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The assessment of the tensile with torsion loading interaction using the selected hypotheses and the experiment

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Abstract. For two steels with different material properties (both cyclic and static ones) were experimentally obtained dependencies $\sigma_a=f(N_f)$ and $\tau_a=f(N_f)$. The specimens of these materials were loaded with multiple tensile and torsion stress combinations. It was found out that the time-depending relationship between the individual stresses was proportional. The results for steel with high ration of Rm/Re are different comparing to the results of the second material. In this contribution, there will be confronted the experimentally obtained fatigue life-time magnitudes with selected multiaxial fatigue life-time hypotheses like Findley, McDiarmid, Dang-Van, Carpinteri-Spagnioli, and Margetin-Ďurka-Chmelko.

1 Introduction

The large number of cumulation hypotheses of fatigue damage which take into account the multi-axial stress state does not need to be further expanded. Rather, the generalization of existing approaches (if at all possible) into a unified fatigue life assessment methodology for multi-axial stress would be a better approach. In this paper, one of the ways of thinking which could be followed for solving the problem is outlined.

Two steels selected for analysis are common structural steels often used in engineering practice. Their difference is in a different Rm/Re ratio. For C55 steel, the strength to yield strength ratio is 2.5, for St-52 steel is less than 1.1. Fatigue life curves for normal stress (alternating tensile tests) and shear stress (alternating torsion tests) were obtained for both steels. This was followed by cyclic loading of specimens of each of the steels with tensile and torsion combinations to involve a lifetime region of order 10^4 to 10^6. The stress criteria Findley, McDiarmid, Dang-Van, Carpinteri-Spagnioli and Margetin-Ďurka-Chmelko were chosen for the fatigue life calculation. Computational results are confronted with experimental obtained lifetimes.

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2 Properties of analysed steels

Materials ST-52 and C55 are medium strength non-alloy steels with distinctly different strengthening modules. All material properties were obtained by direct measurement. The shape of the test specimens for all tests was chosen so as not to cause any factors affecting the results (e.g., the samples did not have an internal opening).
Tensile diagrams of both steels documenting their differences are shown in Fig.1.

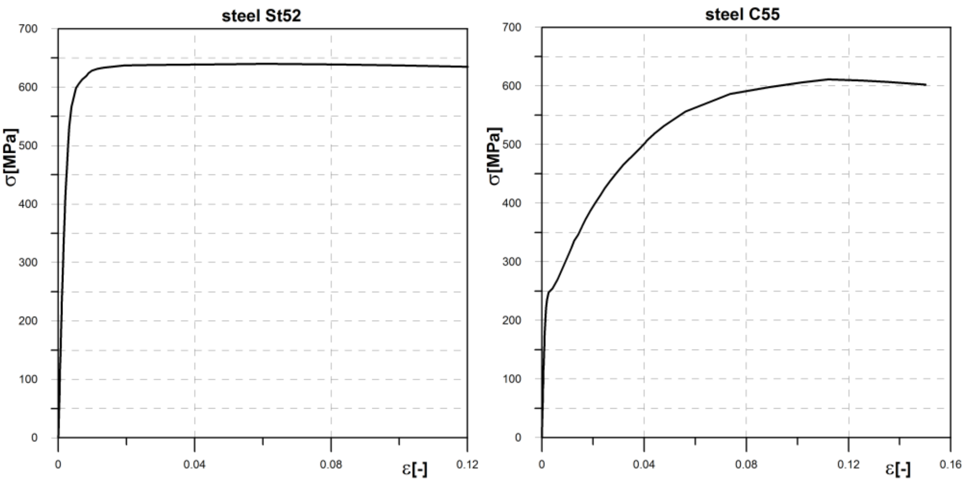

Fig. 1. Tensile diagram for analysed steels St52 and C55

Regression curves of experimentally obtained dependencies $\sigma_a=f(N_f)$ and $\tau_a=f(N_f)$ for both steels are in Fig.2 and Fig.3. The cycles labeled as N_f represent fatigue life up to fracture, as well as the following tensile-torsion combined tests.

