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ANALYSIS OF STRENGTH AND FATIGUE PROPERTIES OF CONSTRU0CTION MATERIALS FOR MANUFACTURING THE PARTS OF SEMI-TRAILERS

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Abstract:
The article presents the preliminary tests results of three high-strength steels, which are used in structural elements of semi-trailer's construction. Paper presents an analysis of tensile and fatigue test results of high-strength steels like Hardox 400, Hardox 450 and Strenx 700MC. The fatigue tests are in the range from 10^4 to 10^7 number of cycles of applied load with a frequency of 40 Hz. The Wöhler curve shows the results of the fatigue properties of these steels, which are used in the construction of vehicles. Fatigue fractures were subjected to fractographic analysis in order to determine the mechanism of fatigue crack propagation. Fractographic analysis confirmed no effect of inclusions on the test results.

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1. INTRODUCTION

The subject-matter of this research was selected in response to demands for the fatigue characteristics of fine-grained steels, expressed by constructors looking for new applications of that group of steels [1,2]. Based on authors' own research and data from the manufacturer, the material characteristics of the steels Hardox (400 and 450) and Strenx 700MC are were presented. Nowadays, those steels are more and more used in design of modern semi-trailers constructions. High mechanical properties and durability of this type of steel are their advantage. The combination of these features enables the construction of lighter semi-trailer's components, which would result in a semi-vehicle with a lower net weight.

The construction departments of the semi-trailers vehicles manufacturers are working on application of the new materials in the semi-trailers construction's elements. The adopted objectives of the research being conducted include: reducing the kerb (curb) weight of a semi-trailer, reducing the use of fuel by a transport set, increasing the carried load weight, and extending the safe operating period of a vehicle. Research and development work are backed up by specialist simulation programs, and the obtained outcomes of the fatigue testing of high-strength steels could be used to verify the accuracy of the adopted mathematical models. In the design of structures, an important element is the issue of resistance to the appearing variable dynamic loads, which are characterized by very rapid changes. Those elements are the guidelines for designers to create structures of new materials. The impact study of the structure material is intended to state the material quality after the heat treatment and the tendency of the material to suffer the brittle fracture state under the influence of load at different working temperatures [3].

2. MATERIAL FOR RESEARCH

The producer of the Hardox and Strenx steels, the SSAB Oxelösund plant, specializes in production of the high-strength steels, which are obtained as the result of application of the special rapid cooling technique. In accordance with the data of the producer, the Hardox steels are supplied after hardening in water and tempering within the following scope of temperatures: 200 –

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Table 1. Chemical composition and mechanical properties of researched materials

Material	*Chemical composition (max %)*									*Mechanical properties*		
										R_e *(MPa)*	R_m *(MPa)*	A5 *(%)*
Hardox 400	C	Si	Mn	P	S	Cr	Ni	Mo	B	1226	1257	12,5
	0.13	0.30	0.95	0.012	0.002	0.25	0.06	0.04	0.002			
Hardox 450	C	Si	Mn	P	S	Cr	Ni	Mo	B	1425	1560	13,5
	0.20	0.39	0.80	0.005	0.005	0.45	0.05	0.01	0.001			
Strenx 700MC	C	Si	Mn	P	S	Al	Nb	V	Ti	796	850	15,5
	0.08	0.10	1.67	0.018	0.0037	0.015	0.06	0.014	0.015			

700 °C [4]. The Strenx 700MC steel for cold shaping is a hot-rolled steel formed in a thermal-mechanical process, in which the processes of heating, rolling and cooling are under careful supervision. The chemical composition of that steel, containing little carbon and manganese, is precisely complemented by alloying enhancers such as niobium, titanium or vanadium [5].

This article presents results of tests on considered steels. The chemical composition and mechanical properties, as declared by the manufacturer, were presented in Tab. 1.

Characteristics of chemical composition declared by the manufacturer are consistent with analytical studies. Mechanical properties obtained in this research confirm the parameters of steel that are declared by the manufacturer in the Safety Data Sheet.

3. METHODOLOGY OF RESEARCH

Static tensile test has been conducted to determine the basic strength properties (yield strength R_e, tensile strength R_m, elongation A_5 and contraction Z) of the analyzed materials. These tests were performed in the fatigue laboratory of the University of Žilina. Research was performed on a Zwick Z050 tensile testing machine at ambient temperature $T = 20 \pm 3$ °C, with operation load range $F = 0 \div 20$ kN and tensile strain rate $\varepsilon_m = 10^{-3} \cdot s^{-1}$. Circular specimens, which were used in the tests, were made parallel to the direction of rolling. The shape and dimensions of the samples were determined according to the requirements of the standard EN 10002-1.

