Proceedings IRF2018: 6th International Conference Integrity-Reliability-Failure
Lisbon/Portugal 22-26 July 2018. Editors J.F. Silva Gomes and S.A. Meguid
Publ. INEGI/FEUP (2018); ISBN: 978-989-20-8313-1

PAPER REF: 7102

STUDY OF THE EFFECT OF STRESS CONCENTRATORS IN FATIGUE FAILURE ANALYSIS OF A CRANKSHAFT

José Rubens Gonçalves Carneiro(*), Leonardo Cardoso de Aguiar, Gilmar Cordeiro da Silva,
João Pedro Santiago Carneiro
Instituto Politécnico (IPUC), Pontifícia Universidade Católica de Minas Gerais, Belo Horizonte, Brazil
(*)*Email:* joserub@pucminas.br

ABSTRACT

This work proposes to investigate, discuss and understand a fatigue failure problem by requesting repetitive efforts with variable loads on the crankshaft, which is a component of an eccentric press with capacity of effort of 200 tons. The intention of this study is show the contributions of the forging process and reorganize the geometry by increasing the radii between the diameters in order to reduce the stress concentrations to increase the mechanical resistance of the part and consequently increase the useful life of it.

Keywords: forging process, mechanical resistance, stress concentration.

INTRODUCTION

The global competition in the automobile market requires practical organizations and process methodologies that ensure low cost, deadline and products and services qualities.

The crankshaft is a structural component which converts the linear piston movement into rotary motion while the force connecting rod is transformed to torque (Li, Wan, Xue, 2015). Most of the times crankshafts have failed by torsional fatigue or bending fatigue or both (de Freitas and Fonte, 2008)

Crankshafts are design with good safety margin to avoid fail, but high cyclic loading and local stress concentrations allow crack propagation and premature fracture in the component.

Forging is forming proceeding by hammering or pressing, it could be hot or cold work. In this process, all components deal with high loads in order to ensure metal forming.

The principle of mechanical operation of the press comes from 2 crankshafts ensuring the movement of the hammer. The hammer is an upper contact component with the stamping tool, and it moves cyclically through the crankshafts. Press has a maximum capacity of 200t of workforce in the 2 axes. The power transmission is via shaft (diameter 200 mm to 280 mm and total length of 1210 mm), bearing and gear.

The shafts were manufactured by machining a cast bar in the 12-inch diameter, and then subjected to a heat treatment of tempering and quenching to reach average hardness of 280 HB.

This axis fractured after 2 years of operation. Based on this, the objective was to investigate the causes of the premature break in service of these shafts using techniques of metallographic analysis, fatigue tests and finite element simulations.

METHODOLOGY

The material used in this work was supposed to be an AISI 4140, but a chemical analysis was made in a piece of this material cut from the broken material in order to confirm that it is really an AISI 4140. After sanding in 180, 300, 600, 1200 grit sandpaper and polishing in diamond paste 9 μm and 3 μm, the piece of shaft was attacked by Nittal 4% to see the microstructure of the material utilized in this study.

Brinell hardness was measured in three points to confirm that hardness of the shaft is met the demands (280 HB) after the heat treatment. A visual analysis has been done in the component after being broken in order to identify what is the root cause of the problem and suggest one possible solution to this broken crankshaft.

It was thought that the reason why the shaft was broken should be the stress concentrator in one specific region: the radius of curvature. So the propose was calculate a factor of stress concentrator in the crankshaft studied and find out a radii of curvature that could improve dramatically fatigue life cycles of the component.

Graphs from Shigley, Mischke and Budynas were the guide to think about an enhancement from 3 mm to 6 mm on the radius of curvature and reduce the stress concentration. The real crankshaft (6 mm of radius of curvature) and the theoretical one (3 mm of radius of curvature) were simulated using the finite element method. The 3D drawing of the part was obtained by Solid works software and it was imported to Opti Stru in order to simulate the structure after a number of fatigue cycles.

