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FATIGUE PROPERTIES OF FINE-GRAINED STEELS APPLIED IN COMPONENTS OF SEMITRAILERS

WŁASNOŚCI ZMĘCZENIOWE STALI DROBNOZIARNISTYCH W KONSTRUKCJI NACZEP SAMOCHODOWYCH

A b s t r a c t

The article presents preliminary fatigue test results of selected grades of constructional steel used for producing elements of semitrailers and trailers, which are made by WIELTON S.A. company. Demand for fatigue tests of fine-grained steel has been reported by designers looking for new applications of high strength steel in new constructions. Fractorapnic analysis of the selected elements proved strong relation between fatigue structure and microstructure of the materials.

Keywords: fatigue properties, trailers construction, higher-strength steel, fractographic analysis

S t r e s z c z e n i e

W niniejszym artykule dokonano analizy badań zmęczeniowych dla stali drobnoziarnistych w zakresie zmęczenia wysokocyklowego, materiałów konstrukcyjnych naczep samochodowych produkowanych przez firmę WIELTON S.A. Prowadzone badania są wynikiem zainteresowania konstruktorów poszukiwaniem nowych możliwości wykorzystania stali wysokowytrzymałych w nowych modelach naczep. Analiza fraktograficzna wybranych elementów potwierdza silną zależność struktury przełomu zmęczeniowego z mikrostrukturą materiału.

Słowa kluczowe: własności zmęczeniowe, konstrukcje naczep, stale wysokowytrzymałe, analiza fraktograficzna

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1. Introduction

In spite of progress and development in science and technology designers have a great deal of grades of materials with different service properties at their disposal, from which they can select depending on the demands on the elements being designed. Satisfying all technical and operational requirements is sometimes difficult, and even impossible. The durability of parts operated during driving and carrying cargoes is connected with complex fatigue and tribological processes resulting from the mode of operation of individual subassemblies and with complex energy interaction processes that occur between the semitrailer's suspension and construction, as well as the load itself. This gives rise to the issue of both appropriate optimization of the part's design and proper selection of its material (in terms of chemical composition and phase structure) in order to increase operational quality and durability [1–4]. The article presents the analysis of preliminary fatigue tests results of two structural steel grades used in structural components of trailers, wagons, farm devices, etc. Getting to know properties of the materials is meant to answer the question whether it is possible to substitute traditional steel with high strength steel, resistant to wear and easily cold-shaped fine-grained steel.

The strategy of companies manufacturing means of transport, including WIELTON S.A., is to design and produce more efficient transport units by using lighter constructions, exchangeable modules and increased specialization of transport semitrailers. The design departments of the company, in cooperation with their partners, are conducting work on the application of new materials for constructional elements of semitrailers with the aim of reducing unladen mass and fuel consumption, increasing the tonnage of transported cargo, and lengthening the safe operation period [5, 6]. The research results will provide a basis for determining new applications of these materials and using them for constructional elements of semitrailers in order to increase their reliability and decrease the complete vehicle kerb weigh.

2. Experimental material

Steels Hardox (400 and 450) and Strenx 700MC have been used for the tests. The samples taken from Hardox 400 and 450 steel plate (13 mm thick) and Strenx 700MC steel plate (10 mm thick) were subjected to chemical analysis. The steel sheets were obtained directly from the manufacturer (SSAB Oxelosund Steel Mill) and taken from the WIELTON S.A. company's storage. The chemical analysis was made by means of the emission spectrometry method on an ICP (JY38S) emission spectrometer using a fast recording system, IMAGE.

The chemical analysis results were compared with the data provided by the high-strength steel manufacturer. The comparative analysis of chemical composition has confirmed that the contents of chemical elements correspond to the parameters provided for by the manufacturer in the material card. The increase in hardenability of these steels is also caused by carbide-forming elements (Cr, Mo) retarding the tempering processes. This is due to the coagulation rate of chromium and molybdenum carbides being lower than that of cementite. The presence of molybdenum (at min. 0.20% Mo) is important, all the more so because chromium (just like phosphorus and other trace admixtures) increases the susceptibility to temper brittleness. Also nickel and manganese in the presence of chromium are favourable to this process. A function similar to that of molybdenum in Hardox steel is performed by boron, which strongly increases hardenability in pro-eutectoid steels. This effect is the more intensive the finer the grain occurring in the steel and the lower the carbon content of the steel (steels of the Hardox group are produced as fine-grained) [7, 8].