The shapes of obtained curves of high-strength materials are typical of strengthened materials, Fig. 1. Due to structure, as well as the mechanical properties of the researched materials in delivery state, they do not display the clear tensile yield.

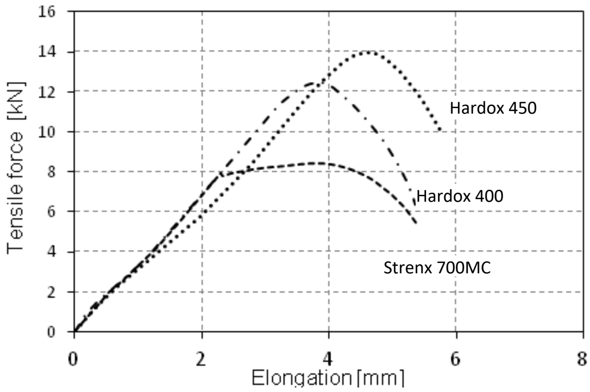


Fig. 1. The characteristics of F = ΔL static tensile tests for materials research

Fatigue tests were performed on a machine Rotoflex, realizing load in bending in rotational mode. During the load cycle the stress ratio was R = -1, with loading frequency 40 Hz and temperature 20 °C ± 3 °C. During the test, the working parts of the specimens were cooled by fans. Results of the reference material were obtained from tests performed in identical conditions [6].

The tests results formed a curve, Fig. 2, which clearly shows that the stress amplitude σ_a decreases with increase of cycles number N beyond the conventional fatigue limit $N_c = 10^7$ cycles. Based on obtained results, the fatigue limits for Hardox 400 reached the level of 490 MPa, stress amplitude decreased about $\Delta\sigma_a = 233$ MPa.

The fatigue limit of the other tested material (Hardox 450) clearly reached the level $\sigma_c = 460$ MPa of load cycles $N = 10^7$, Fig. 3. The results are close to each other; the difference is due to the higher strength and toughness properties of steel Hardox 450. In order to develop the full fatigue curve, further studies are needed to confirm obtained results. As determined from experimental results, the Whöller curve shows a decrease in the stress values at the sample destruction, with increasing number of cycles to the level of fatigue limit for steel Strenx 700MC (440 MPa), Fig. 4.

