A Study of Crankpin Failure in I.C. Engine

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Abstract

A detailed study was carried out on crankshafts used in two wheeler made from C45 (EN 8/AISI 1042) steel. Undesirable noise was heard in crankshaft when the engine is in running. This was stated as failure of crankshaft. Material has been peeled off and seemed to be scraped at the central portion of the crankpin. It was the bearing seating place where oil hole also provided. Under analysis the crankpin was identified as tempered. Chemical composition, micro-hardness and microstructure were studied and compared with the specified properties of the crankpin material. Reason for failure is identified as wear due to lower hardness, improper lubrication and high operating oil temperature.

Keywords

crankshaft, crankpin, chemical analysis, micro hardness, finite element analysis,hardening.

1. INTRODUCTION

Crankshaft is the heart of an Internal Combustion Engine [2]. The reciprocating motion of Piston is converted into rotary motion by crankshaft. Crankshafts are generally subjected to torsional stress and bending stress due to self-weight or weights of components or possible misalignment between journal bearings. Crankshaft failures may be resulted from by several causes which are oil absence, defective lubrication on journals, high operating oil temperature, misalignments, improper journal bearings or improper clearance between journals and bearings, vibration, high stress concentrations, improper grinding, high surface roughness, and straightening operations. The crankshaft faults caused high cost of maintenance in automotive industry [3].

Reasons for failure of crankshaft assembly and crankpin may be

A)Shaft misalignment
B) Vibration cause by bearings application
C) Incorrect geometry (stress concentration)
D) Improper lubrication
E) High engine temperature
F) Overloading
G) Crankpin material & its chemical composition

H) Pressure acting on piston

Osam asi et al [3] have conducted failure analysis of a diesel engine crankshaft used in truck made of ductile cast iron. The crankshaft was found to break into 2 pieces at the crankpin portion before completion of the warranty period. The crankshaft was induction hardened. Failure analysis including visual examination, photo documentation, chemical analysis, micro-hardness measurement, tensile testing and metallographic examination were conducted. Test results showed that the material was EN-GJS-700-2 ductile cast iron as induction hardened and tempered condition. The failure zones were examined using Scanning Electron Microscope with EDX facility. They identified that the absence of hardened case in fillet region caused fatigue initiation and this was the cause of premature failure.

B.Kareem [4] ,has studied mechanical crankshaft failure for automobile .This was done using data gathered by oral interviews and questionnaire on mechanical failure of crankshafts. He has done research using Nissan, Datsun and other Japanese cars. Finally he has concluded that the failure of crankshaft in automobile came as a result of oil leakages in engines, overloading, misalignment, poor surface finishing, misassembling, poor reconditioning of thrust bearing and adultered engine oil. And the failure can be reduced by production of crankshafts with locally sourced materials, improvement on the local roads, right mechanical maintenance practice and educating the users.

Jian meng et al,[5] have done stress analysis and model analysis of four cylinder engine crankshaft using FEM .The three dimensional model of diesel engine crankshaft was created by pro-e and also they analysed the vibration model , the distortion and stress status of crank throw and they found the dangerous areas by stress analysis. The relationship between the frequency and the vibration modal was examined by the modal and harmonic analysis of crankshaft using ANSYS. They concluded that the maximum deformation appeared at the centre of crankpin neck surface. The maximum stress appeared at the fillets between the crankshaft journal and crank cheeks, and near the central point journal. The edge of main journal was high stress area. The failure was due to bending fatigue.

S.M.Sorte et al, [6] have analysed the stress and design optimization of a single cylinder crankpin of TVS Scooty Pep crankshaft assembly. Three-dimension models of crankshaft and crankpin forces were created using Pro/ENGINEER software and software ANSYS was used to analyze the stress status on the crankpin. The maximum deformation, maximum stress point and dangerous areas are found by the stress analysis.