a) b)

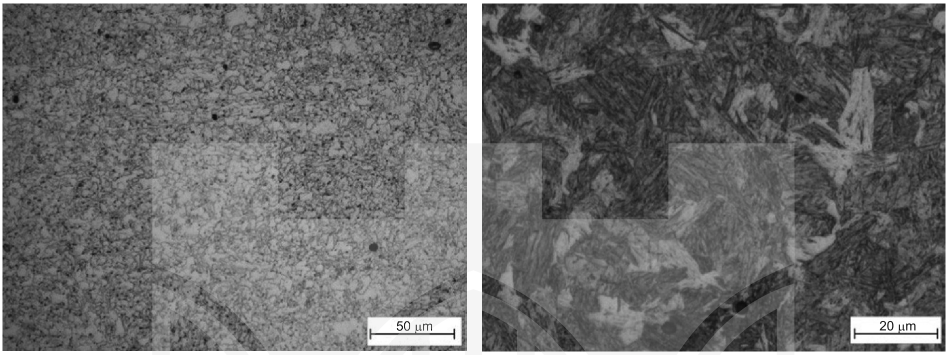

Fig. 1. Microstructure of the analyzed steel materials in the state as delivered, etched with 1% Nital: a) Strenx 700MC, b) Hardox 400

The observation of Strenx 700MC steel samples (Fig. 1a) showed that the steel was characterized by a fine-grained structure. The presented microstructure image revealed sparse titanium nitride particles with a regular geometric shape. The test material is also characterized by the occurrence of few inclusions in the form of black manganese sulphide (MnS) particles [3, 5]. The observations of the samples of Hardox 400 steel in the state as delivered (and etched with Nital) showed a structure of tempered martensite and retained austenite (Fig 1b). The structure of Hardox 400 steel exhibits high homogeneity over the entire cross-section; only few small inclusions were observed, which were unevenly distributed within the sample space. The analysis of the Hardox 450 steel microstructure also showed the occurrence of a martensitic structure.

The results of fatigue testing of specimens are strongly dependent on their surface. Therefore, the specimen working part must be prepared very carefully to have the surface roughness parameter of Ra – 0.32. During fatigue testing on the ROTOFLEX machine, the load cycle asymmetry factor was $R = -1$, and the specimens were loaded at the frequency of 30 Hz, at the ambient temperature of 20°C ± 10°C. The specimen working part was cooled during testing by means of fans. Based on the obtained results, the curve of the applied load amplitude versus the number of cycles to specimen fracture, $\sigma_a = f(N)$, was plotted. The results of the tests carried out are illustrated in Fig. 2.

Figure 3 represents the fatigue testing results of the materials analysis in a high-cycle range [9, 10]. The experimentally determined Whöler curve shows a decrease in the magnitude of specimen fracture stress with the increase in the number of load variation cycles up to the fatigue limit of Strenx 700MC steel (440 MPa). For the examined Hardox steels, the occurrence of a fatigue limit can be clearly seen, which for Hardox 400 steel is at the level of 490 MPa, while for Hardox 450 steel at 460 MPa. The obtained results are similar; the difference is caused by the higher mechanical properties and hardness of Hardox 450 steel.

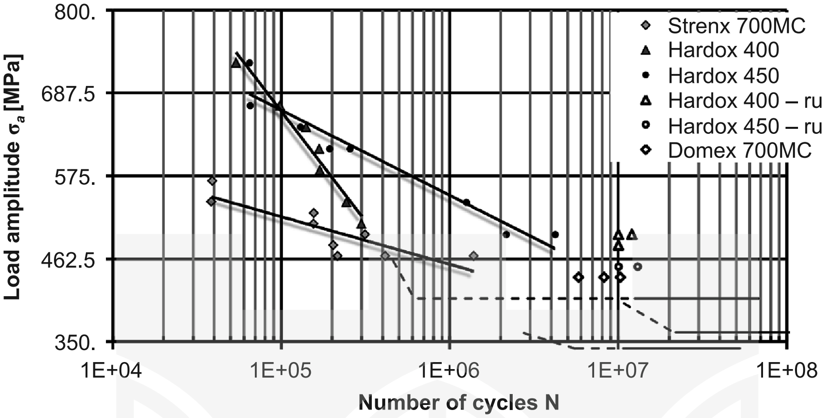

Fig. 2. The fatigue life of researched steels; fatigue test, rotary bending in the high--cycle interval [f = 30 Hz, T = 20°C ± 10°C, R = –1]

3. Fractographic analysis of fatigue fractures

For the fractographic analysis, a VEGA 3 SB scanning electron microscope (SEM) was used. A fatigue fracture analysis was made for each series of Strenx 700MC, Hardox 450 and Hardox 400 steel specimens after fatigue testing [11, 12].

