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INFLUENCE OF STRESS CONCENTRATION ON MECHANICAL PROPERTIES OF HIGH STRENGTH LOW ALLOYED STEEL GRADE

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Abstract

The analysis of stress concentration influence to mechanical properties at high strength steel grade is considered in this paper. Experimental testing was done on specimens with different radius of the U-shaped circumferential groove in a bar of circular cross section made of S690QL high strength low alloyed steel in static load condition. The influence of stress concentration to mechanical properties is analyzed by correlating of yield stress limits and maximal stress limits obtained for different stress concentrations due to variation of radius of the U-shaped circumferential groove and related limits obtained at same specimens without stress concentration. The numerical models were developed by finite element method for each type of specimens and related results, obtained by numerical simulations, are correlated. Yield stress limits and maximal stress limits obtained by experimental and numerical approach are compared in order to verify the usage of numerical simulation methods on elements made of high strength low alloyed steels. On the basis of the obtained results it is implicated that

1. Introduction

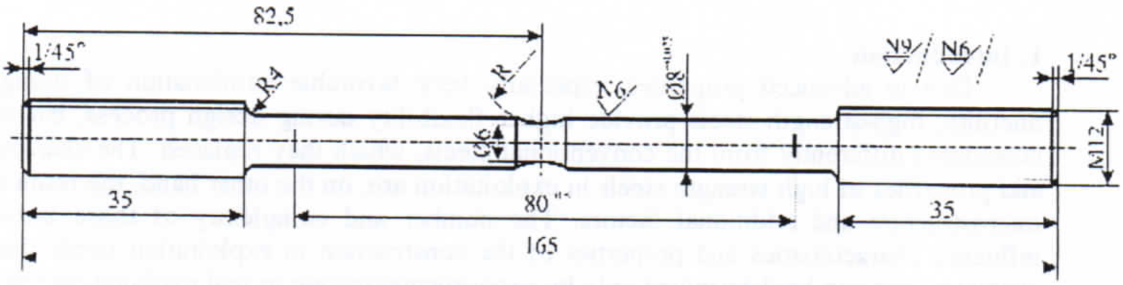
Due to advanced properties, especially very favorable combination of strength and ductility, high-strength steels provide higher flexibility during design process, but must be considered differently from the conventional steels, which they replaced. The characteristics and properties of high strength steels in exploitation are, on the other hand, the result of their microstructure and additional factors. The number and complexity of those factors that influence characteristics and properties of the construction in exploitation imply that those characteristics can be determined only by experimental testing in real exploitation conditions. Stress and strain distributions are determined by stress concentration caused by geometrical discontinuities and heterogeneouity of material. Stress concentration changed the stress distribution, position of maximal stresses and, by that, the position of the critical cross section zone, which acts both as damage and integrity safety risk. The stress state of the mechanical construction elements, made of high strength steel, in exploitation, is complex and it resulted from number of various factors. The characteristics of those constructions and their response to load are, besides of factors related to their microstructure also influenced by factors related to their stress-strain state. The sensitivity of this steel to stress concentration is the major factor that defines the construction response to loads as well as its mechanical properties.

2. High-strength low alloyed steels

High-strength steels were developed and produced in order to improve the mechanical characteristics and resistance to corrosion in relation to conventional carbon steel grades. They are selected based on the minimal required mechanical properties, while the producers determine their chemical composition. The chemical composition of those steels can even vary in order that those variations provide uniformity of mechanical characteristics. Common usage and development of those steels are linked to seventh decade of the 20th century and to the beginnings of commercial production of iron alloys, especially ferroniobium. The structures of low-alloy steels, after the processing, are typically fine grain and consist of ferrite (α) grains of small sizes and with shape homogeneity. In addition, the small amount of cementite is present in microstructures of those steels, as the fine dispersed particles of carbon nitride, which can be identify only by electron microscope. During the final rolling process, there are favorable conditions for creation of the large number of referent locations within the distinct formation of α metal grains. The density of those locations in the steels structures is a consequence of a production process and the level of material deformation. The effects of regeneration of deformed microstructure are present, such as recuperation and recristalization. By those phenomena, the deformed microstructure turns into the undeformed, what results in decrease of dislocation density in the microstructure. During the production process of steels, the different phenomena, with opposing consequences, are induced. Those phenomena cause increase, as well as decrease of the dislocation density. The recristalization process is suppressed by decrease of speed of grains' nuclei formation and by the reduction of movement of metal grains and sub grains boundaries. The recrystallization process is a consequence of the presence of alloying elements' atoms in the solid solution of steels and it is induced by continual rolling with short break periods, when the effect of niobium is dominant. In addition, the recristalization process is induced as the consequence of precipitation during the reversible rolling with longer break periods, when the dominant process is separation of carbon nitride.

3. Experimental testing

Experimental testing was done on series of three specimens with different radii of the U-shaped circumferential groove in a bar of a circular cross section (Fig. 1) made of S690QL high strength low alloyed steel, in static load condition, on the Zwick/Roell Z100 testing device. Forces dependences on elongations were recorded automatically on the testing device and the yield stress limit and maximal stress limit were determined. The obtained results show very small relative variations, thus they can be taken as relevant for further analysis (Fig. 2).