R.K.Pandey[7],investigated the failure of diesel engine crankshaft used in tractor made from C45 steel.Premature failure was reported in the web region of the crankshaft. The crankshafts were forged, normalized and partly induction hardened. The investigation included determination of chemical composition,microstructural examination, evaluation of tensile properties and charpy toughness as well as hardness determination. The fracture toughness was estimated from the charpy energy data. The failure zones in various crankshafts were examined using the scanning electron microscope (SEM) and the micro mechanism of failure in the crankshafts was studied. Fractographic studies indicated fatigue as the dominant mechanism of failure of crankshafts. The studies indicated that fatigue initiation from the crankpin-web fillet region necessitated a stress level of about 175 MPa. To avoid recurrence of failure, machining and final grinding has to be done carefully to prevent formation of discontinuities or crack-like defects in the fillet region and induction hardening of the fillet is desirable. Also, the fillet radius needs to be increased.

Changli Wang et al, [8] have conducted a test run for only 20 min and a crankshaft cracked in a strange manner. The crankshaft is made of 40CrMnMo alloy steel. Four cracks were found on the edge of the oil hole. Using mechanical analysis, microstructure and metallurgy the reason of this event has been revealed. Force of friction caused by improper crankshaft repair and assembling is main factor of the failure. Why friction occurs, how the crack initiates and expands and what the process of failure were studied. They concluded that the crankshaft cracked by shearing stresses, caused by unusual friction between surface of shaft and the main bush, due to improper repairing and assembling and Friction can cause slip on the surface of friction boundary, especially when the temperature goes up to a critical level. To 40CrMnMo 300–500°C is a special temperature which may lead to temper brittleness. Finally they stated that it is possible that molten copper from the bearing shell caused liquid metal embrittlement in the crankshaft journal.

Ali Keskin et al, [9] have gone for failure analysis of nodular graphite cast iron crankshaft used in petrol engine. They tested mechanical and metallurgical properties of the crankshaft including chemical composition, micro-hardness, tensile properties and roughness and were compared with the specified properties of the crankshaft materials. In the comparison, there were no metallurgical defects apart from slightly higher carbon content. All other measured values were within the specified values. The reason identified for the failure was the thermal fatigue because of contact of journal and bearing surface. This condition led to the formation and growth of fatigue cracks. The contact was resulted from defective lubrication or high operating oil temperature.

A failed crankshaft was analyzed for the cause of failure. When the crankshaft was taken from engine, it was found that crank pin was worn out severely and looked like material has been peeled off and scraped at the centre of the crankpin.

Item	Specification
Number of Cylinder	Single
Cycle	4 stroke
Stroke(mm)	49.5
Bore(mm)	50
Displacement(cc)	97.2
Compression ratio	9:1
Maximum power	5.5 kW at 8000rpm
Maximum Torque	7.95 Nm at 8000rpm

