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FATIGUE LIFE ANALYSIS OF DIE FORGED RAILWAY AXLE MANUFACTURED FROM C30 STEEL

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Resume

With respect to the manufacturing process, different parts of one structural component can have different fatigue properties. In this study, the fatigue life of a railway axle manufactured from C30 steel by die forging is evaluated in the part of the axle bolster and axle body. According to the fatigue test results obtained at high frequency tension - compression fatigue tests (f ≈ 20 kHz, R = -1, T = 20 ± 5 °C), due to the higher level of work hardening of the axle bolster, the fatigue strength of material in this part is significantly higher than in the axle body. Different fatigue strength of these parts were observed despite the fact, that results of static tensile tests did not proved any important differences in the ultimate tensile strength, yield point and elongation.

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1. Introduction

Even due to years of intensive research, fatigue of metals is still a serious engineering problem and fatigue fractures appear very frequently on common cyclically loaded structural components. One of the reasons why the problem of material fatigue was not solved until today is, that fatigue life of material is influenced by many factors which can be divided into two types. One type of factors influencing the fatigue life are so called “internal” what means, that these are connected with the material characteristics e. g. microstructural state, work hardening level, the surface state and so on. The second type of factors include so called “external” which are represented by the working conditions, type of applied load and environment. Various combinations of these factors create the very complex character of fatigue damage which is the reason, why fatigue failures are still present in all types of structural components [1, 2].

With respect to the technology used for manufacturing, different microstructural and work hardening state can be present in just one structural component. This means, that different parts of the component can have different fatigue properties and tests done with use of specimens prepared from various parts are not equal [3, 4]. In this study is analysed fatigue life of specimens prepared from different parts of a railway axle, manufactured from steel C30.

2. Experimental material and procedures

As experimental material was used C30 steel obtained from a manufactured railway axle. Quantitative chemical analysis (Table 1) confirmed that the chemical composition fulfil the prescribed standard for this steel [5]. To produce a railway axle are used large steel ingots, which are hot-rolled to a bar-shaped semi-product. After hot-rolling is carried out homogenization annealing and normalization to homogenize the chemical composition and polyhedrization of the deformed material grains. The microstructure is then formed by polyhedric ferritic and pearlitic grains [6]. This bar is then die forged to a shape very close to the final axle and machined for a final axle. The resulting mechanical properties are determined by the degree of plastic deformation during the die forging process. To assure high value of plastic deformation strengthening, large degree of area reduction during the die forging process is necessary and the hot rolled bar diameter must be at least double size of the largest diameter of the final axle.

Deformation strengthening by die forging is more significant on the surface than in the core of the material. During machining a part of the strengthened surface layer is removed. The depth of removed layer is higher in the body of axle (the middle part of the axle with diameter of 160 mm in Figure 1, marked B) than in the axle bolster (the part of the axle with diameter of 185 mm, marked A in Figure 1). Removing of the surface layer also causes compressive residual stress relieve from the material. Also the stress relieve is more significant when deeper surface layer of material is machined of. Due to these facts, the mechanical properties of various parts of the axle can differ.

Table 1

C30 steel chemical composition in weight %.

C	**Mn**	**Si**	**P**	**S**	**Cu**	**Ni**	**Cr**	**Al**
0.26	0.96	0.35	0.019	0.02	0.05	0.02	0.07	0.017

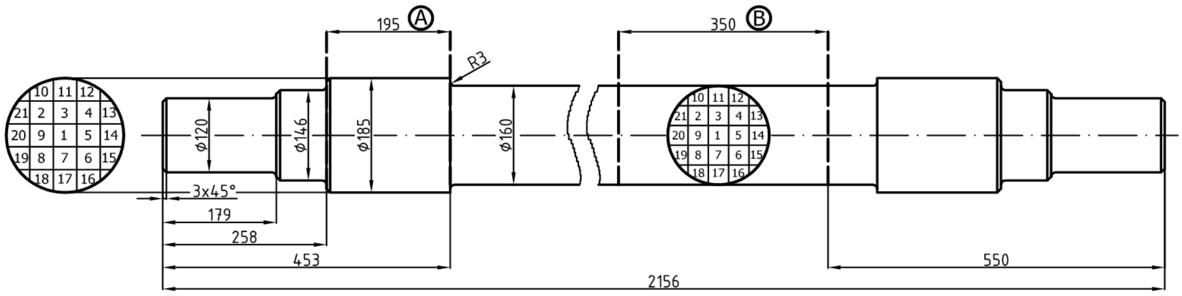
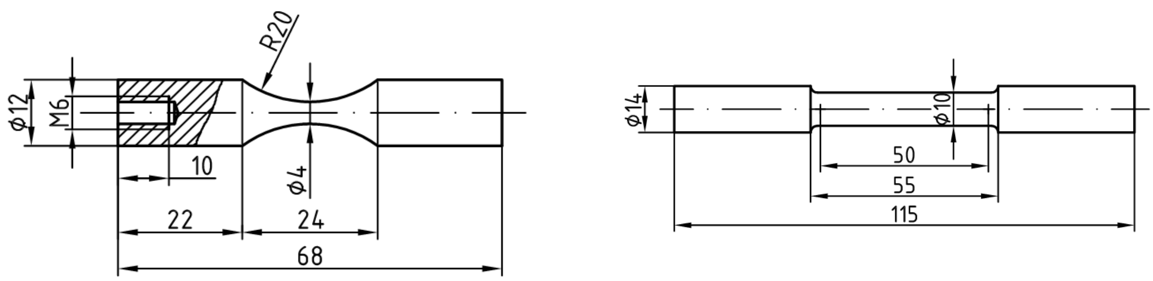