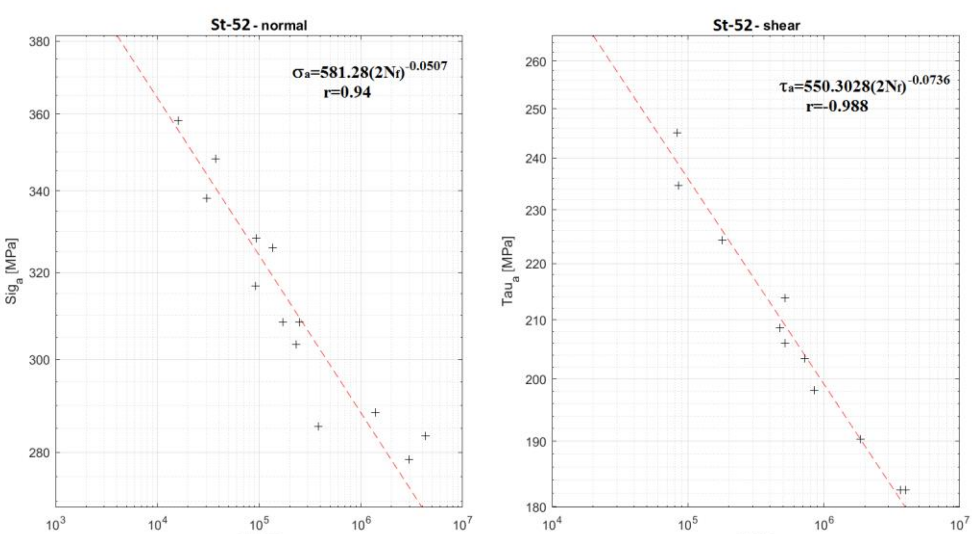

Fig. 2. Basquin curves for analysed steel St52

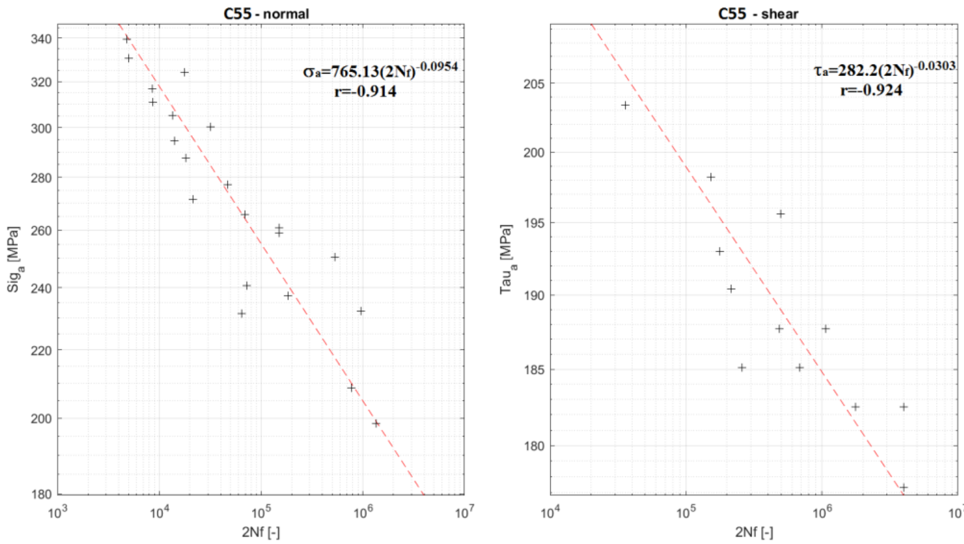

Fig. 3. Basquin curves for analysed steel C55.

3 Obtained results

The specimens of these materials were loaded with multiple tensile and torsion stress combinations in frame of electrohydraulic pulsator MTS 370.02. It was found out that the time-depending relationship between the individual stresses was proportional. Frequency of cycling was less than 5Hz. Obtained experimental values of life-time for both steels was confronted with selected multi-axial fatigue damage criterions as shown in the diagrams Fig.4-Fig.8. The prediction intervals for 90% probability of occurrence of experimental points are shown in diagrams by dashed lines.

