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FAILURE ANALYSIS BY NUMERICAL SIMULATION OF A CRANKSHAFT MODEL MWM 229

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Abstract. Crankshafts are important components for the operation of internal combustion engines, compressors, etc. The premature failure of these components may lead to serious damage or accidents. The failure analysis search causes that resulted in failure of engineering products or components, aiming at the improvement of new products and minimizing these possible causes of failures. The failures can be classified in different situations: design, material, manufacturing process or even an improper operation. The Numerical Simulation is a new tool that has been used in these failures checking operations, aiding in the prediction of the behavior of the equipment currently being applied for solving mechanical problems or even before any physical prototype is tested. Along with the simulation, failure analysis is considered a tool of project optimization. Therefore, the objective of this study is the failure analysis of a crankshaft model MWM 229 by Numerical Simulation. In the crankshaft was identified the region of onset and the micromechanisms of fracture. Through the results it was possible to observe that the microstructure is characteristic of ferrite and perlite, with microhardness of 230HV. The numerical simulation allowed to identify the fracture regions through stress concentrators along the rounding radius.

Keywords: Numerical simulation, Failure analysis, crankshafts, Microstructural characterization.

1. INTRODUCTION

During a considerable service period, the crankshafts lose their service life due to external causes that can speed up the components failure process. Any failure in the crankshaft seriously compromises the operation of combustion system. A common cause of failure in crankshaft is the formation of a fatigue crack at the shaft base. The natural factors of the equipment operation lead to the growth of the crack to its critical size, thus causing an imbalance in the rotation of the component that leads to failure (Prakash et al., 1996; Sivaprasad et al., 2010).

The failure analysis of crankshafts is present in several case studies noted in the literature (Li et al., 2015; Khameneh and Azadi, 2018). As the work of Witek et al. (2017), an analysis of failure in a crankshaft of diesel engine showed that the fracture surface had typical beach marks of fatigue failure, nucleation zones, propagation and rupture were also observed. Finally, a finite element analysis was used to estimate quantitatively the tension distribution along the workpiece during service. It was possible to observe in this study by finite elements, a great amount of tension in the zone where the fracture begun. The authors were able to conclude that the failure occurred by high cycle fatigue through the fracture surface and by the small concordance radius at the shaft base.

Harris and Birkitt (2016) carried out an inspection of a crankshaft of an oil rig compressor. The authors carried out inspection by Magnetic Particle and fractographic analysis. They might conclude that the failure was due to the presence of pitting corrosion located in the crack nucleation zone where noted large concentrations of tension, so the failure was characterized by a process of corrosion-fatigue.

Therefore, the objective of this study is to conduct a failure analysis on the crankshaft model MWM 229 by numerical simulation. The region of beginning and the micromechanisms of fracture were identified as well as the tension distribution by numerical simulation.

2. MATERIALS AND METHODS

2.1 Fracture and Microstructure Analysis

For the analysis of crankshaft fracture surface, initially was photographed as received and identified its parts. Then a fracture surface cleaning with mild soap and water, and a brush to remove layers of oxides.

For the microstructure analysis of the crankshaft, in accordance with the work of Azevedo et al. (2016), samples were selected, cut into abrasive cut-off wheel refrigerated and then mounted in cold acrylic resins, sanded with sandpaper of SiC of particle size 120 to 1200 mesh. The polishing was done in polishing machine using abrasive diamond paste. For revelation of the microstructure, the chemical attack carried out will be with Nital (15 ml HNO₃ and 85 ml H₂O). For the microstructural analysis of samples and purchase of images was used an optical microscope.

The Vickers microhardness test identified the hardness of the crankshaft material. The tests were carried out on the samples previously prepared for metallography. The tests shall be done according to the procedures in ASTM E92 (2003). Vickers microhardness tests were performed with a microdurometer tester (INSIZE ISH-TDV 1000) through five indentations in each of the three metallographic samples.

2.2 Analysis by Numerical Simulation

For the estimate and observation of tensions concentration in the nucleation of failure during operation, were initially made models that represent the real dimensions of the crankshaft, then these models were imported into the software of simulation.