Fig. 1. Drawing of the tested railway axle and sketch of machining positions of the specimens.



a) *b)*

Fig. 2. Geometry of specimens used for fatigue (a) and tensile (b) tests.

Tensile test specimens and fatigue test specimens were machined from a new, not used railway axle (Figure 1). One set was machined from the axle bolster (marked A in Figure 1) and the second from the axle body (marked B in Figure 1). The position of the machined specimen, with respect to the cross section position is described by the drawn mesh in the circles representing the cross sections (Figure 1). Specimens for fatigue tests (Figure 2a) were machined from all 21 bars and from the rest of bars from positions marked 1, 3 and 11 were machined specimens for tensile tests (Figure 2b).

High frequency tension – compression fatigue tests (f ≈ 20 kHz, R = -1, T = 20 ± 5 °C) in high and ultra-high cycle region were carried out on high frequency experimental test device KAUP (complex acoustic fatigue strength) of the Department of Materials Engineering, University of Žilina, Slovakia (Figure 3) [7 - 9]. The electric power from ultrasonic generator is transferred to mechanical vibration in the piezo-ceramic converter of the ultrasonic horn. This causes vibration of both ends of the specimen at resonance frequency. The power is increased until requested displacement amplitude is obtained (measured by displacement amplitude reader on the end of the specimen). The displacement amplitude is in correlation with electric current value on the input of the piezo-ceramic converter. A current probe measures this value. Due to the heating of the specimen, the resonance frequency slightly changes during the measurement (increase of the temperature causes decrease of the resonance frequency). This is compensated by computer program, which reads the value of input current from the current probe and automatically adjusts the frequency of ultrasonic generator. By this close loop system the power input in the ultrasonic horn is constant, what keeps the stress amplitude of the specimen constant (the displacement amplitude can slightly change due to the process of deformation strengthening or softening during the cyclic loading).

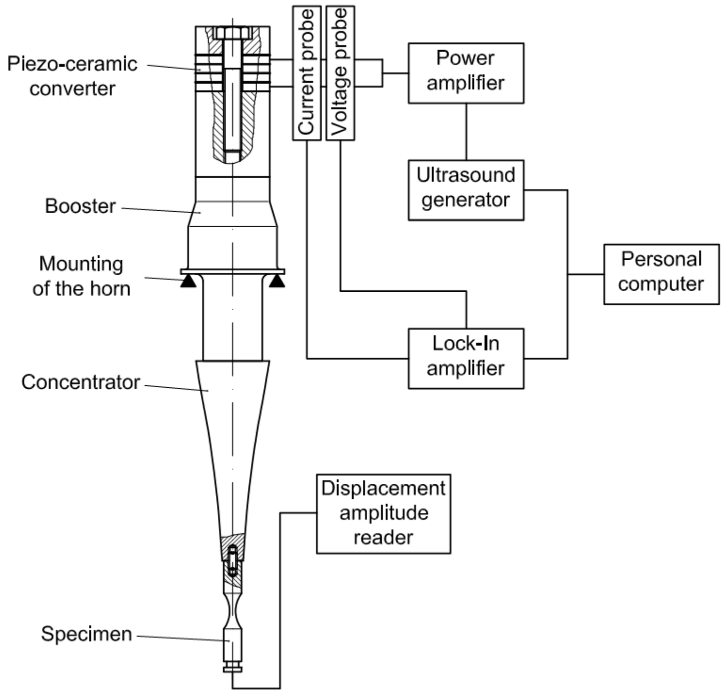


Fig. 3. KAUP device for ultrasonic fatigue test at frequency f ≈ 20 kHz.

Table 2

Results of tensile tests of steel C30.

Specimen No.	Axle bolster (A)			Axle body (B)		
	Yield point (MPa)	UTS (MPa)	Elongation (%)	Yield point (MPa)	UTS (MPa)	Elongation (%)
1	331.0	573.0	30.3	334.2	550.7	30.4
3	331.0	566.6	28.5	337.4	563.4	30.4
11	343.8	579.3	29.8	342.7	563.4	31.1
Average	335.2	572.9	29.5	338.1	559.1	30.6

3. Results and discussion

Tensile test results of specimens from positions 1, 3 and 11 obtained at deformation rate 2 $mm.min^{-1}$ are shown in Table 2. According to the results, there is no significant difference between the values of ultimate tensile strength (UTS) of specimens machined from different parts of the cross section and there is also no significant difference between the axle bolster and axle body.