For almost all specimens, the initiation of fatigue cracks occurred on the specimen surface (Fig. 3), with the initiation location being dependent on the surface type (surface development degree), stress amplitude σ_a, as well as number of cycles to specimen failure,

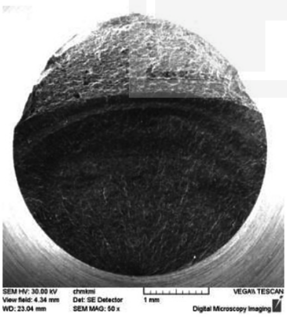

Fig. 3. Fatigue fracture of specimens on a macro scale: surface fatigue crack initiation for steel Hardox 450

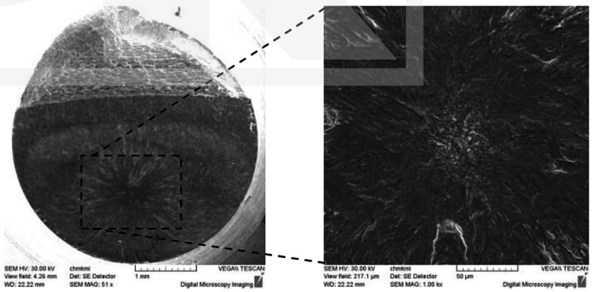

Fig. 4. A fracture of the Hardox 450 steel specimen on a macro scale; sub-surface fatigue crack initiation with a distinct crack initiation with a “fish-eye”

N. All the specimens except for 2 specimens from Hardox 450 steel were broken due to the initiation of fatigue cracks from the specimen surface as a result of formation of intrusions and extrusions. No more sub-surface fatigue crack initiation was observed.

The determination of the type of inclusion that was the point of stress concentration and the "fish-eye" mechanism initiation location for Hardox 450 steel was impossible (Fig. 4). The reason for this could be sought in the long-lasting fatigue effect (crack opening and closing), which resulted in the complete refinement of the inclusion particles.

On the surface of fatigue fractures of the test specimens made of Strenx steel, there occurs a transcrystalline fatigue fracture of a very fine morphology, which is characteristic for fine-grained steels. The character of the fatigue fracture for this steel in the unstable fatigue crack growth region before the final fracture region – radial steps and secondary cracks occur here. The final fracture region is characterized by a ductile fatigue fracture with a dimple morphology.

The examined fatigue fractures of Hardox 400 steel are characterized by a transcrystalline fracture of tempered martensite with a locally occurring intercrystalline fracture in the form of isolated intercrystalline facets, sometimes occurring on the surface of the fatigue fracture. The amount of intercrystalline failure on the fatigue fracture surface generally did not exceed 1%. In the stable fatigue crack propagation region, the propagation followed transcrystalline mechanisms, which was reflected in the **occurrence of striation** oriented perpendicularly to the fatigue crack propagation direction. The occurrence of fatigue striation is not typical for the fatigue fracture of high-strength materials. On the test specimen fracture, the increase in the distances between striations towards the final fracture regions can be seen.

4. Conclusions

High-strength steels of the Hardox type are distinguished by high sensibility to the occurrence of notches; this is associated with the presence of martensitic structure. During testing, particular attention should be given to inclusions, and particularly to their shape and size. The following rule applies: the harder and tougher the steel is the more it is prone to the occurrence of inclusions. In the case of Hardox 400 steel, whose matrix is by 50 HB softer than Hardox 450 steel, no impact of inclusions on fatigue failure was observed, and the initiation of all fatigue cracks took place on the specimen surface, following the same mechanism as for Strenx 700MC steels [13].

