FATIGUE PROPERTIES OF WEAR RESISTANT MARTENSITIC STEEL

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Abstract

In the automotive industry about 60% of mass of the car continue to represent structural elements, formed of steel plates of increasing strength while maintaining good plastic characteristics and susceptibility to stamping. Constructors seek to reduce the mass of cars and semi-trailers and it is possible through the use of fine-grained and quench and tempered high strength steels. An important factor that guarantees safety of use is the knowledge about safe operation life. In order to answer to this question are needed relevant studies including fatigue tests. The article presents the results of fatigue tests in the range of low and high cycle fatigue of wear resistant quenched and tempered martensitic steel on example of Hardox steel 400 and 450. There is also discussed the influence of grain size on the shape of fatigue curves. Obtained results of wear resistant martensitic steels are compared with the results of fatigue tests of S355J2 structural steel.

Keywords: Hardox, wear resistant steel, fatigue, trailers construction

1. INTRODUCTION

The concept of material fatigue can be defined as the material properties process of changes caused by the cyclic load [1]. According to [2, 3], material fatigue is a defects accumulation process of a continuous form in sufficiently long time under the influence of variable mechanical stresses, which causes nucleation and propagation of cracks, and ends in failure of the material. Low cycle fatigue tests are carried out at relatively high stress and low frequency of changes in the stress (up to 10 Hz) and with fatigue life about $N_C \approx 5.10^4$ cycles. These research parameters reproduce the conditions of construction use under the influence of loads which are large in value, but not often repeated. Defect or failure of the material during low cycle fatigue occurs in conditions of elastic and plastic strain, as compared with high fatigue cycles for which generally elastic strain is relevant [2÷5].

Basic characteristics of fatigue are obtained after the appointment of the fatigue curve, which is a graphical representation of the relationship between the level of σ_a stress and the fatigue life N_f in tests carried out under the same conditions. The process of fatigue is influenced by several factors, which may significantly delay or accelerate the fatigue process. These factors can be divided into internal and external ones [6÷10]. Internal factors can include: the structure of the material, chemical composition, grain size, specimen size, shape and distribution of non-metallic inclusions. The external factors can include: frequency, cycle asymmetry, the average stress and stress condition.

Malle with co-authors [11], while researching steel with different grain size (3 and 7μm), linked the grain size with the load that causes fatigue. He found out that to cause the fatigue effect in the fine grained steel there is the need for higher stresses, whereas coarse grained steel has lower resistance to crack propagation. Fracture specimens were shown in **Fig. 1**, and the fatigue of the two variants of graphs was shown in **Fig. 2**. The grain effect size depending on the da / dN = f (K_a) function was shown in **Fig. 3**.

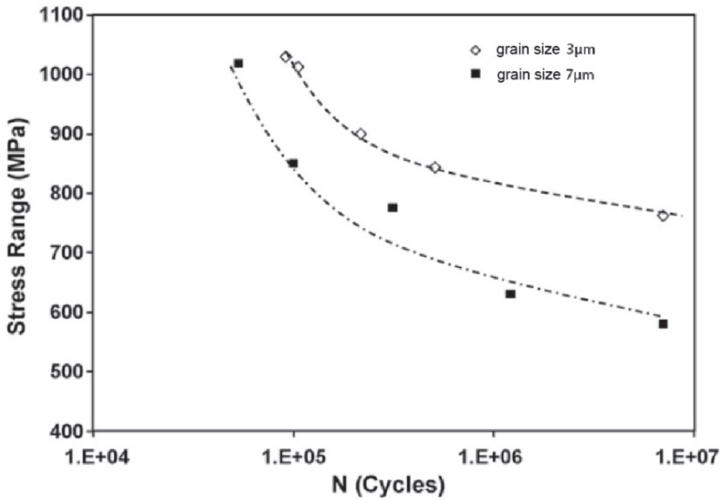

Fig. 1 Fatigue diagram of steel with a grain size 3 and 7μm [11]

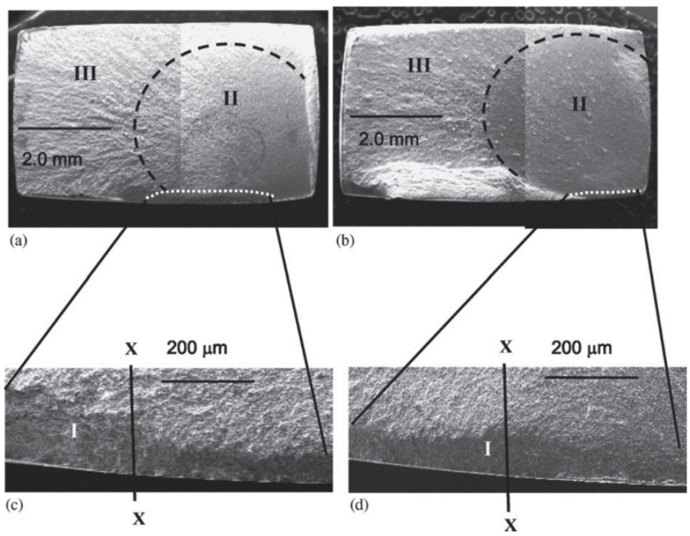

Fig. 2 Fracture surface of steel with a, c- a grain size 7μm, b, d - a grain size 3 μm [11]