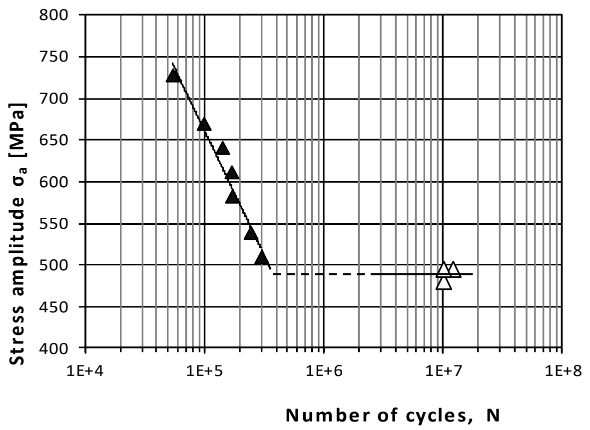


Fig. 2. Hardox 400 – fatigue test results

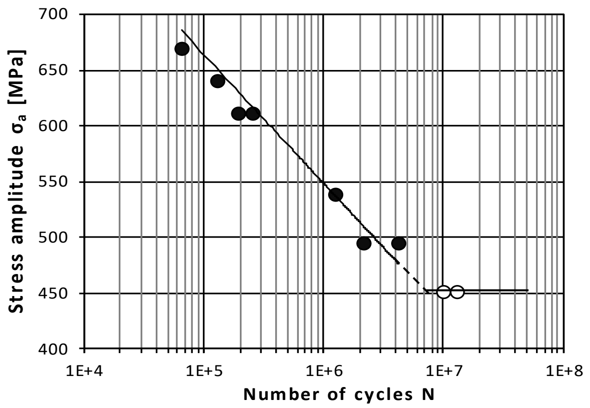


Fig. 3. Hardox 450 – fatigue test results

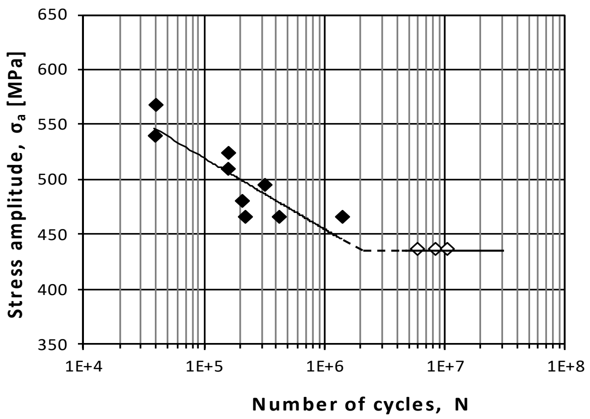


Fig. 4. Strenx 700MC – fatigue test results

In order to learn about nature of the bending process of the tested materials, the fractographic tests for fatigue fractures have been performed. Test results for both materials Hardox 400 and Strenx 700MC confirm the occurrence only of the surface fatigue crack initiation (Fig. 5). Only two samples of steel Hardox 450 showed fatigue crack initiation point below the surface of the sample. In these cases, the fatigue fractures showed characteristic formations known in the literature by the term "fish eyes” [7], Fig. 6. On the fatigue fracture surface of Strenx 700MC specimen there are transcrystalline fatigue fracture of very fine particle morphology, Fig. 7.

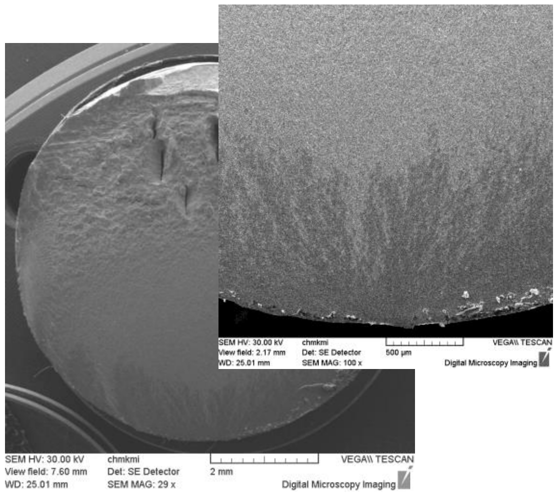


Fig. 5. Surface fatigue crack initiation for Strenx 700MC steel; σ_a = 495 MPa, N = $3.1 \cdot 10^5$

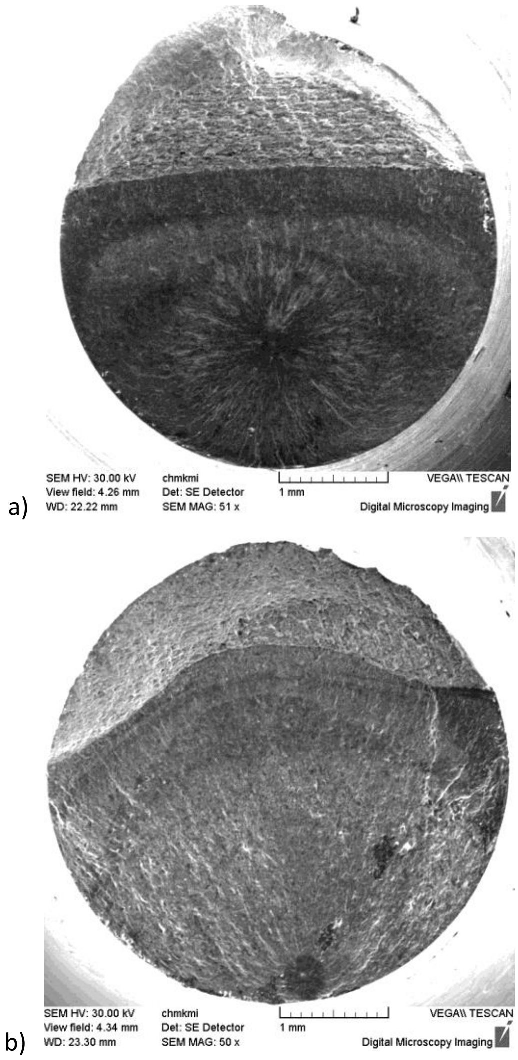
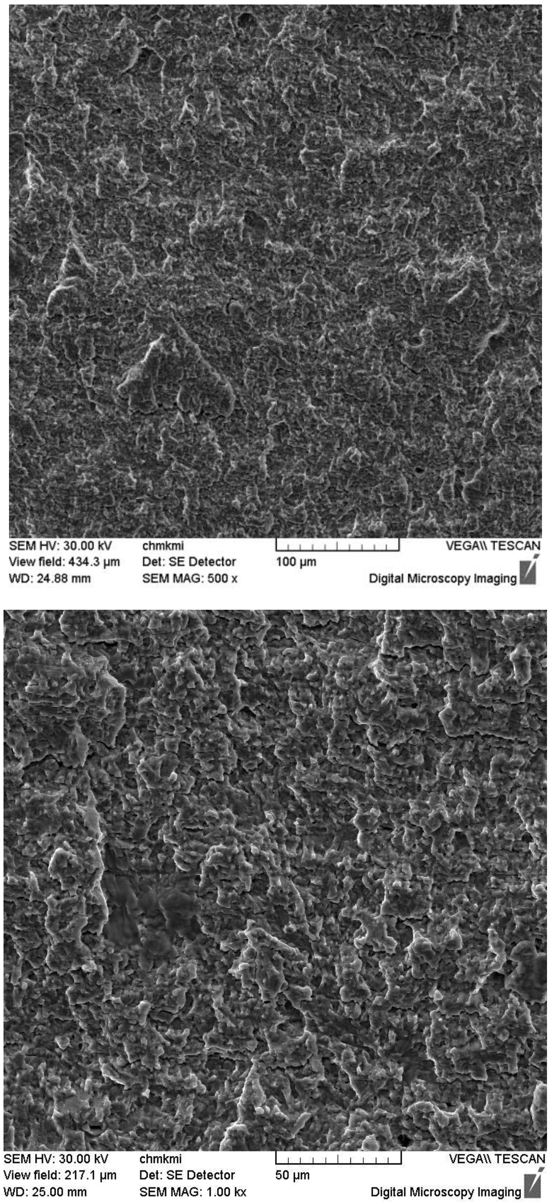


