THE EFFECT OF MEAN STRESS ON FATIGUE CHARACTERISTICS OF S355 NL+N STEEL

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Abstract

The effect of mean stress on fatigue life and fatigue limit was investigated for S355 NL+N ferritic-pearlitic steel. Changing stress ratio from R=0 corresponding to pulsating regime to R = -1, which is in conformity with alternating regime, the fatigue life was changed when applying the mean stress for the same stress amplitude. Although this phenomenon is generally very well known it is important to investigate it further regarding to commonly applied material. Research results of this topic could help to structure designer better utilize fatigue behaviors of materials as S355 steel which is commonly used for constructions of welded structures. Since this steel is favored for production of structures, it is extremely important how the alternating stress ratio affects their service life. The experimental results show that with increasing mean stress of loaded S355 steel and growing stress ratio, the fatigue limit diminishes and fatigue life is getting shorter. Then for a given value of the limited amplitude the number of cycles up to failure with increasing stress ratio decreases. This effect is much more substantial when the limited amplitude approaches to the fatigue limit for a given value of the stress ratio. Discussed experimental results help to optimize mechanical design of steel welded structures.

Keywords: Fatigue, mean stress, ferritic - pearlitic steel, fatigue limit, mean stress, stress ratio

1. INTRODUCTION

Fatigue of material is a phenomenon that is a long time known. Many of operational failures is caused just by the fatigue. Fatigue is a degradation process of the material when during the time-varying loading is damage in the material accumulated and explicitly is manifested with the formation of microcracks, macrocracks and at the end final fracture. [2, 7, 10] In most publications is research is focused primarily on the fatigue more materials when changing amplitude stress. Many publications also list fatigue characteristics when loading is only in tension. In most cases, there are shown the stress amplitude, which is obviously very important mean stress value, which is equally important, is neglected. This publication describes the effects of mean stress on the fatigue characteristics, and especially to fatigue limit just for S355 NL + N steel. This paper does not aim to bring the innovative idea in the field of research fatigue damage. The main objective is to focus on the influence of the value of a mean stress of specific, commonly used structural material.

Therefore, for testing was selected known and widely used steel for welded structures. This paper will highlight the reduction of fatigue life due to changing tensile stress to alternating tension-pressure. Although this effect is well known it shall be still studying. Now the study of fatigue properties of commonly used construction material allows good dimensioning of mechanical properties of the material to the stress state of structures.

2. MATERIAL

For investigation was was chosen commercial material S 355 NL + N. This is commonly available and usable construction ferrite-pearlite steel. This steel is used for its properties primarily for welded structures as basic material. Marking NL + N sets normalizing with minimum impact values in a flat bend. Basic mechanical properties are given below in **Table 1**.

Table 1 Basic mechanical properties of S355NL + N steel

R_m [MPa]	R_{p02} [MPa]	A [%]	KV -20 [J]	HV10
566	405	36	131	154

The chemical composition, indicated in **Table 2**, which does not differ from commercial standard for this material.

Table 2 Chemical composition

Element	C	Mn	Si	P	S	Cu	Ni	Cr
wt. %	0.172	1.380	0.360	0.016	0.002	0.070	0.020	0.080
Element	**Mo**	**V**	**Ti**	**Al**	**N**	**Nb**	**CEV**	
wt. %	0.021	0.004	0.003	0.024	0.005	0.020	0.43	

From the metallographic point of view, it is fine-grained ferritic - pearlitic structure. In **Figure 1** is shown a significant banded texture caused by the rolling process. That the pearlite as a two-phase material consisting of hard and brittle lamellar cementite in ferritic matrix significantly affects the life of the material exposed by time-varying stress component.