The results of fatigue tests of the investigated steels, carried out in the high-cycle range on a Rotoflex machine – the relationship $\sigma_a = f(N)$ assume the classic shape of the Wohler curve with a distinct fatigue limit. Determined from the experimental results, the curve showed a decrease in the magnitudes of stress amplitude σ_a with the increase in the number of load cycles N up to the fatigue limit level. The determination of the fatigue strength of new materials is crucial for assuring the reliability of designed equipment and extending its service life.

The obtained results have provided a basis for the development of new application capabilities of high-strength fine-grained steels to be used in the structural parts of machinery and equipment, as well as for the improvement of simulation models of automotive semitrailer loading and operation. Research on fatigue testing in the high and ultra-high cycle fatigue is becoming increasingly important, taking into account the increased exploitation of constructed machines and devices, as well as their extended service life. Strength testing of high-strength steels has confirmed their high property declared by the manufacturer. New semi-Master series, which are manufactured by WIELTON S.A., represent new directions of development of the company. Possibilities of using the tested materials in the construction of semi-trailers manufactured by the company have been confirmed by the results of all the material research. Hardox has been used in parts of boxes semi-hoppers (such as: floor panels, side panels, front and rear wall flaps) in the parts in which high resistance to abrasion is an important feature. Steel Strenx 700MC can be used to make many items of chassis trailers discharge (chassis frame, the mounting plates and cross beams), a basic requirement in relation to this material in the first place being good weldability.

References

[1] Szataniak P., Novy F., Ulewicz R., *Fatigue Properties and Application Options of the Fine-Grained Steel of DOMEX Type*, Transcom Proc. of 11th Europ. Conf. of Young Researchers and Scientists. Sec. 5 – Material Engineering Mechanical Engineering Technologies, 2015, 309-314.

[2] Armigliato A., *Light Weighting in Commercial Transport*, Conference "Connecting Innovations. Wielton", Warsaw, 3–4 June 2014, presentation.

[3] Barani A.A., Ponge D., Raabe D., *Strong and Ductile Martensitic Steels for Automotive Applications*, Steel Research International, vol. **77** (9–10), 2006, 704-711.

[4] Sońta G., Dudek A., Selejdak J., Ulewicz R., *Analysis of Structure of Elements for Automotive Industry*, App. Mech. and Mat., vol. **712**, 2015, 81-86.

[5] Ulewicz R., Szataniak P., Novy F., *Fatigue Properties of Wear Resistant Martensitic Steel*, Proc. of 23rd Int. Conf. on Metallurgy and Materials METAL 2014, 21–23 May 2014, Brno, 784-789.

[6] Trško L., Bokůvka O., Nový F., Lago J., *Quality and fatigue characteristics relation*, Production Engineering Archives, vol. **10**, 2016, 9-12.

[7] Mroziński S., *Stabilizacja własności cyklicznych metali i jej wpływ na trwałość zmęczeniową*, Wydawnictwa Uczelniane Uniwersytetu Technologiczno-Przyrodniczego, Bydgoszcz 2008 [in Polish].

[8] Blicharski M., *Inżynieria materiałowa. Stal*, Wydawnictwa Naukowo-Techniczne, Warszawa 2004 [in Polish].

[9] Kokavec M., Konečná R., Nicoletto G., *Nodular cast iron fatigue lifetime in cyclic plane bending*, Materials Engineering – Materiálové inžinierstvo, vol. **19** (3), 2012, 104-109.

[10] Bokůvka O., Nový F., Mintach R., Činčala M., *Influence of Loading Type on the Shape of Lifetime Curve*, International Journal of Applied Mechanics and Engineering, vol. **15** (2), 2010, 321-328.

[11] Ulewicz R. Szataniak P., *Fatigue Cracks of Strenx Steel*, Materials Today: Proceedings, vol. **3** (4), 2016, 1195-1198.

[12] Szataniak P., Mazur M., Ulewicz R., Novy F., *Fractographic analysis of Hardox steels research in the field of high-cycle fatigue regime*, Communications Scientific Letters of the University of Žilina, **18**, 2016, 89-92.

[13] Mazur M., Ulewicz R., Bokůvka O., *Mechanical and Fatigue Properties of Hardox 400 and 450 Steels*, Advanced Manufacturing and Repairing Technologies in Vehicle Industry – 30th International Colloquium, Visegrád, Hungary 2013, 61-66.