Fig. 6. Fatigue fracture Hardox 450 steel in the macro scale; subsurface fatigue crack initiation with structure "fish-eye"; a) σ_a = 451 MPa, N = $1.3 \cdot 10^7$; b) σ_a = 438 MPa, N = $1.25 \cdot 10^6$



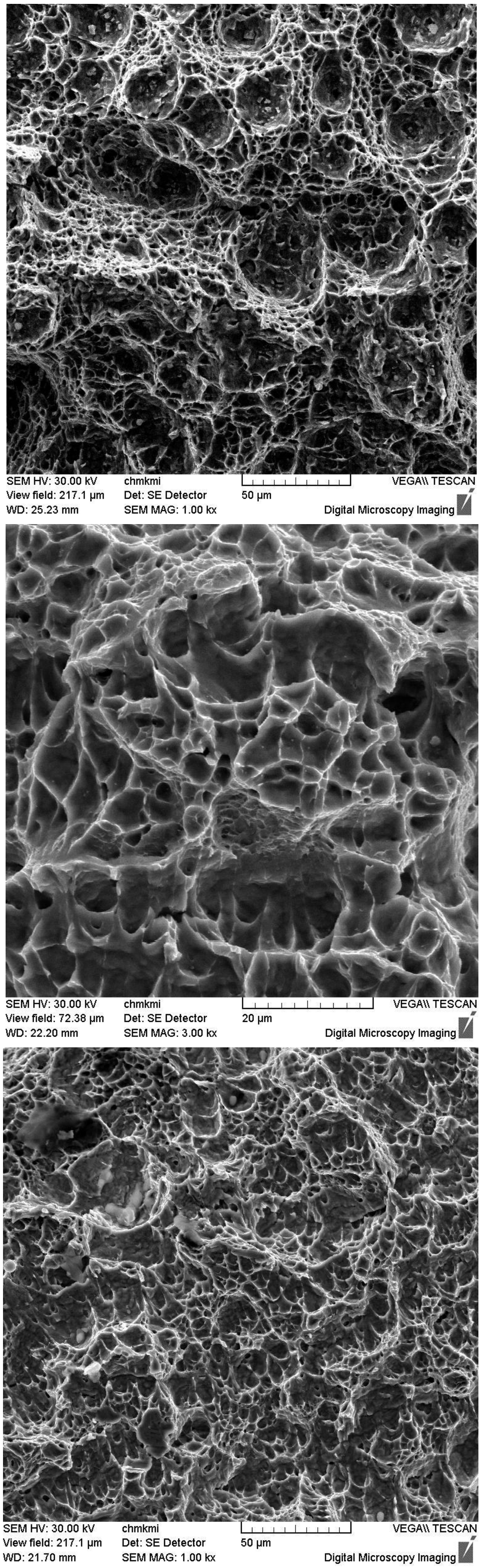
a)

b)

Fig. 7. Fatigue fracture surface, area of stable crack propagation for Strenx 700MC; a) σ_a = 524 MPa, N = $1.5 \cdot 10^5$; b) a detailed view of Fig. 7 a.