The mesh of this model had tetrahedron of second order form. There were 111443 elements and 170084 nodes in all simulated component. The parameters utilized to define the material in simulation is shown in Table 1.

Table 1 - Parameters used in the simulations

Parameter	**Value**
Young's modulus	2,1 GPa
Poisson ratio	0.3
Yield stress	714 MPa
Ultimate stress	1046 MPa

RESULTS

The results of chemical analyses are presented in Table 2 (percentage of weight). It confirms the fact that steel utilized in the manufactured crankshaft is an AISI 4140. Considering this, it is needed to know if it was not a problem in the heat treatment of this material or some processing trouble.

A metallography sample was prepared and the image in the optical microscope is shown in Figure 1.

Table 2 - Results of chemical analyses in the crankshaft

Element	Percentage of weight
Fe	Balance
C	0,416
Mn	0,915
Si	0,230
P	0,016
S	0,005
Cr	1,016
Mo	0,197

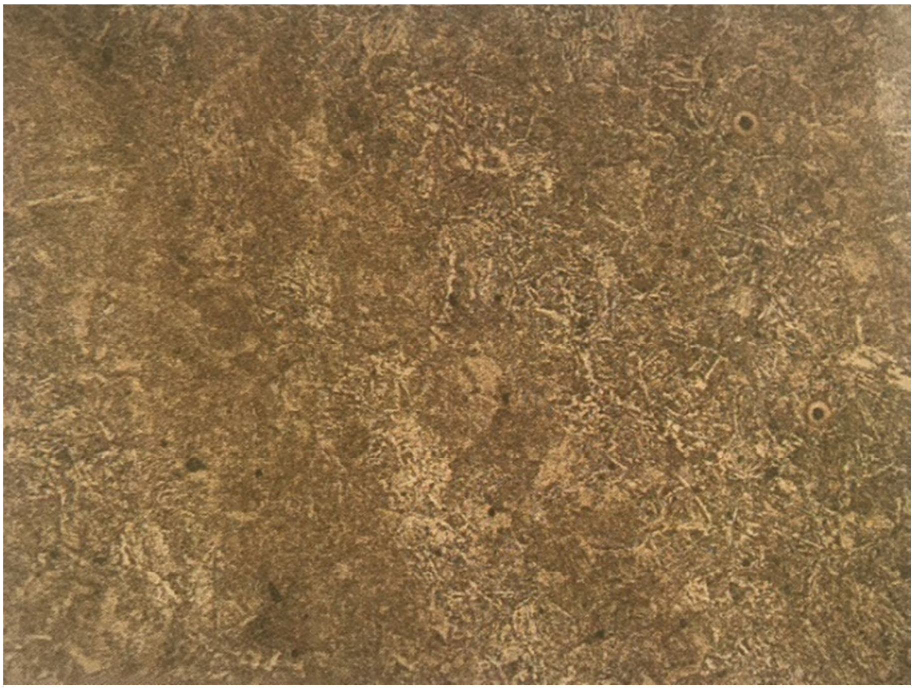

Fig. 1 - Microstruture of AISI4140 utilized to manufacture the crankshaft in this study (magnification 200X)

Figure 1 shows that microstructure is a perlite matrix with some ferrite areas. It seems to be a bulk steel of solidification.

Hardness tests carried out indicated that hardness Brinell of this component is just 3-5% lower than the reference value (280 HB), so it is almost impossible to verify any type of problem related to the material used in the crankshaft.

Figure 2 shows the broken crankshaft that was analyzed in order to identify root-cause of problem in this case.

