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Tow truck frame made of high strength steel under cyclic loading

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Abstract

The paper presents experimental results from test on tow truck frame made of the high strength steel S700MC subjected to fatigue loading. The mounting manner of the frame with anti-vibration platform and connection with a coupling ball to apply the loading are presented. Cracks features captured by means of macrophotography and microscopic observations are illustrated. Reasons for the crack occurrence are discussed by the use of fractography, hardness tests, microstructural analysis of the parent material, Heat Affected Zone and weld.

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Keywords: cyclic loading; fatigue; fracture; crack; higth strength steel; hardness; microstructure; welding; HAZ

1. Introduction

Modern materials of high strength are employed for new critical working conditions that are often taking place in many exploited devices and constructions. Among such materials the Strenx Steel MC plays an important role [1]. This material (S700 MC) is recommended for production of special trucks frames. It is manufactured using hot-rolled process (M) for cold forming (C). The main advantages of the steel are high elastic limit, yield point and ultimate tensile strength for longitudinal direction usually equal to: 688 MPa, 750MPa and 810 MPa, respectively, Fig. 1. Minimum impact energy is also attractive, because this parameter reaches the following values 40 and 27J at temperature of -20 and -40ºC, respectively [1]. Good welding, cold forming and cutting performance are another

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important features of the steel. These advantages are strongly related to heat treatment, because at temperature above 540°C the material may lose its guaranteed properties.

The S700 MC steel can be characterized by the attractive mechanical parameters. A good welding properties are of particular importance. For this type of steel the hardness in the heat affected zone (HAZ) should be lower than that for the parent material, Fig. 2. An importance of HAZ is related to the dominant crack appearance, i.e. the multi-axial stress state components appear in the HAZ, and as a consequence, prevent further crack propagation. Therefore, failure does not take place in the HAZ, but in the parent material [2].

In the case of Strenx steels a hydrogen cracking, named cold cracking is very low, but this type of cracking during welding is related to amount of alloying elements. This is followed by the carbon equivalent (CE) content, Fig. 3. In the case of conventional steels such as of: S235JR, S275JR and S355JR [3] the CE value is up to 0.36% causing a very high resistance of these materials on the hydrogen cracking. In the case of the high strength steels the content of the carbon equivalent is slightly higher, i.e. 0.4%. This means that in the case of Strenx steels the risk for the hydrogen cracking is not higher than that for the conventional steels observed [2].

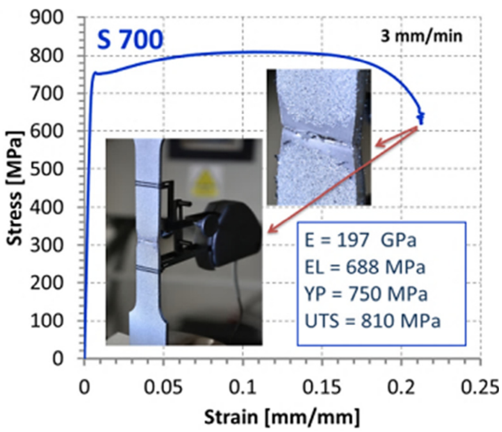


Fig. 1. Tensile curve of the S700 MC steel.

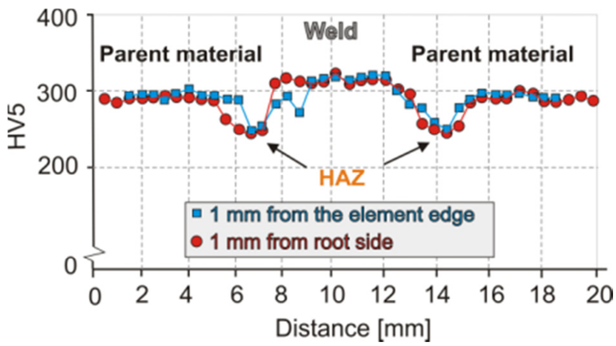


Fig. 2. Vickers hardness distribution for the S700 MC steel after welding, plate thickness 6 mm [2].