Model type	Value of radius
A	R = 10 mm
B	R = 20 mm
C	R = 30 mm

Fig. 1. Shapes and dimensions of tested models

Comparison of mechanical properties of tested specimens is shown in Fig. 2 and Fig. 3. The trend of decline in mechanical properties, yield strength limit and maximal stress limit of tested models is a consequence of the stress concentration influence.

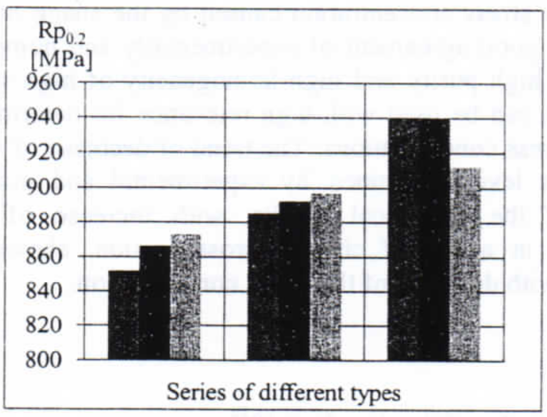


Fig. 2. Experimentally obtained yield strength limit of models

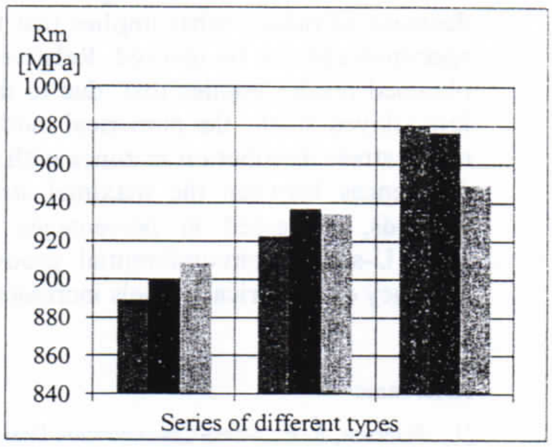


Fig. 3. Experimentally obtained maximal strength of models

4. Numerical simulation

Numerical simulation considered in this paper is done by using the software package Autodesk® Inventor® 2013. The three dimensional tetrahedral discretization with density variation is done at the first stage of numerical model generation. The zone with stress concentration, as the zone of interest, is discretized by the finite elements with the smallest dimensions. The boundary conditions are defined according to theoretical considerations of stress state distributions. The numerical models are loaded with the same level of maximal forces that are obtained experimentally on related models. Appearance of the stress distribution at zone of stress concentration for one of the tested models is presented at Fig. 4. The differences between the maximal stress levels, obtained by experimental and numerical methods, expressed in percentages of the numerical results, are shown in Fig. 5.

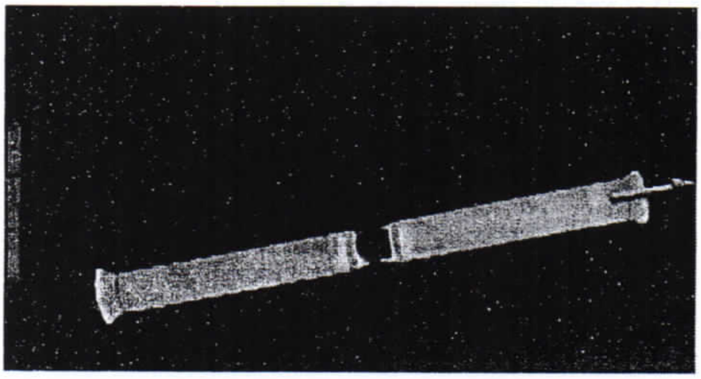


Fig. 4. Appearance of stress distribution in stress concentration zones

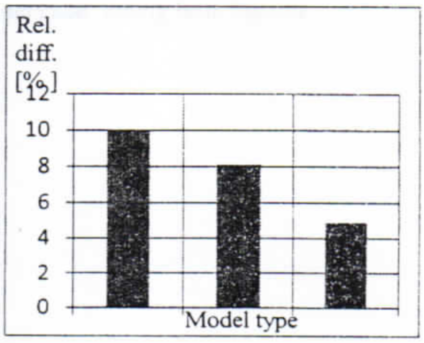


Fig. 5. The average differences between experimentally and numerically obtained results

4. Conclusion

The used material for testing is a high quality structural steel, which fully meets the required mechanical properties, both in terms of mechanical strength and plasticity, which was experimentally confirmed. Based on results obta. .ed by testing the models with stress concentrators it was shown that adequate use of mechanical characteristics and properties of applied material can be achieved by appropriate constructional solution with low level of stress concentration. The plasticity of material in the zones with high stress concentration is higher than plasticity of the parent material due to complex stress distribution, which is confirmed experimentally and it is in accordance with current literature sources related to these problems. Achieved stresses at the yield limit and tensile strength of models with different radii of the U-shaped circumferential groove show the decreasing trend with decrease of radius, what implies that the stress concentration caused by the shape of tested specimen can not be ignored. Relatively good agreement of experimentally and numerically obtained results implies that, due to the high purity and high homogeneity of high strength low alloyed steels, the numerical models can be used with high relevance for determination of the stress distribution in zones with stress concentrations. The trend of decrease of relative differences between the maximal stress levels, obtained by experimental and numerical methods, expressed in percentages of the numerical results, with increase of radius of the U-shaped circumferential groove in a bar of circular cross section, showed that accuracy of numerical models increases with decrease of the stress concentration.

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