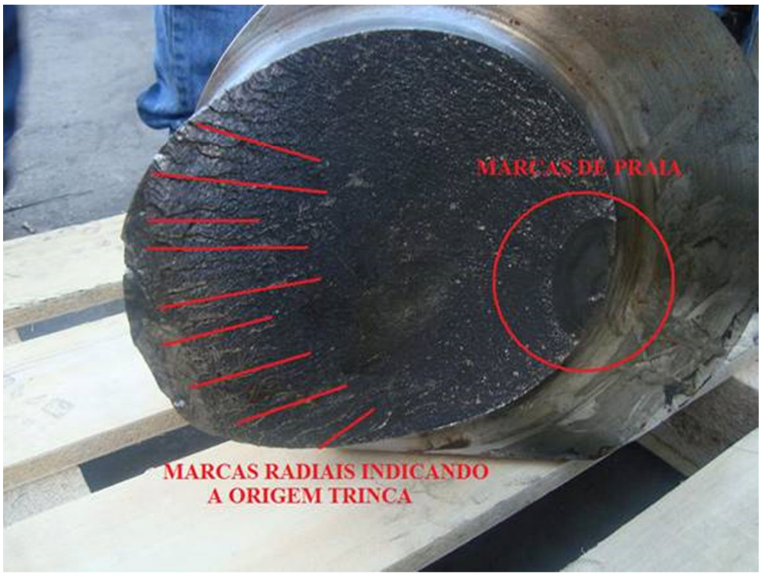

Fig. 2 - Broken crankshaft

Analyzing the break, it is possible to verify that the fracture occurred close to radius of curvature, a stress concentrator, by the radial marks. It presented bench marks, a typically fatigue loads failure.

The shaft has failed close to the radii of curvature, so it has been supposed that it was a stress concentrator and the possible stress concentrator was calculated based on Shigley, Mischke and Budynas (2005) graphic. The results are indicated in Figure 3, where K_t is the stress concentrator.

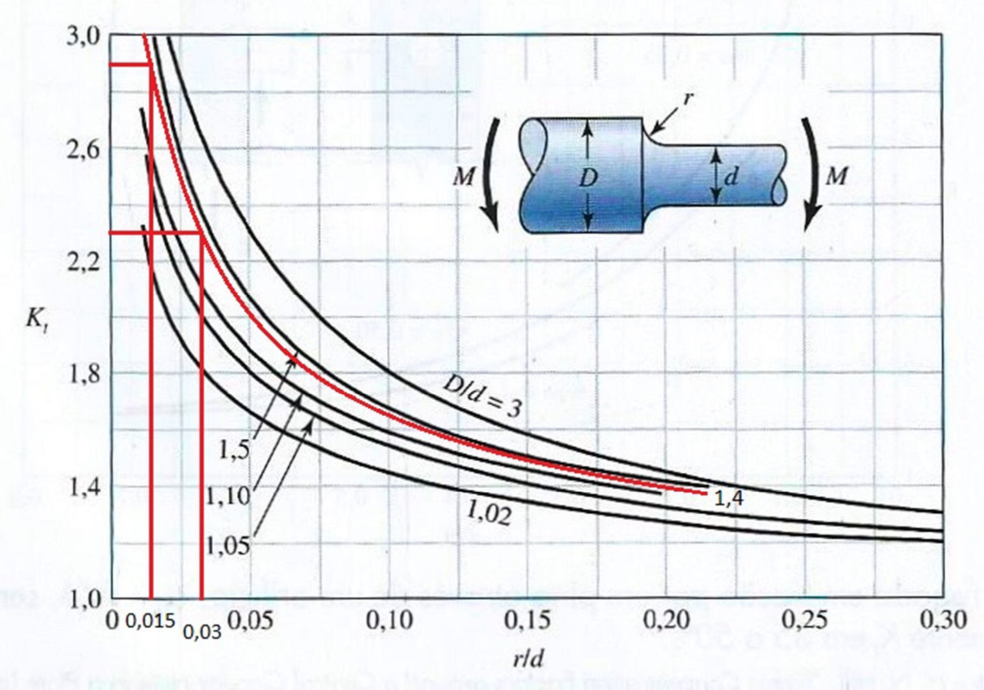

Fig. 3 - Graph adapted from Shigley, Mischke & Budynas (2005)

The values are indicated the stress concentrator factor drop to almost 3,0 to 2,3, so it is expected that this component will not fail too early next time. The simulation was done to confirm this expectation.