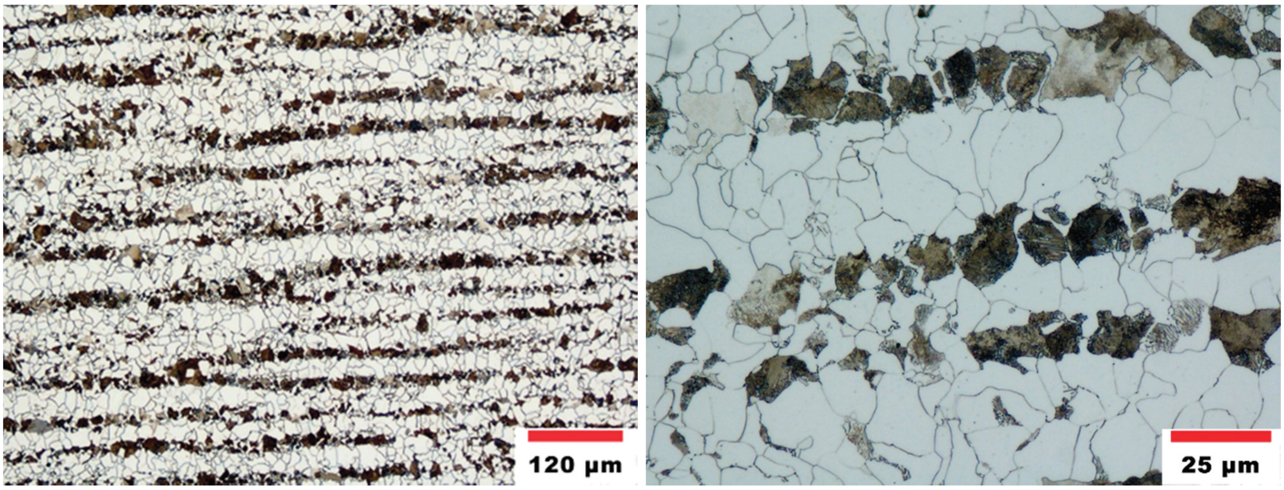

Figure 1 Microstructure of the material S355 NL + N, left - a small magnification show well band texture, right - the detail of the microstructure

3. TESTING PROCEDURE

All specimens were tested on fatigue biaxial servohydraulic machine INSTRON 8802. Soft control mode was chosen, typical for high-cycle fatigue. The machine was driven only by force. In the early stages of fatigue testing was based from theoretical knowledge of fatigue limit, $0.35R_m$. [4] Testing was performed in a wide range of stress amplitudes. Subsequently testing was focused on the of high-cycle fatigue area, thus 10^4 - 10^5 cycles to fracture [6], where were calculated Wöhler equation coefficients. The first testing was aimed at mean stress value $\sigma_m = 0$ (R = 0), in a second stage to nonzero mean stress (R = -1).

In **Figure 2** are depicted waveforms of variable stress component in the stress ratio R = 0 and R-1. There are visible differences between maximal and mean stresses. Maximal stress has a significant influence on the resulting number of cycles to fracture, even if the amplitudes are equal.