Table.1. Engine Specifications

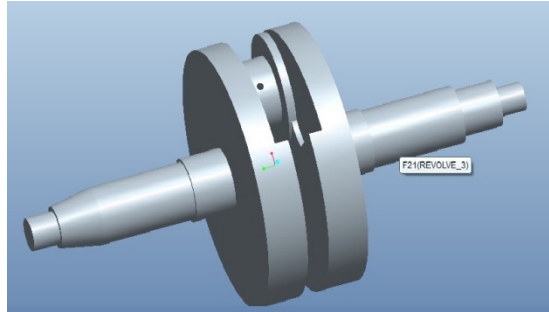## 2. Finite Element Analysis

Fig.1. Pro-e Model of the crankshaft

There are two critical locations identified as cause of crankpin failure and it is compared with FEA results.
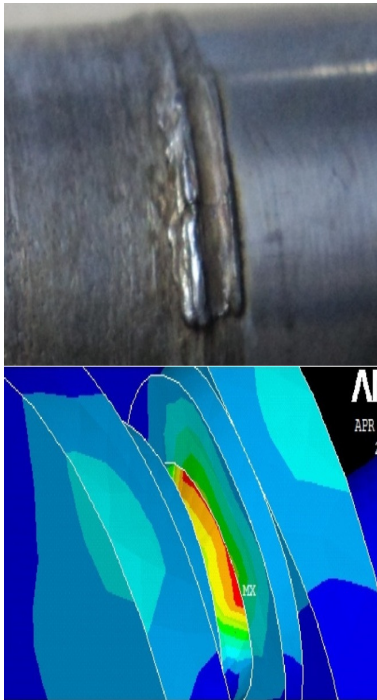

Fig.2. Stress concentration on fillet area

The original image of failed crankpin shows that the wear is maximum at the fillet region where the crank web contacts with the crankpin. And this region is considered as one of the critical locations. The same is validated in finite element analysis.
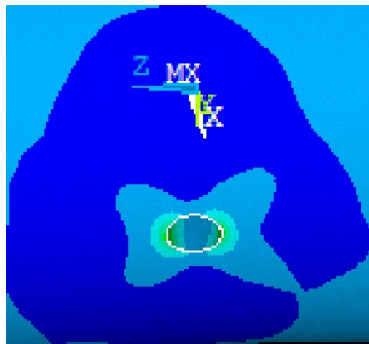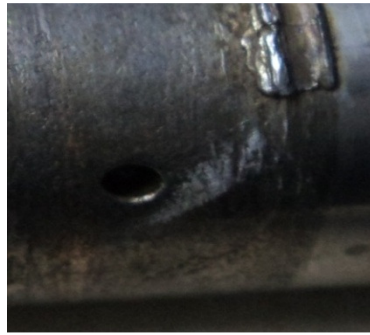
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Fig.3. Stress concentration on oil hole

The original image of failed crankpin shows that the oil hole provided at the centre of crankpin for lubrication of connecting rod and connecting rod big end bearing. And this region is considered as one of the critical locations where the stress concentration will be more. The same is validated in FEA

The stress level of the failed crankshaft is analyzed by finite element method.Fig.4-7 gives the finite element model of crankshaft and shows us the stress results at the crankpin location. Crankshaft assembly and crank pin are analyzed separately.
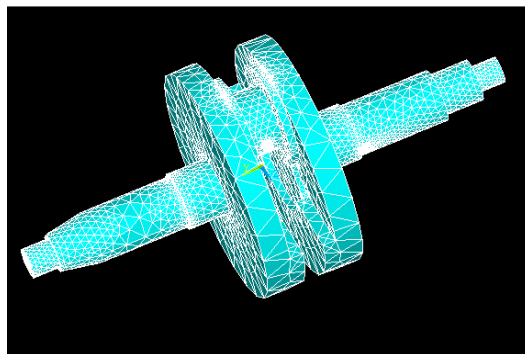