It was simulated using the finite element method for a situation that enhanced the radius of curvature (6mm) and another with the radius of the component, which has already been made (3mm). Figure 4 shows the fatigue results

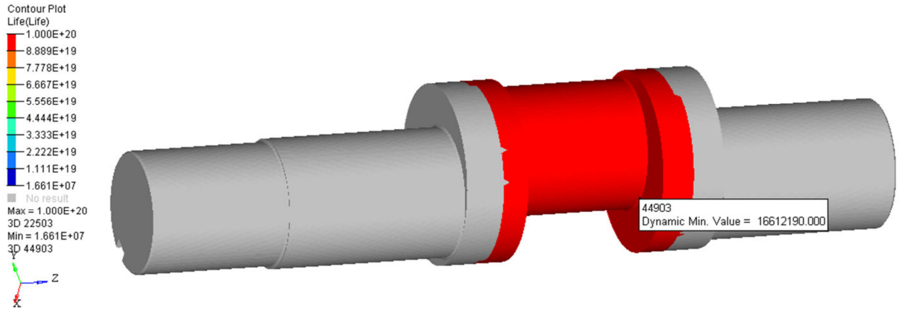

Fig. 4 - Fatigue results (recent situation)

In this simulation, the shaft has broken after 16612190 cycles almost the same as real situation (16115808 cycles). Figure 5 presents fatigue outcome when the radius of concordance is enhanced to 6 mm.

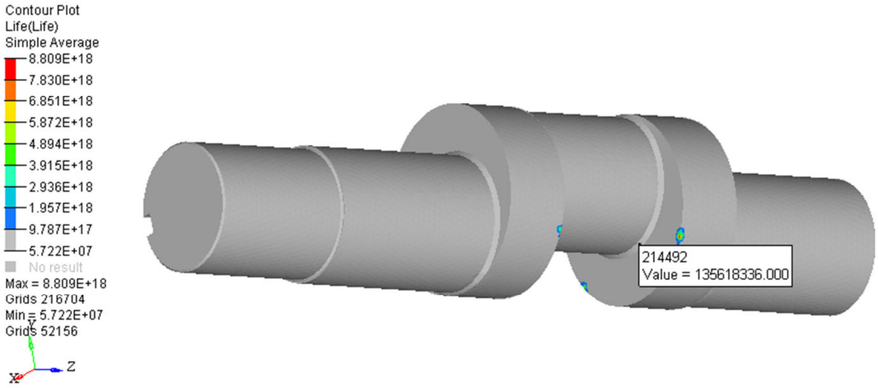

Fig. 5 - Fatigue results (increased radius of curvature situation)

The life of this component increases undoubtedly. It has supported over 135000000 cycles, which is more than 8 times, compared to the actual situation.

CONCLUSIONS

There are lots of different factors that makes a component fail by fatigue including geometry, manufacturing process and material are just a small part of them.

However, in this case it is possible to ensure that radii of curvature of just 3 mm is too low and the increase to 6 mm reduces loads in the structure and enhances the life of the component theoretically and using the finite element method.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding by CAPES (Centro de Aperfeiçoamento de Pessoal Superior).

REFERENCES

[1] Li, W., Yan, Q., and Xue, J. (2015). Analysis of a crankshaft fatigue failure. Engineering Failure Analysis, 55; pp.139-147.

[2] Fonte, M., & De Freitas, M. (2009). Marine main engine crankshaft failure analysis: a case study. Engineering failure analysis, 16(6); pp. 1940-1947.

[3] Espadafor, F. J., Villanueva, J. B., & García, M. T. (2009). Analysis of a diesel generator crankshaft failure. Engineering Failure Analysis, 16(7); pp. 2333-2341.

[4] Kovacı, H., et al. "Fatigue crack growth behavior of DLC coated AISI 4140 steel under constant and variable amplitude loading conditions." Surface and Coatings Technology 304 (2016); pp. 316-324.