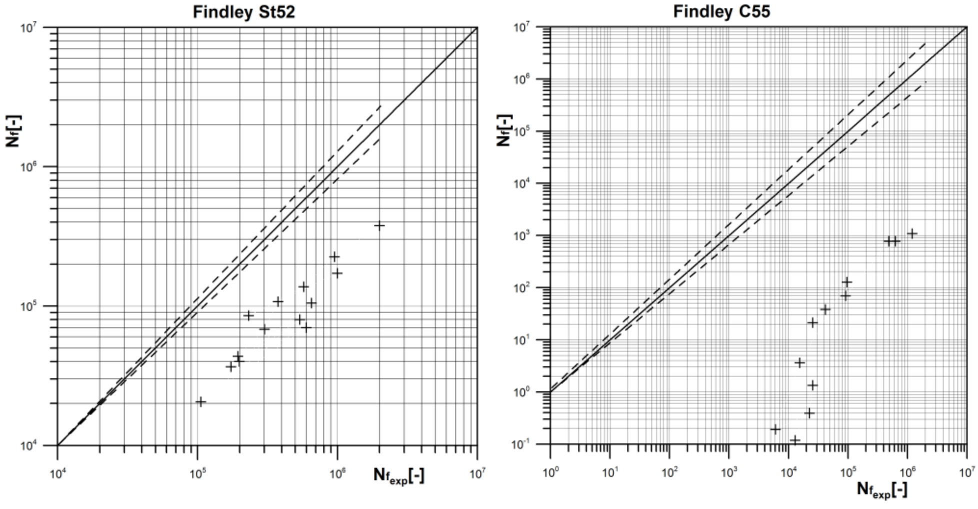

Fig. 4. Confronting of lifetime applying Findley approach [1] and experimental results for analysed steels

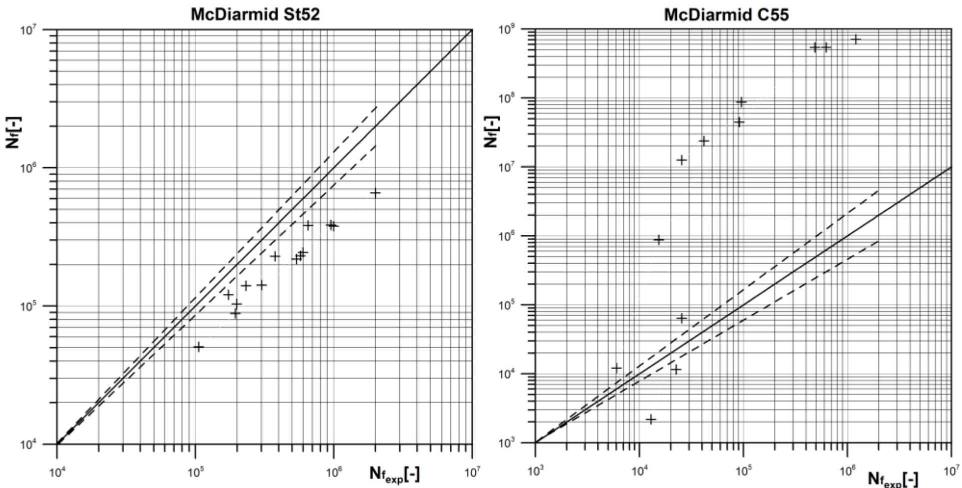

Fig. 5. Confronting of lifetime applying McDiarmid approach [2] and experimental results for analysed steels

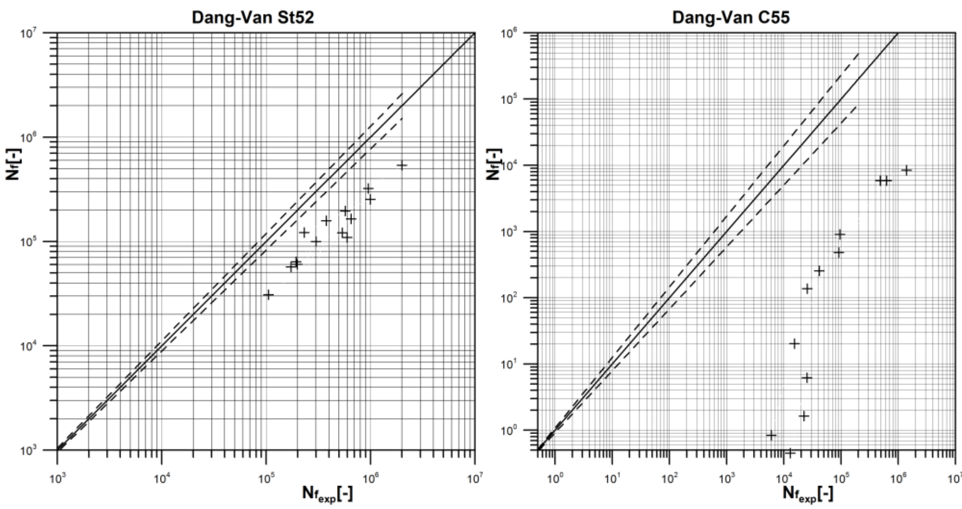

Fig. 6. Confronting of lifetime applying Dang-Van approach [3] and experimental results for analysed steels