The value of the yield point is higher for all specimens of the axle bolster when compared to the ones from axle body. The reason, why UTS does not change in different parts of the railway axle is because during the tensile test, similar plastic deformation strengthening mechanisms occur during the stretching of the specimen as when the axle is forged [6].

By indirect ultrasonic resonance method [7] was determined the modulus of elasticity of specimens machined from position 14 (Figure 1) from axle bolster (A) and axle body (B) and it can be observed, that the modulus of elasticity of specimen from axle bolster (A) is slightly higher than from the axle body (Table 3).

Higher yield point and modulus of elasticity is a result of higher pre-deformation (increase of the dislocation density) of the material in the area of axle bolster than in the axle body due to the manufacturing process.

Table 3

Modulus of elasticity of two parts of railway axle.

Specimen from	**$E \times 10^{11}$ (Pa)**
Axle bolster (A)	2.06505
Axle body (B)	2.05168

Results of fatigue tests, stress amplitude vs. number of cycles to failure (or run-out), S-N curves are shown in Figure 4. Results were approximated by the Basquin function (1) with use of least square method [10]:

$$\sigma_a = \sigma'_f \times (N)^b \qquad (1)$$

where σ_a is the stress amplitude, σ'_f is the coefficient of fatigue strength, N is the number of cycles to failure and b is the exponent of fatigue life curve. Coefficients of regression curves for both types of specimen are in Table 4.

Table 4

Regression curve coefficients.

Part of the axle	**σ'_f**	**b**
Axle bolster (A)	998	-0.085
Axle body (B)	649	-0.053

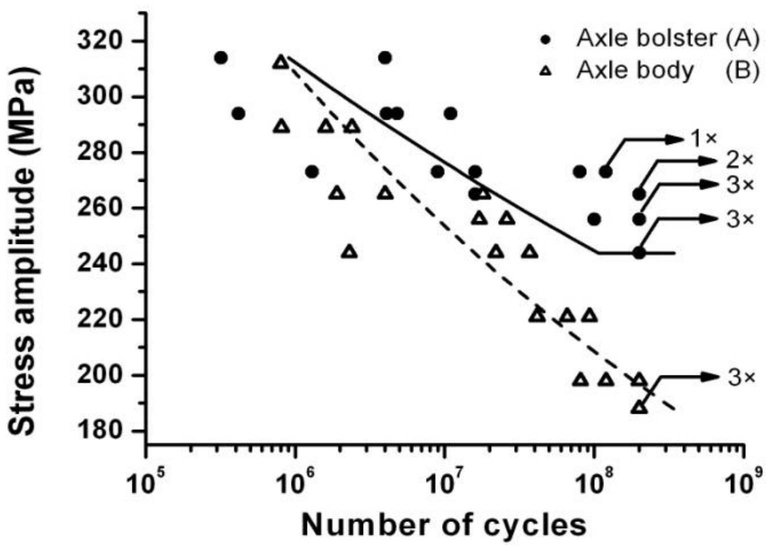


Fig. 4. Comparison of fatigue life of specimens machined from axle bolster and axle body, steel C30.

According to the results of fatigue tests (Figure 4), the fatigue strength of specimens machined from the axle bolster is higher than of the specimens machined from the axle body. Specimens fracture was observed even beyond the conventional fatigue limit, usually evaluated for N = 10^7 cycles and the fatigue limit was estimated for N = 2 × 10^8 cycles, where the fatigue test was terminated and marked as run-out. Specimens were machined from the whole cross section of the axle parts, which had different level of deformation. This probably caused the high scatter of the results, but in general, the higher level of deformation in the axle bolster resulted in the fatigue limit (for N = 2 × 10^8 cycles) σ_a = 244 MPa, which is significantly higher than for the axle body, where the fatigue limit was σ_a = 188 MPa. According to this, different parts of one component, even when it is from one material and manufactured by one technology, can have significantly different fatigue properties and these are not always reflected by other standard tests e. g. tensile test [11, 12].

4. Conclusions

Based on experimental results obtained by tensile and fatigue tests on C30 steel obtained from a two parts of a railway axle (axle bolster and axle body) can be concluded:

- there is no significant difference in UTS between specimens machined from axle bolster and axle body and there was also no significant influence of the cross section position, from which specimens were prepared,

- due to the higher level of deformation, the yield point and modulus of elasticity of the material in the area of the axle bolster is slightly higher than from material in axle body,

- specimens machined from the axle bolster show a significantly higher fatigue limit for N = 2 × 10^8 cycles with value of σ_a = 244 MPa than for specimens machined from axle body with value of σ_a = 188 MPa,

- different deformation levels of materials created during the manufacturing process can result to very different fatigue properties in various parts of the component and these can't be reliably verified by other common methods for evaluation of mechanical properties.

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