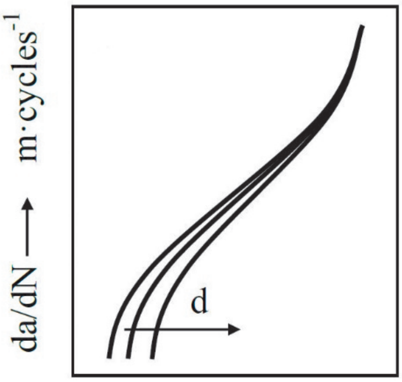

Fig. 3 The influence of different factors on the da /dN = f (K_a) function course: the size of the grains

2. MATERIAL AND EXPERIMENTAL PROCEDURES

As experimental materials were used two steels of Hardox type 400 and 450 as well as structural steel S355J2. From these steels were made specimens for research of mechanical properties and fatigue properties. Control analysis of the chemical composition confirms that the content of chemical elements corresponds to the parameters provided by the manufacturer in sheet materials. According to the manufacturer information, Hardox steels are defined as "high-quality abrasion-resistant steels". They are characterized by high resistance to abrasive wear, the possibility of specialized machining tools, good weldability, excellent mechanical properties and resistance to impact loads. Hardox steels are produced in six types. Among the six types of materials most widely used in the construction of tippers is Hardox 400 and 450. In the enterprise Wielton S.A. Hardox steels found application in: the bottom and sides of open load-carrying body, welded sides of the motor-car body, mudguards, linning of the bottom and sides. Hardox steel microstructures, mechanical properties are show in **Table 1** and **Figs. 4 and 5**. As a result of carried out analysis of microstructure it was found that Hardox 400 and 450 steel has a structure of tempered martensite. Steels that have been tested are characterized by coarsely acicular martensitic structure.

Table 1 Hardox steel mechanical properties

Steel	Hardness	$R_{p0.2}$	R_m	A_5	KV_{-40}
	HB	MPa	MPa	%	J
Hardox 400	370÷430	1000	1250	10	45
Hardox 450	425÷475	1200	1400	10	40

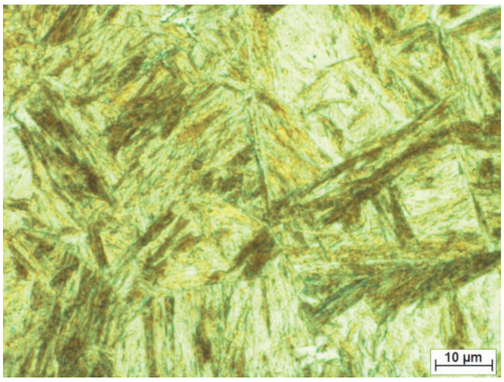

Fig. 4 Microstructure of Hardox 400 steel

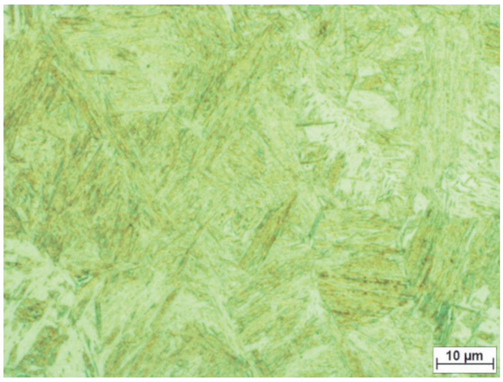

Fig. 5 Microstructure of Hardox 450 steel

While previous studies the experimental results were obtained and identified key aspects of fatigue damage of various materials. Amplitude dependence of the number of cycles to fracture (as S - N) and the resistance to fatigue are the main parameters for assessing the fatigue of structural steels [12÷15]. Fatigue characteristics (dependence $\sigma = f(N)$) of Hardox 400 steel have been determined at low testing frequency. The test was performed on Rotoflex device in a research laboratory of the Department of Materials Engineering at University of Zilina in Zilina. The device will make it possible to load the specimen in such a way that the bending moment, along the entire working length of the specimen, has a constant value.