Fig.4.Meshing

Design calculation

Single Cylinder Engine

Swept Volume,

$$V \quad = \quad \prod/4 \; x D^2 x L.$$

$$= \quad \prod/4 \; x 50^2 x 49.5$$

$$= \quad 97.19 x 10^3 \, mm^3$$

Mean effective pressure $\quad = \quad (P x 60 x \, n) / (N \, x \, v)$

$$= \quad (60 x 2 x 5500) / (97.19 x 10^3)$$

$$= \quad 0.85 \, MPa$$

$$F \quad = \quad \prod/4 \; x d^2 x P$$
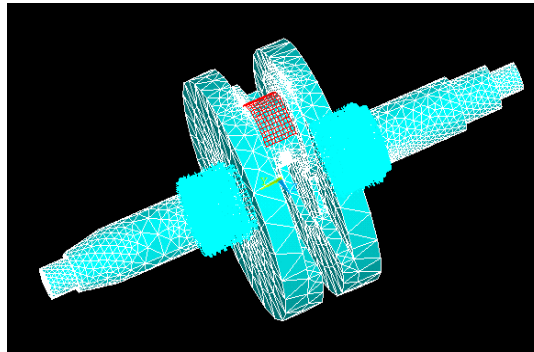
$$F \quad = \quad 1.669 \, kN$$
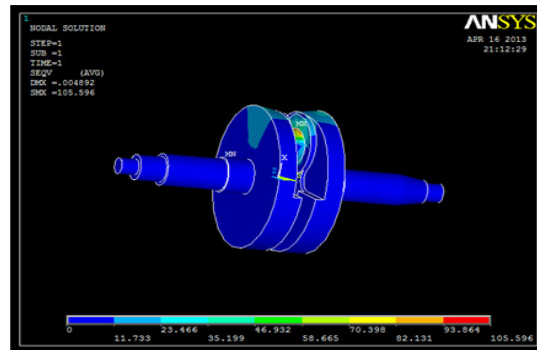

Fig.5.Boundary conditions

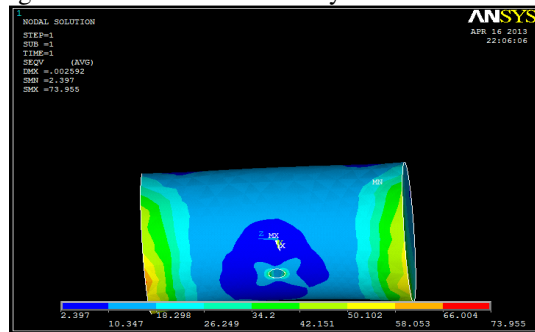Fig.6.Finite element stress analysis of the crankshaft

Fig.7.Finite element stress analysis of the crankpin

The model was imported to ANSYS. The finite element mesh is generated with SOLID 185 element and meshed using tetrahedra freemesh.The node numbers are 19329 and number of Elements are 94584.

Bearings are assumed as boundary conditions and their displacement is assumed zero. Force is applied from the crankpin bearing location for 120°angle of contact [12]. Vonmises stress in the failure location and fillet radius are higher and hence they are considered as critical location for the analysis.

3. EXPERIMENTAL METHODS

A. Chemical analysis

Fig.8.Crankpin

The crankpin was cut perpendicular to its axis to find out the chemical composition.Table.1 and 2 gives the specified chemical composition of crankpin material. In the same table the chemical composition of the material from the failed shaft and crankpin is reported by using Optical Emission Spectroscope (OES) analyzer. Analysis revealed that the crankpin material is SCM 420 and crankshaft material is EN 8 of BS 970(C45 steel).It is observed that the chemical composition of crankpin is within the specified range.
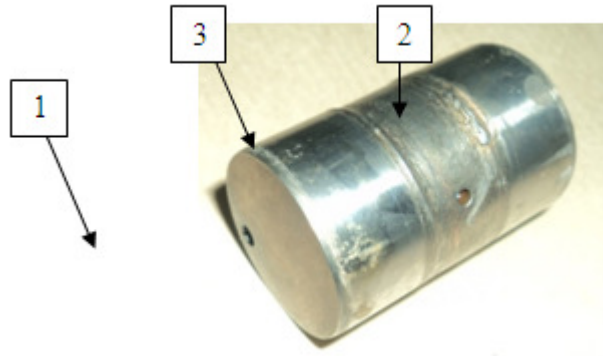
Fig.9.Failed crankpin

Composition	Wt.% as Specified	Wt.% based on analysis
Carbon	0.18-0.23	0.18
Manganese	0.6-0.85	0.79
Silicon	0.15-0.35	0.31
Sulphur	Max 0.03	0.006
Phosphorus	Max 0.03	0.005
Chromium	0.9-1.2	0.958
Molybdenum	0.15-0.3	0.15

Table 2.Chemical composition of crankpin material

Properties	Values
Young's modulus	190-210GPa
Density	7.9^3 kg/m^3
Poisson ratio	0.3
Yield stress	434MPa
Tensile stress	715Mpa
Elongation	15%

Table 3.Material properties of crankpin.