The numerical simulation was performed in linear elastic regime under static loading conditions. At the end of the simulation, the resulting tensions were observed and compared to the required tensions to reach the fatigue limit of the material used by the manufacturer.

Have been assigned to this simulation 200 GPa of modulus of elasticity, Poisson's Coefficient of 0.3 and density of 7.85×10^{-9} (tons/mm³).

The boundary conditions for the model, was described pinning the crankshaft on the x and y axis and free in z for a complete freedom in rotation. Then it was applied a 3000 RPM rotation. The Figure 1 shows de assembly representation of the crankshaft.

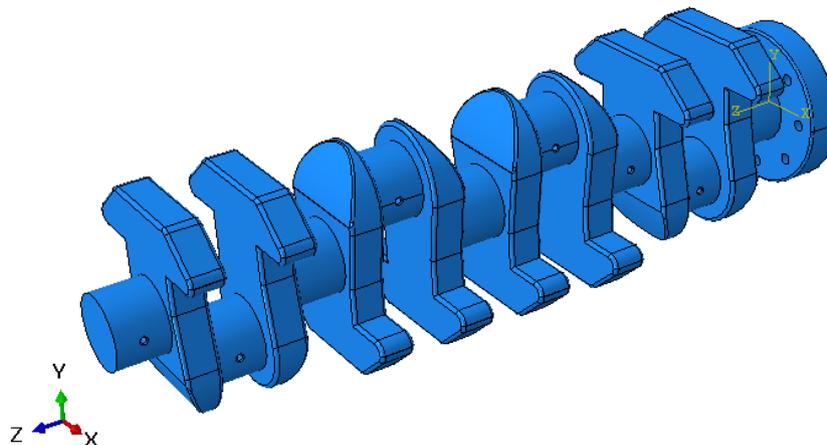


Figure 1. Assembly representation of the crankshaft. Source: Authors (2019)

3. RESULTS

3.1 Fracture and Microstructure Analysis

Figure 2 below shows the fracture surface as received. There was a need for superficial pickling for deeper cleansing with nitric acid.



Figure 2. Representation of the fracture surface received for analysis. Source: Authors (2019)

Figure 3 presents the fracture surface after cleaning treatment with nitric acid. We see through this macrography the presence of nucleation punctual (Fig. 3a), followed by beach marks observed by fatigue stretch marks until the internal middle of the crankshaft (Fig 3b). The presence of fibrous surface on the bottom is marked by catastrophic failure by not supporting external effort (Fig. 3c).

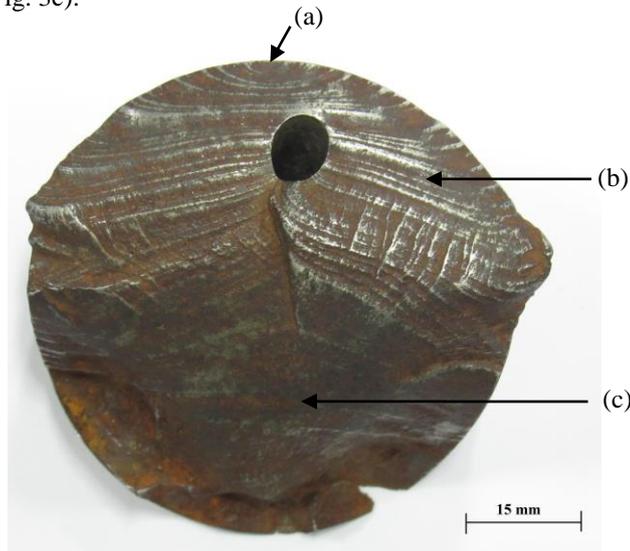


Figure 3. Representation of the fracture surface of the crankshaft in analysis. We can observe perfectly the three zones: nucleation in (a), propagation in (b) and final fracture in (c). Source: Authors (2019)

The crankshaft microstructure observed in Fig. 4 is characteristic of a perlitic steel of medium hardness. We observed the presence of ferrite and perlite in the entire microstructure. The crankshaft microstructure observed is characteristic of a AISI 5135 Steel.