Schematic representation of the test apparatus, along with the course of the bending moment and load distribution on the cross section was shown in **Fig. 6**. The asymmetry factor of load cycle is always for such tests R = -1.

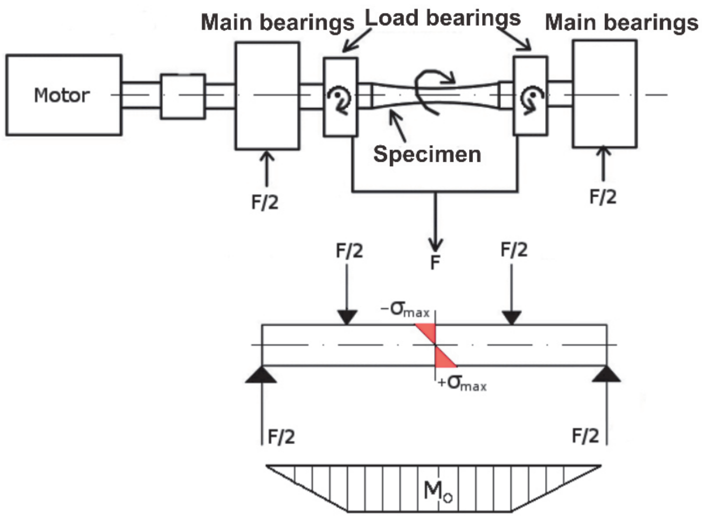

Fig. 6 Rotoflex - apparatus for testing flexural strength in the rotation mode

For the low-frequency fatigue test were used specimens with shape and dimensions shown in **Fig. 7**. Obtained results of fatigue strength of specimens are strongly dependent on the state of their surface. Therefore, the working part of the specimens has to be prepared very carefully, with roughness parameter of R_a = 0.32. The specimens were made of structural steels constituting elements of tipper trucks and Lorries in the audited company. Research was carried out in accordance with the procedure described in [4]. Specimens, their shape and size were made in accordance with the requirements of STN 42 0362 standard.

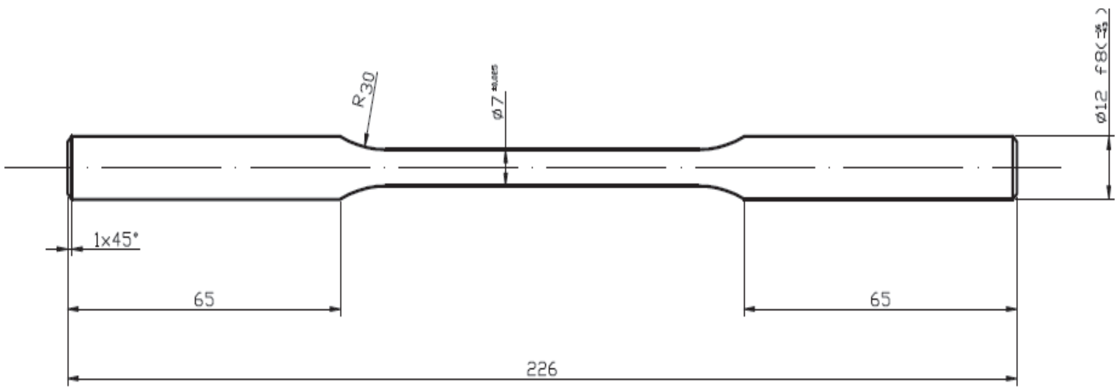

Fig. 7 The shape and dimensions of the test specimen for the device Rotoflex

In order to determine fatigue strength of the material, 12 specimens of S355 structural steel and Hardox 400 and 450 were subjected to the test of low-cycle fatigue. Fatigue tests were carried out on the machine Rotoflex implementing load in bending on rotation mode. In the load cycle asymmetry coefficient was R = -1, with load frequency of 40 Hz and an ambient temperature of 20 ° C ± 3 ° C. Working part of specimens during the test was cooled by fans.

3. RESULT AND DISCUSSION

The fatigue phenomenon is a progressive, localized, permanent structural change that occurs in materials subjected to repeated stresses and strains. For a given material the relation between applied cyclic stress amplitude and the number of cycles to failure is customarily identified from its S-N diagram in which the stress amplitude is plotted with the corresponding number of cycles N, to failure using a semi logarithmic scale. **Fig. 8** shows the results of fatigue tests (Low-Frequency Fatigue Testing) of Hardox 400, Hardox 450 and S355J2 structural steel. The number of cycles of stress that the metal can endure before failure increases with a decreasing stress amplitude and for some engineering materials the S-N curve becomes horizontal at a certain limiting stress known as the fatigue limit or endurance limit. Below the fatigue limit, the material will not fail in an infinite number of cycles. Most nonferrous metals do not exhibit a fatigue limit. Instead, their S-N curves continue to drop at a slow rate at high numbers of cycles.