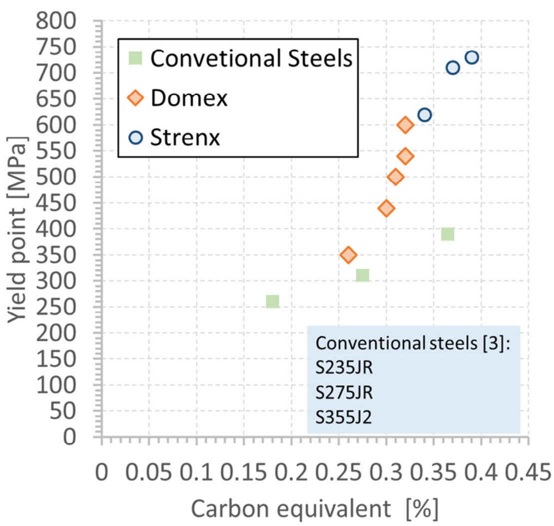
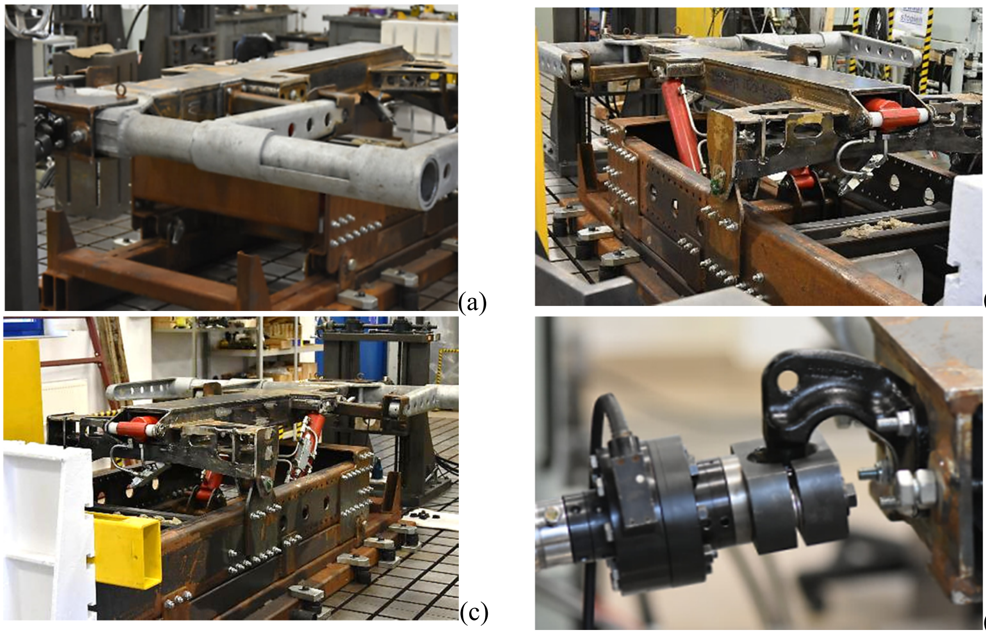


Fig. 3. Relationship between carbon equivalent and yield point for different steels [2].

The aim of the paper was to examine durability of the special tow truck frame, containing welded joints, (Fig. 4) subjected to cyclic loading.

2. Details of experiment

All tests were carried out on testing stand equipped with servo-motors, digital controller, anti-vibration platform (9 m × 3 m) and coupling grip. A force signal in the form of sinusoid was used to control a piston movement. The tested component (Fig. 4a, b, c) was placed on the anti-vibration platform, Fig. 4c. The loading process was executed by means of the spherical grip connecting the piston to the ball of the coupling device A50-X, Fig. 4a, d.



(a) (b) (c) (d)

Fig. 4. The tested object on anti-vibration platform with T slots: (a) general view; (b) first side view, (c) second side view, (d) connection of the servo-motor and coupling device.

The 3D object (3.5 m×2 m×1.5 m), recommended for pulling of damaged vehicles (trucks, lories or cars) due to road accidents was tested. It was mounted to the anti-vibration platform using chassis frame of tow truck by means of screws and clevises, Fig. 4a-c. Elements of the frame made of the high strength steel (S700 MC) were connected using welding technology.

Parameters of the testing procedure were established on the basis of the 55 Regulation UN ECE [4]: amplitude of the force signal - ±18.6 kN, frequency - 4Hz, and limit number of cycles - 2×10^6. A slope of the acting force with respect to the horizontal platform was equal to 15°. The frame behaviour was evaluated on the basis of force and displacement variations versus time. Also an optical system was applied for damage development inspections.