The transcrystalline fatigue fractures of tempering martensite are characteristic for both analyzed Hardox steels. In the area of stable fatigue crack, the propagation was proceeding according to transcrystalline propagation mechanisms, which was confirmed by the presence of striations. Areas of rupture for all the three tested materials are characterized by ductile fatigue fracture with dimple morphology (Fig. 8).

Characteristics of the ductile fracture of the fatigue area are strongly related to the material's structure. Results of fractographic tests proved absence of factors that would have an impact on decreased strength of materials and inclusions present were not a direct cause of the initiated fatigue crack.



a)

b)

c)

Fig. 8. Transcrystalline ductile fracture with dimple morphology in steel; a) Strenx 700MC, b) Hardox 400, c) Hardox 450.

4. SUMMARY

Strength testing of the high-strength steels confirmed their high properties declared by the producer. The new semi-trailers from the Master series, manufactured by the WIELTON S.A. Company, represent the new directions in the development of the company. One of the principal elements of the development in question is developing new, "lighter" than predecessors, self-dumping semi-trailers. The possibilities of reducing the kerb weight of a semi-trailer were based by the constructors upon changes in the shape of constructions, and also upon the application of new materials. The possibilities for application of researched materials in the constructions of vehicle semi-trailers, produced by the WIELTON S.A. Company, were presented in Fig. 9.

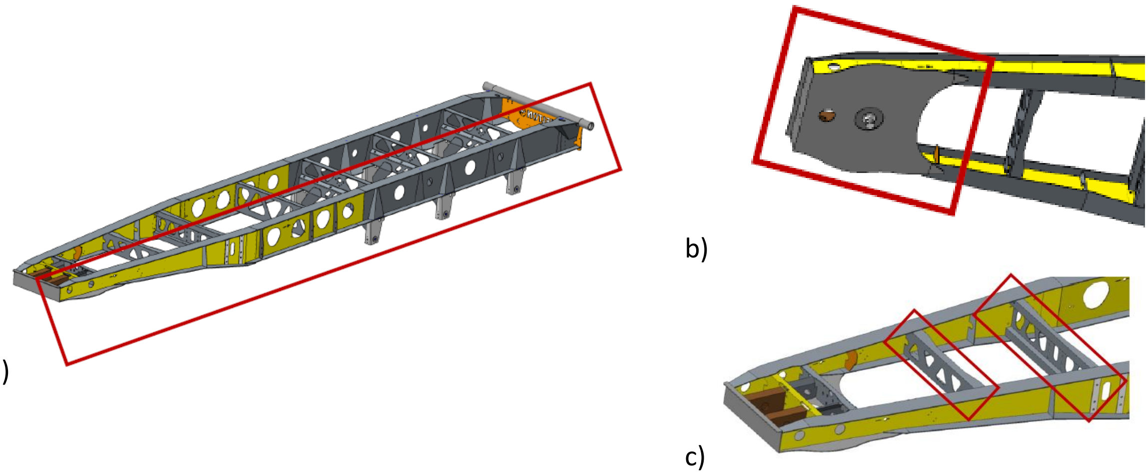

a) b) c)

Fig. 9. Examples of application possibilities of the Strenx 700MC steel in constructions of the elements of semi-trailers chassis made by WIELTON S.A.: a) frame stringers, b) tractor plate, c) frame crossbars

The Strenx 700MC steel may be applied for making many elements of the self-dumping semi-trailers chassis, and the basic requirement in the case of this material is, first of all, good weldability. The tensile yield of this material for the construction of chassis frame stringer may not be lower than 600 MPa, at the tensile strength above 700 MPa. In the case of an element of the tractor plate, those requirements are at the level of $R_e \geq$ 580 MPa, as well as $R_m \geq$ 650 MPa, for the frame crossbars $R_e \geq$ 540 MPa, and also $R_m \geq$ 650 MPa. The Hardox 400 and 450 steels are used in elements of the carrying bodies of self-dumping semi-trailers, among others, in floor plates, side and frontal walls, and also rear hatches, and that means the elements in which an important feature is high abrasive resistance as well.

Knowledge of the material characteristics is a necessity in the process of construction of special equipment items. New structural materials, such as Strenx and Hardox, are expanding range of their application more and more. It is necessary to determine the effect of temperature on the mechanical properties including the impact toughness.

Impact test are used to determine the toughness of the material, its brittleness threshold and degradation of the material.

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