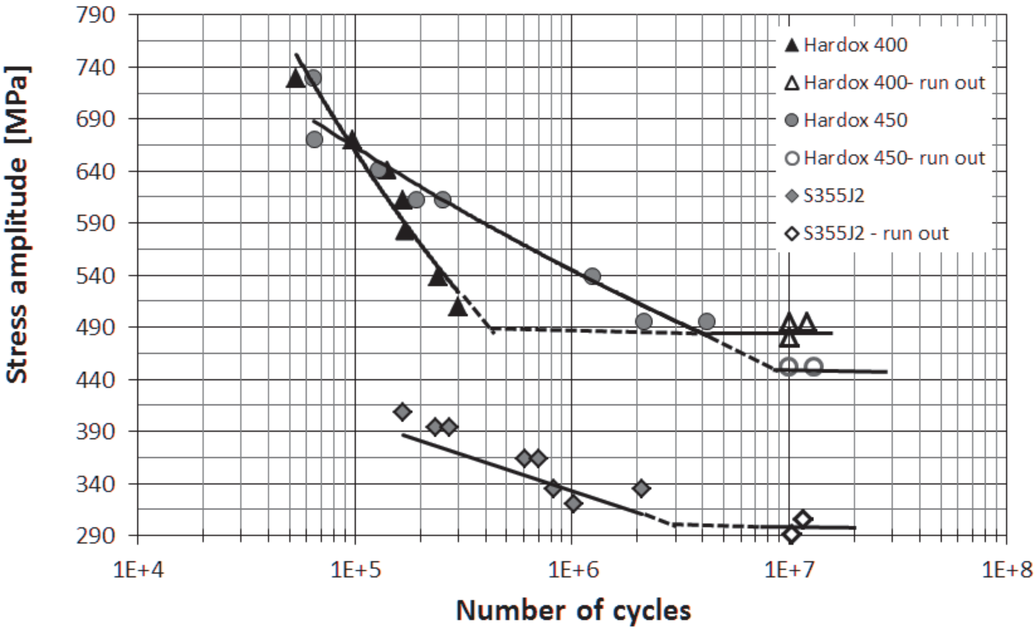

Fig. 8 Fatigue lifetime of Hardox 400, 450 steel and S355 steel

The tests results are presented in the form of Wohler curve (**Fig. 8**). Based on the obtained results the fatigue limits for Hardox 400 reached the level 490 MPa, stress amplitude decreases about $\Delta\sigma_a$ = 233 MPa. Fatigue limit of the other tested materials (Hardox 450) clearly reached the level σ_C = 460 MPa of load cycles N = 10^7. The results are close to each other and the difference in fatigue strength of Hardox 400 and 450 is due to the higher strength and toughness properties of steel Hardox 450. In the case of specimens made from Hardox 400 steel the stress amplitude decreases about $\Delta\sigma_a$ = 277 MPa (in the range of N = 10^4 ↔ N = 10^5 cycles). The 355J2 steel showed fatigue strength of 290 MPa.

CONCLUSION

Material resistance to fatigue depends on the state of the microstructure, of phase composition, the presence of factors affecting the continuity of the materials and the stress level in the different zones. The characteristics of fatigue strength are more sensitive to structural changes compare to other mechanical properties. In the greatest extent sensitive to a change of the structure is resistance to fatigue crack propagation in all ranges of the fatigue crack kinetics. In the greatest extent sensitive to a change of the structure is the fatigue resistance in low-amplitude range. In case of Hardox steel we are dealing with the after-martensite structure a little bit different from the other microstructures occurring in quenched steels [16]. In the opposite to standard martensitic steels the microstucture of Hardox is characteristic by coarse acicular martensitic colonies. The data obtained indicate the advantage of martensitic steel of Hardox type in aspect of fatigue resistance over conventional structural steels such as S355J. Constructors of the automotive industry increasingly date back to the steels from the group of HSLA steels but also increasingly from the group of UHSS (Ultra High Strength Steel) designed to lower the kerb weight of the vehicles, semi-trailers which is crucial for the transportation of cargo. Lower kerb weight translates into the possibility of transport of greater mass of cargo. It is therefore necessary to provide engineers with information on fatigue properties and determine safe service life of individual structural components. Presented results are output point to create the fatigue curve for steel of Hardox type in low-cycle range but also outside the conventional number of cycles 10^7 in the range of ultra-giga cycle.

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