3. Results

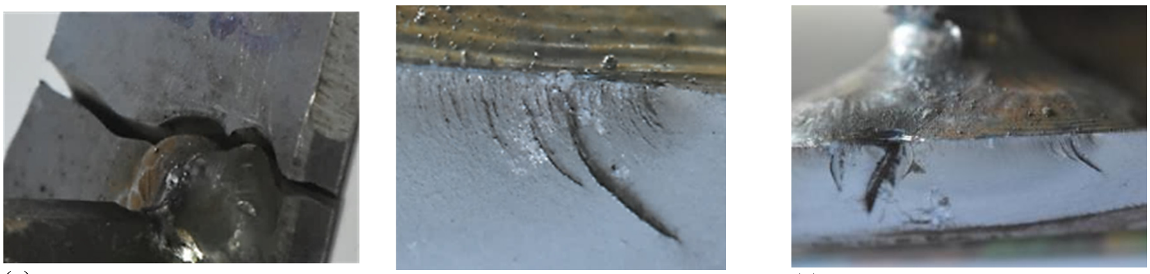
The experiment was carried out up to the frame fracture that has taken place after 573 000 cycles. The crack developed along two paths in the upper and lower parts of the arm, Fig. 5. This was observed in the section between the hole and the edge of arm, Fig. 5b. The crack path had non-linear shape throwing the upper beam of the arm, Fig. 6. The lower region of the beam indicated on significant role the Heat Affected Zone for the crack nucleation, Fig. 7. The fatigue traces were located close to the outer section of the upper beam of the arm with various sizes, Fig. 7b. The zone containing traces was vanishing with material fracture development, Fig. 7c. A fracture zone was represented by a plane oriented at different angles, which expressed variations of stress state components. This was also reflected by the significant crack located in the middle of the beam.

(a) (b)

Fig. 5. Localisation of the cracks in the high strength frame: (a) general view; (b) side view on the arm and crack

(a) (b)

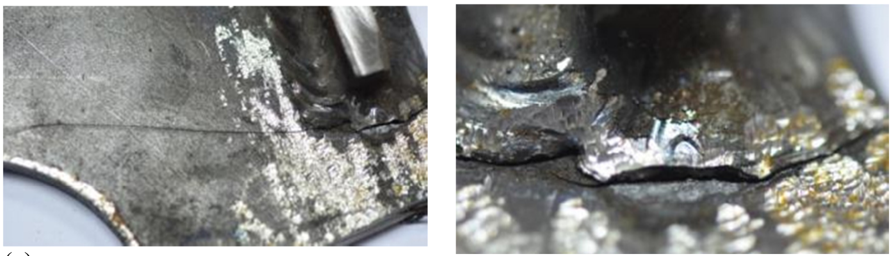
Fig. 6. Visualization of the crack in the frame‘s arm (a) general view; (b) magnified view of the upper part.



(a) (b) (c)

Fig. 7. Visualization of the crack in the upper beam: (a) general view; (b) fatigue traces; (c) the major crack.

The fracture zone of the lower beam of the arm exhibited similar reason of the crack occurrence, but in this case the crack did not reach the opposite edge of the beam, Fig. 8. This was related to lower values of stress state components than in the case of the upper beam. This feature was connected with the kinematics of the tested object under cyclic loading. Nevertheless, this fact did not allow to explain the cracks occurrence. In order to get better understanding of the fracture microstructure and hardness tests were carried out. Measurements were conducted along both lines throwing parent material, HAZ and weld, Fig. 9.



(a) (b)