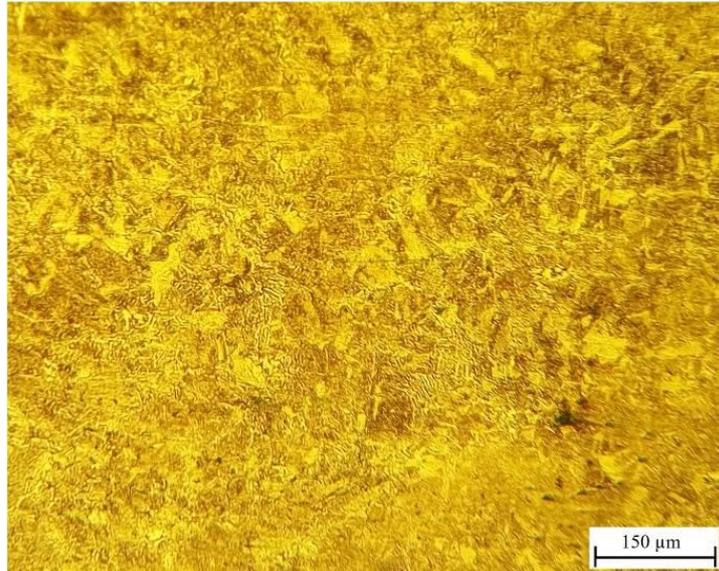


Figure 4. Crankshaft metallography. It was observed region of pearlite and ferrite characteristic of medium carbon steel.

Source: Authors (2019)

3.2 Microhardness

The analyzed crankshaft has a microhardness of 230 HV. This hardness is characteristic of a steel-chromium AISI 5135, commonly used for manufacture of forged crankshaft.

3.3 Numerical Simulation

The numerical simulation analyses were able to observe that the highest tension concentrations during the simulation of the crankshaft is at the base of the concordance radius precisely where the nucleation started.

The numerical simulation showed that probably an imbalance of the crankshaft caused a roto-flexion during use and caused the tension concentrations at the nucleation point of the failure to overcome the fatigue limit for the AISI 5135 steel.

Figure 5 presents a study of the stress concentration regions that coincides exactly with the failure of this component. A small rounding radius presented by the arrow shows a stress concentration that caused premature failure of the component in service. A possible imbalance must have caused the acceleration of this failure.

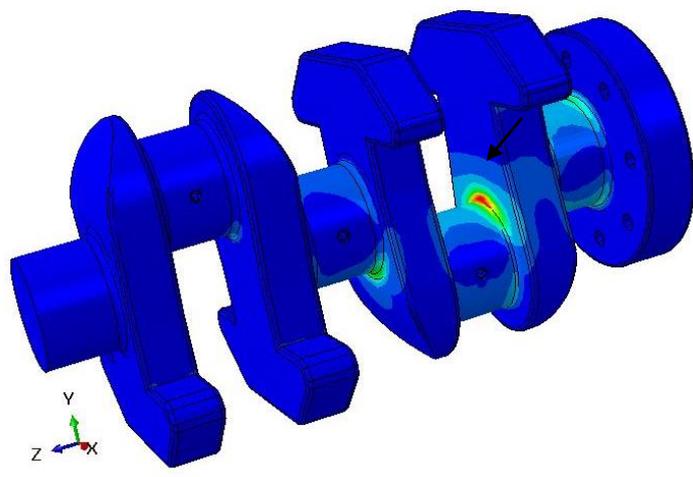


Figure 5. Numerical simulation of the crankshaft. The reddish areas present higher stress concentrations.

Source: Authors (2019)

4. CONCLUSIONS

Therefore, through the analyses presented it was possible to observe that the failure occurred due to an imbalance submitted to roto-flexion, concentrating punctual stress above the fatigue limit of the AISI 5135 Steel.

There were no microstructural changes in the crankshaft steel.

The numerical simulation showed the stress concentration regions, which coincide with the location of the component failure.

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