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Fatigue analysis of the connecting rod in internal combustion engines

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Fatigue analysis of the connecting rod in internal combustion engines

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Abstract. The connecting rod along with the crankshaft turn the translation movement of the piston into rotation. The alternating forces acting on the connecting rod caused micro-fissures, resulting in materials breaking at much lower forces than the maximum allowable stress. This work presents the finite element analysis to determine the fatigue strength of the connecting rod. The results of the study show the dependence of fatigue resistance on the configuration of the connecting rod processing surface for the two types of the steel being analysed.

1. Introduction

Internal combustion engines convert chemical energy into mechanical energy in the form of reciprocating motion of the piston. Crankshaft and connecting rod convert reciprocating motion into rotary motion. Connecting rod (CR) is one of the important driving parts of light vehicle engines. The connecting rod experiences various forces of both piston acceleration and deceleration from the stroking motion, friction-generated loads and the load caused by the cylinder pressure during the combustion stroke. If not strong enough, CR fatigue failure would occur, further leading to component fracture and engine failure [1].

To get the most competitive prices, car manufacturers choose software specifically for the design, analysis and execution of the parts required for the assemblies. Thus, sizing and checking the components shall be made for a certain number of cycles and for a specific operating period. Analysis programs have been developed to predict over which period of time the first damaging micro-fissures begin to occur.

In the fatigue processes the surface effects are very important. In most cases the degradation, as a result of the local plastic deformations, takes place at the surface layer [2], where the resistance to deformation is modified at the same time with the cyclic fatigue loading based on a hardening/and/ or softening mechanism. In his studies, Seiler revealed that the processed surfaces had a better fatigue resistance [3].

The work is intended to study the occurrence of the phenomenon encountered in the literature as the fatigue of the material. This phenomenon occurs as a result of repeated cycles to which the connecting rod is subjected. It can be subjected to 12 cycles per second up to 66 cycles per second in the specific case of cars, and in the case of small engines (e.g. motorcycle, boat) it can reach 135 cycles per second.

2. Materials and Methods

2.1. Materials

For simulation purpose, two types of steel AISI 4340 and AISI 1050 are used [4]. The properties of these materials are presented in Table 1, as provided by Autodesk Simulation database.

Table 1. Steel physical properties

Materials	Mass Density	Yield Strength	Ultimate Tensile Strength	Young's Modulus	Poisson's Ratio	Shear Modulus
Steel AISI 4340 409 QT	7.85 g/cm^3	1371 MPa	1467 MPa	207 GPa	0.33	77.8195 GPa
Steel AISI 1050	7.85 g/cm^3	206.842 MPa	517.104 MPa	199.947 GPa	0.3	76.9027 GPa

2.2. Calculation method

To determine the theoretical parameters, the physical parameters of a 2.0 litters TDI engine, of 102 kW, with a bore × stroke of 81 × 95.5 mm and a connecting rod length of 144 mm have been adopted.
The forces acting on the connecting rod are dependent on the stroke and crankshaft position. They are calculated according to [5] as presented below [6]. The gas force that acts on the piston was calculated as [7]:

$$F_g = \frac{\pi D^2}{4}(p_c - p) \quad [N] \tag{1}$$

where: D - cylinder bore, in mm;
p_c - cylinder gas pressure, in MPa;
p - crankcase pressure, in MPa.

The inertial force was expressed as:

$$F_i = -m_i a_i = 10^{-3} m_i r \omega^2 (cos\theta + \mathrm{rl}^{-1} cos2\theta) \quad [N] \tag{2}$$

where: mi - reciprocating mass, which is the sum of the piston mass and a percentage of the connecting rod mass, in kg;
a_i - instantaneous acceleration of the piston, in m/s^2;
r - crank radius, in mm;
ω - crank angular velocity, in rad/s;
θ - crank rotational angle from top dead center, in °;
l - connecting rod length, in mm.

The resultant force acting on the cylinder axis was calculated as:

$$F = F_g + F_i \tag{3}$$

Conventionally, it is assumed that the resultant force acts upon the piston pin axis. The dependence of this force as function of the crankshaft angle is presented in Figure 1.

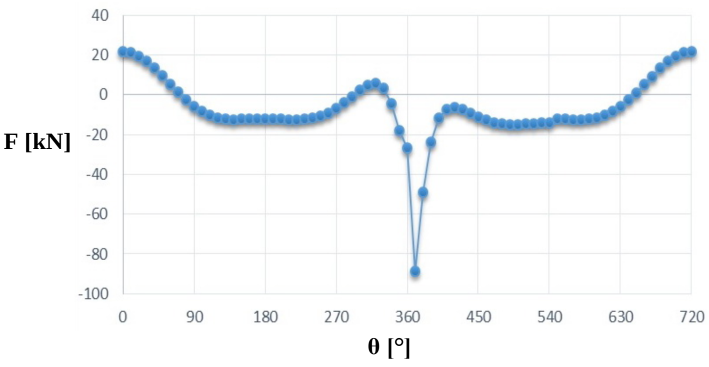


Figure 1. Resultant force function vs. crankshaft angle

2.3. Experimental determinations

Experimental determinations were focused on the influence of the degree of surface processing on the behaviour of a structural steel subjected to variable loads. The experimental results show that the roughness parameters of the surface layer change with the variable load. Thus, the microgeometry is considered as surface defect that can characterize its integrity.