Fig. 8. Visualization of the crack in the lower beam

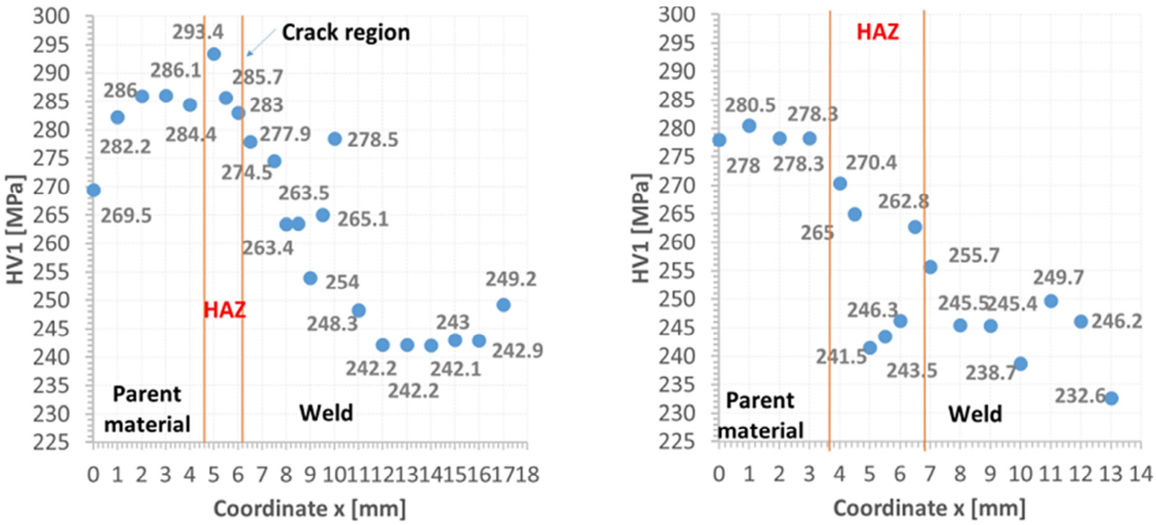


Fig. 9. HV distribution for directions of measurements: (a) No.I, (b) No. II.

On the fracture plane the hardness of the parent material was equal to 285 MPa. It was larger of around 40 MPa than that in the weld section measured. It should be taken into account, that the soft zone was not identified, Fig. 9. These features were examined for both measuring directions throwing the fracture zone (Fig. 9a) and a region without the crack (Fig. 9b). The hardness values of the HAZ with the crack were 15 MPa higher (Fig. 9a) than in the case of the similar region outside the main fracture zone (Fig. 9b). Moreover, differences between the HAZ width were clearly evidenced. In the case of region with the crack (Fig. 9a) the HAZ zone was 3 times smaller.

Microscopic observations expressed various microstructure features, Figs. 10-12. In the case of parent material a ferritic/bainitc microstructures was evidenced, Fig. 11. In the HAZ a higher content of sintered carbides can be observed in comparison to the parent material. This was evidenced by SEM analysis at magnification of 1500×. It also revealed their irregular distribution, Fig. 12.

Fig. 10. Microstructure of the parent material (S700 MC) at magnification of 500×

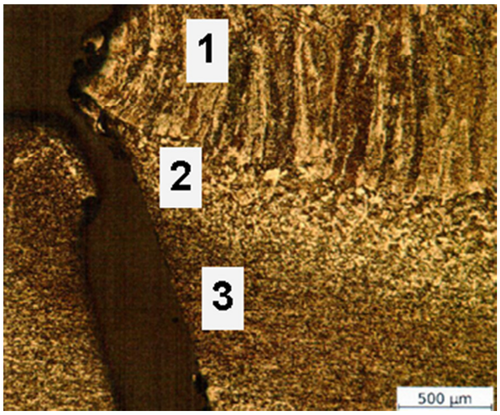
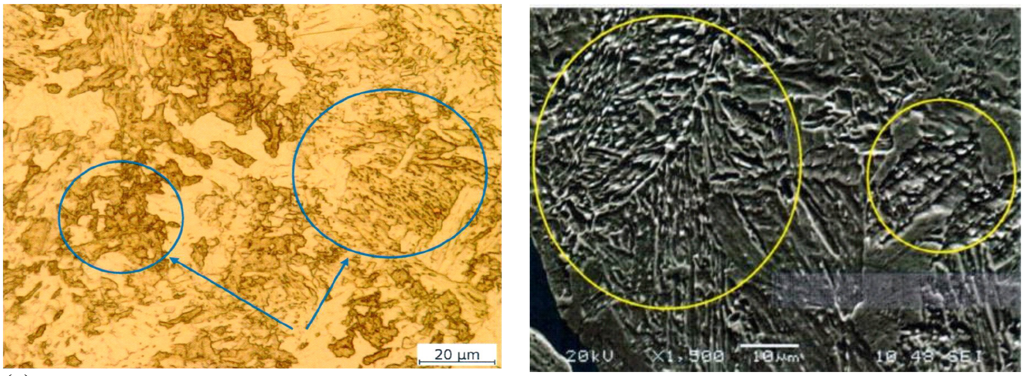


Fig. 11. The crack zone at magnification of 25×; 1- weld ; 2- HAZ; 3 – normalized area



(a) (b)

Fig. 12. The HAZ from microscopic observations: (a) LM 500×; (b) SEM 1500×.

4. Summary

Welding of the high strength steel requires more advanced technology than that for typical steels applied. The soft zones mainly located in HAZ are important features of the welded region. If the soft zone areas have not an adequate mechanical parameters associated with the microstructure, then the fatigue cracks may develop in HAZ.

Acknowledgements

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