B.Hardness Measurement

Hardness of crankpin was tested using Vickers micro hardness tester. The test load was 1kg and three locations in cross section were tested [10].

Hardness of the failed crank pin and a new crank pin was tested at both cross section side and centre of the crankpin around the circumference at different points by using Vickers micro hardness tester. The mean hardness value at the three locations (Fig.9) is listed in Table.4 and Table.5.

positions	1	2	3
Results	716	711	699

Table.4.Vickers micro hardness results (HV1) of failed crankpin

Positions	1	2	3
Results	722	719	716

Table.5. Vickers micro hardness results (HV1) of new crankpin

Hardness result shows that the failed region (centre of crankpin) has lower hardness than cross section sides and hence the wear was initiated earlier due to friction and it propogated due to improper lubrication with oil temperature.

C. Microsturcture analysis

The crankpin was tesred using METSCOPE (Metallurgical microscope).The image of 500X magnification shows that fine tempered martensite structure is throughout the matrix [3] .Tthe microstructure is not the cause for the failure.
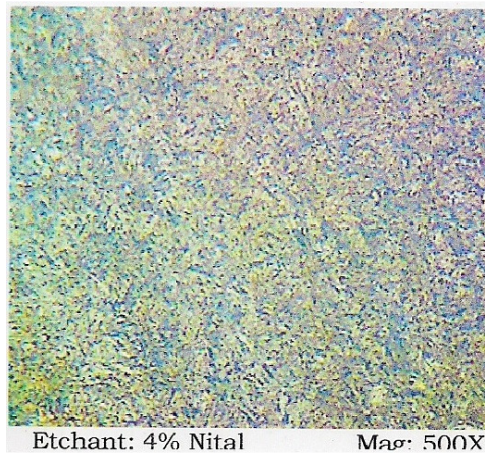

Fig.10 .Microsructure of the crankpin cross section With 500X

The macro etched crank pin doesn't show any crack. Hence, the failure is only due to friction occurred by improper lubrication.

4. Solution

Then the crankpin central portion was subjected to selective induction hardening to the depth of 3mm followed by salt bath quenching [11]. The hardness measured after hardening is listed in table 6.

position	1	2	3
Results	721.6	227.8	267.1

Table.6. Vickers micro hardness results (HV1) of new crankpin after Induction Hardening

The measured value shows that there is increase in

Hardness value after induction hardening. Due to this life of the crankpin can be increased.

5. Results and discussion

It is found that the chemical composition of the crankpin is within the range of the technical specifications and no manufacturing and machining defects were found. The crankpin was not case hardened except tempering followed by general hardening.

However the hardness value at the failure region was lower (699 HV1) than other locations (716 HV1) and it is the cause for the rapid wear of the crankpin at the contact region. This initiation of failure is consequently propogated by improper lubrication. Hence the stress and wear at this region becomes more.

6. Conclusion

1. The crankpin wears at the centre and caused failure. The lower value of hardness increases the wear between contacts.
2. Two critical locations have been identified and Finite Element Analysis result confirmed that the highly stressed regions are the contact region with the web and centre of crank pin where oil hole is provided.
3. Improper lubrication increases the wear rapidly and hence noise is heard when the engine is in running. Hence, the life of crankshaft becomes shorter.

7. Future work

In Case Hardening, Nitriding process will improve hardness in better way and this process has been used to increase hardness of crankpin in many crankshaft applications. But due to the size insufficiency in our crankpin it was not possible to do. In future, we will try for Nitriding and optimize the hardening process to give the maximum hardness at the surface area of crankpin to increase the life of the crankshaft.

Another possibility we are going to try is giving a Nano coating over the surface area to reduce the wear of crankpin. Here also, we will go for optimization of parameters like depth of coating, processing time etc.

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