Based on the experiments conducted regarding the behaviour to fatigue considering roughness as surface defect, it has been established the influence of the factors that determine the evolution of the resistance to fatigue, under different surface processing conditions.

The experimental results were presented in a number of previously published papers [2, 8, and 9].

3. FEM Analysis

The 3D model was created in the Autodesk Inventor Part Design module. With the same program the static analysis of the finite element was performed, resulting a safety factor of 1.65.

The 3D model has been exported to Autodesk Simulation Mechanical program. The simulation of alternating cycles to obtain fatigue resistance requires the selection of a coefficient that varies depending on the surface area of the connecting rod. It has several types of pre-defined processing surface, like: polished, ground, machined, rolled, forged. In most cases, a connecting rod has an unprocessed surface resulting from the forging process. The model that needs to meet more special working conditions also has the exterior surfaces mechanically processed.

3.1. Mesh generating

The automatic generation method with tetrahedral elements was used for meshing. The solid model of the H-beam connecting rod has been meshed into 11260 elements and 20090 nodes.

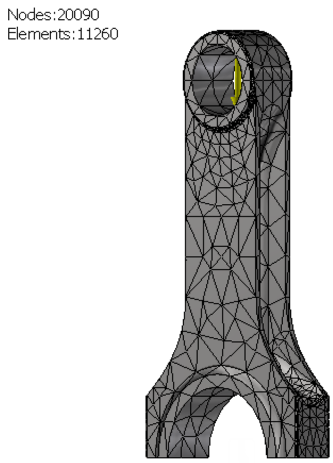


Figure 2. H-beam mesh

3.2. Boundary conditions

Constraints were applied according to the loadings in the connecting rod. Thus, the connecting rod is mainly subjected to compression and bending – because of the gas pressure inside the cylinder – as well as to tensile load – because of inertia (inertia increases when rotation speed and mass of oscillating parts increase). Inertia load is ignored when calculating the compressive load. In this assumption, calculations are more accurate since inertia load acts in opposite direction to the gas pressure load when the expansion in power stroke starts.

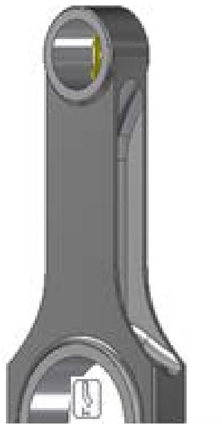
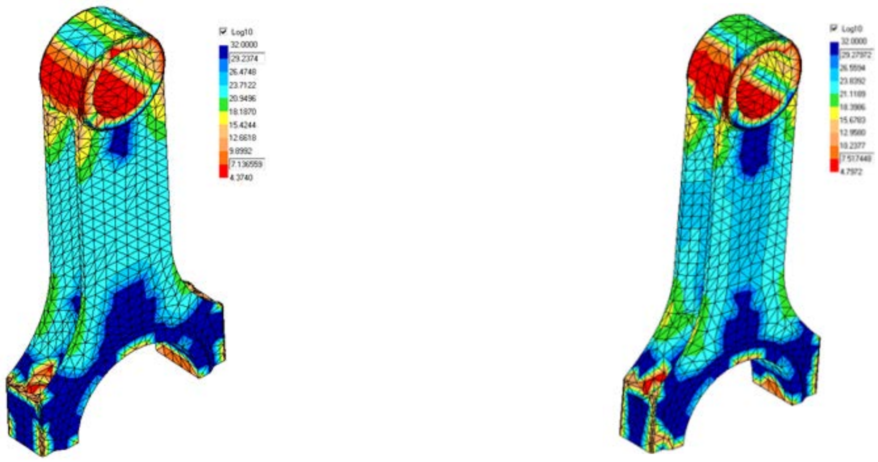


Figure 3. The constraints of the connecting rod

Based on the above aspects, the big end was considered fixed. The force calculated with formula (3) was applied to the connecting rod in vertical direction according to [10].

4. Results and Discussion

The simulation was performed in the two scenarios that are experienced in the real case. For the forged surface, the program defines Surface Factor coefficients of 0.429. If the connecting rod is processed after the forging process, the surface factor becomes 0.762. Autodesk Simulation calculates the safety factor or the cycles to failure. The calculation can be stopped if the safety factor has been reached or it can be done until the connecting rod is destroyed. Also, it may be imposed a certain "lifetime" to reach optimizations. Figure 4 illustrates the areas predisposed to fatigue. The critical areas are represented by the embedded (the threading of the end bolts) and the small end of the connecting rod.



a) b)

Figure 4. Graphic results: a) surface forged, b) surface machined

The failure is predicted after 62685 cycles at the maximum power of the vehicle. These would be equivalent to an operating time of 31.34 minutes at 4000 rpm at full throttle. The evolution of the micro-fissures, occurrence and propagation are represented in Figure 5.