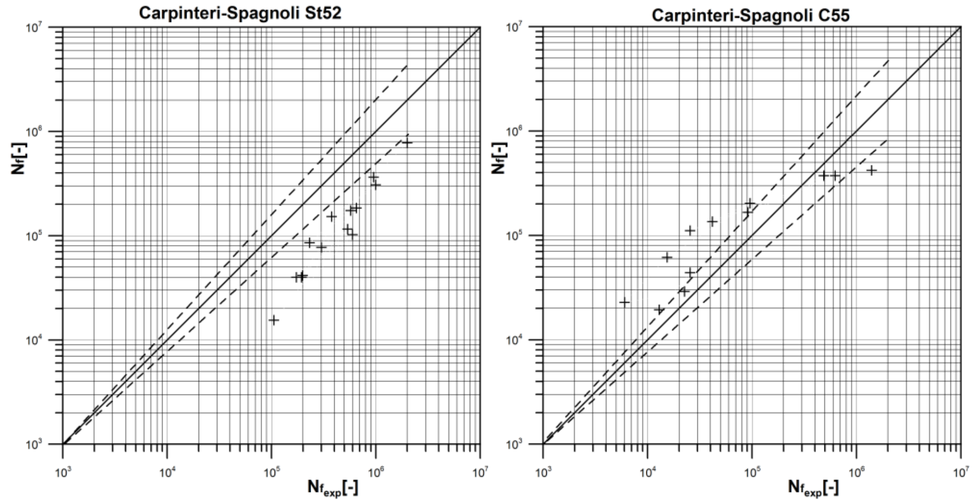

Fig. 7. Confronting of lifetime applying Carpinteri-Spagnoli approach [4] and experimental results for analysed steels

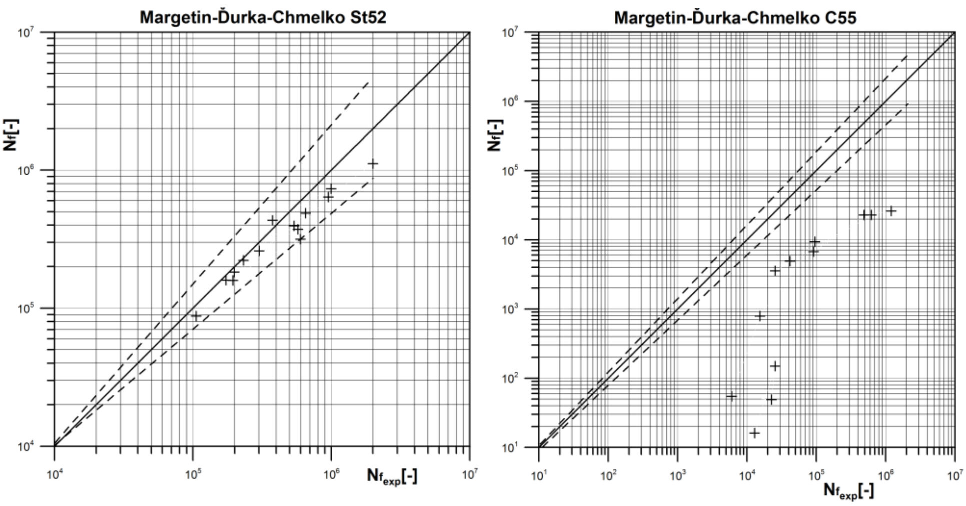

Fig. 8. Confronting of lifetime applying Margetin-Ďurka approach [5,6] and experimental results for analysed steels

4 Discussion of results and conclusions

In this paper, there were confronted the experimentally obtained fatigue life-time values with calculated values using selected multiaxial fatigue life-time hypotheses like Findley, McDiarmid, Dang-Van, Carpinteri-Spagnioli, and Margetin-Ďurka-Chmelko (MDC). The results of the fatigue tests (presented with statistical intervals of probability) and the results obtained by the computational approaches are very different for the steels analysed.
For St52 steel

- all the used approaches resulted in conservative results
- the MDC approach best matched the experimental results
- the most conservative results were obtained by Findley's approach

- the results of using the McDiarmid, Dang-Van and Carpinteri-Spagnoli approaches are very similar

For C55 steel

- the Findley and Dang-Van approaches have led to very conservative results
- the MDC approach has led to less conservative results, but correlation with experimental results is also unsatisfactory
- the McDiarmid and Carpinteri–Spagnoli approach has in majority led to non-conservative results, while Carpineri-Spagnoli's approach has the best correlation with experimental results

Overall, the results of computational approaches are generally poorly satisfactory for both steels, and even very unsatisfactory for C55 steel. The MDC criterion has a real best correlation with experimental results, but it does not capture the reality for C55 steel.
The specificity of C55 steel can capture some of the deformation criteria [7], which often require additional material parameters. The results of material C55 lead to the idea of introducing an additional material parameter that would correct such specifics using relatively simple stress criteria.

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