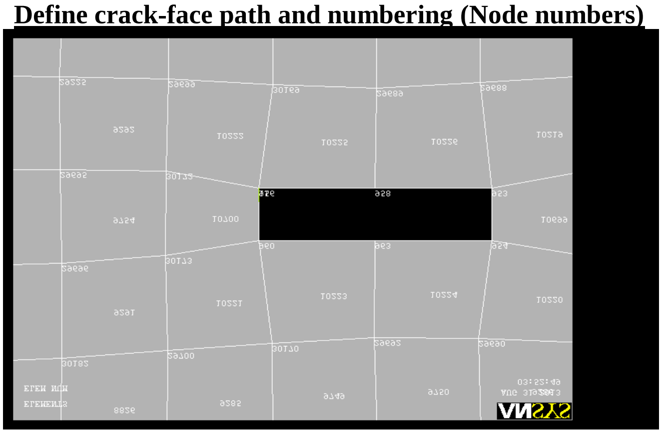


Element solution – Stress Intensity



VII. 2-D FRCTURE ANALYSIS OF THE CAMSHAFT

Define crack-face path and numbering (Node numbers)



Determine the Mode-I Stress Intensity Factor using KCALC

**** CALCULATE MIXED-MODE STRESS INTENSITY FACTORS ****
ASSUME PLANE STRAIN CONDITIONS
ASSUME A HALF-CRACK MODEL WITH SYMMETRY BOUNDARY CONDITIONS (USE 3 NODES)

EXTRAPOLATION PATH IS DEFINED BY NODES: 960 963 954
WITH NODE 960 AS THE CRACK-TIP NODE

USE MATERIAL PROPERTIES FOR MATERIAL NUMBER 1
EX = 0.17000E+06 NUXY = 0.29000 AT TEMP = 0.0000
**** **KI = 23.61** , KII = 0.0000 , KIII = 0.0000 ****

VIII. CONCLUSION

1. The stress analysis of the camshaft is carried out for the determination of the stress concentration level at the fracture region by the finite element method.

2. Von Misses stress distribution (MPa) on the camshaft at the most critical loading condition. The highest stress concentration occurs at the cracked location.
3. SIFs at the crack tip are KI = 23.71 N/mm^2 ; KII = 0 ; KIII = 0.Note that the results KII = 0 and KIII = 0 are obvious for this problem.
   The ANSYS solution for KI (23.61 N/mm^2) is in very good agreement with that obtained from analytical approach.
4. The discrepancy is

$$\varepsilon = \frac{K_I^{ANA} - K_I^{ANSYS}}{K_I^{ANA}} = \frac{23.71-23.61}{23.71} = 0.42\%$$

Recommendations

Suitable normalizing process should be performed on the blank before carburizing to eliminate the banded structure of the camshaft material. The carbon content of the case must be controlled to a level at which carbide will not be precipitated at grain boundaries. Select an appropriate carburizing process to decrease the extent to which the carburized camshaft would need to be straightened.

Also, the non destructive testing procedures of the component should also be improved as the defect can easily be detectable by standard non destructive techniques.
Future scope – experimental techniques can be used for quality check as surface cracks, X Ray, ultrasound, adhesion tests.

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