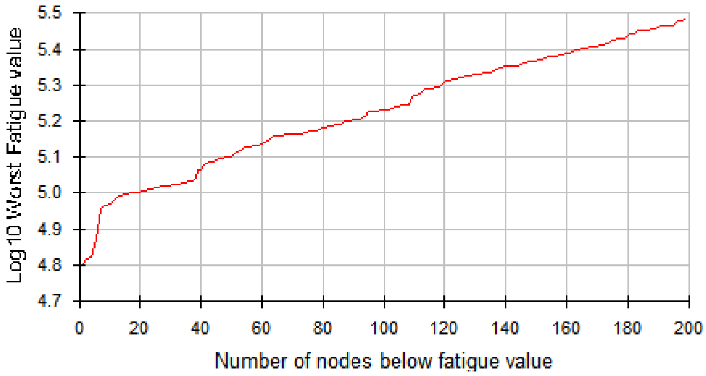


Figure 5. The evolution of micro-fissures for surface forged

If the surface of the connecting rod is mechanically machined, its roughness decreases, the surface factor increases to the value of 0.762, typical for a surface area processed by machining.

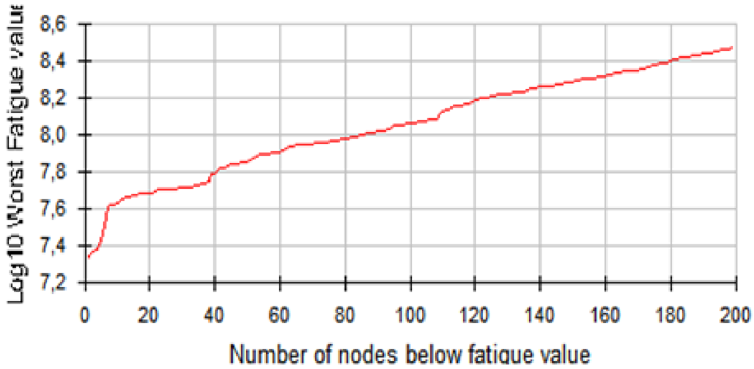


Figure 6. The evolution of micro-fissures for surface machined

In this simulation the failure is predicted after 2.16 x 107 cycles at the maximum power of the vehicle. These would be equivalent to an operating time of 180 hours at 4000 rpm at full throttle. The analysis was repeated for the AISI 1050 material, as shown in Table 2.

Table 2. Predicted number of cycles to failure

Material	Surface forged	Surface machined
AISI 4340	62.685 cycle	21.630.950 cycle
AISI 1050	15.766 cycle	171.684 cycle

Considering the external feature of the internal combustion engine, it was possible to determine the operating time of the engine until the shaped connecting rod was destroyed.

After simulation it can be noticed that the processing of all surfaces is delaying the appearance of the micro-fissures and its propagation, the small end being the most sensitive area. Regardless of the material used, the reliability of the elements subjected to alternating cycles can be increased by mechanically processing the surface, as shown in Figure 7.

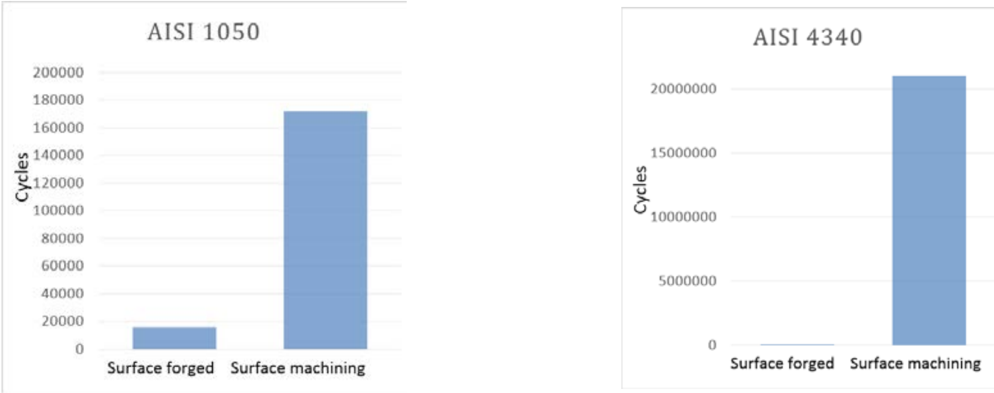


Figure 7. Working time of the connecting rod

5. Conclusions

The alternating forces to which the connecting rod is subjected, determine the aging of the material by the appearance of local plastic deformations favouring the occurrence of micro-fissures. The choice of material has a predominant role in determining the fatigue resistance of the connecting rod.

Surface quality of a connecting rod, resulting from processing, plays an important role in the degradation process by fatigue. The study shows that the surface mechanical processing can increase the life of the connecting rod for the two materials concerned.

The results obtained, following the FEM analysis, are in agreement with the experimental results, regarding the influence of the surface roughness on the fatigue strength and can be used to optimize the connecting rod manufacturing without testing prototypes series.

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