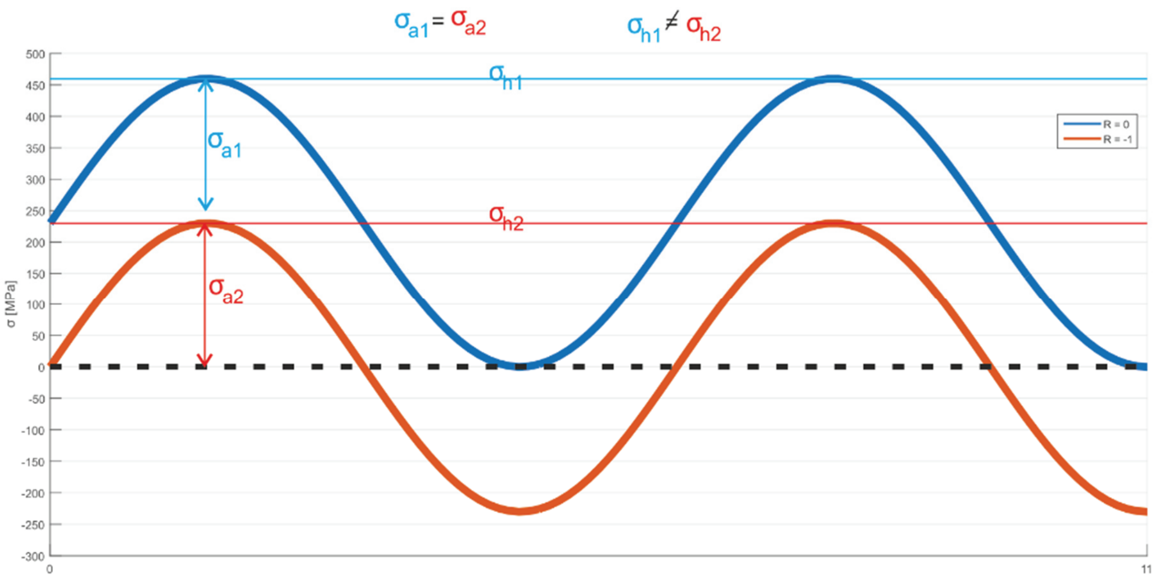

Figure 2 Schematics of changing R ratio

Specimens for fatigue tests were chosen in a cylindrical geometry based on the standards for tensile and fatigue tests. Geometrically they were adapted to the capacity of the testing machine and its clamping jaws. Specimens was machined with surface finishing. The basis for the geometry was plate of material with thickness of 60 mm. Orientation of the microstructure shown in **Figure 1** is a cross-sectional of specimen. The geometry of the specimen is shown in **Figure 3.** The time-varying force component, was applied at a frequency of 10 Hz with shape corresponding with sinus functions.

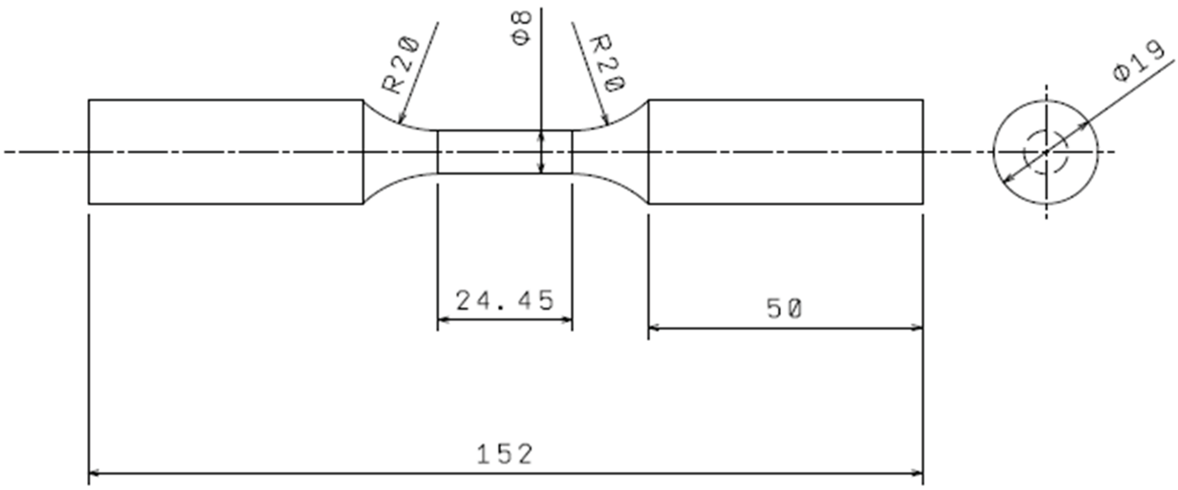

Figure 3 Geometry of specimens

4. RESULTS

Based on the results of experimental testing were plotted S-N curves. The figures below are listed S-N curves (Wöhler curves) combined for R = 0 and R = -1. These curves are generally known as Stress-life diagram [1, 3, 4]. **Figure 4** shows a semi-logarithmic standard display - the number of cycles to fracture against to the amplitude of the applied load. On this figure are also indicated theoretical values for fatigue limits $0.35R_m$ and $0.45R_m$.

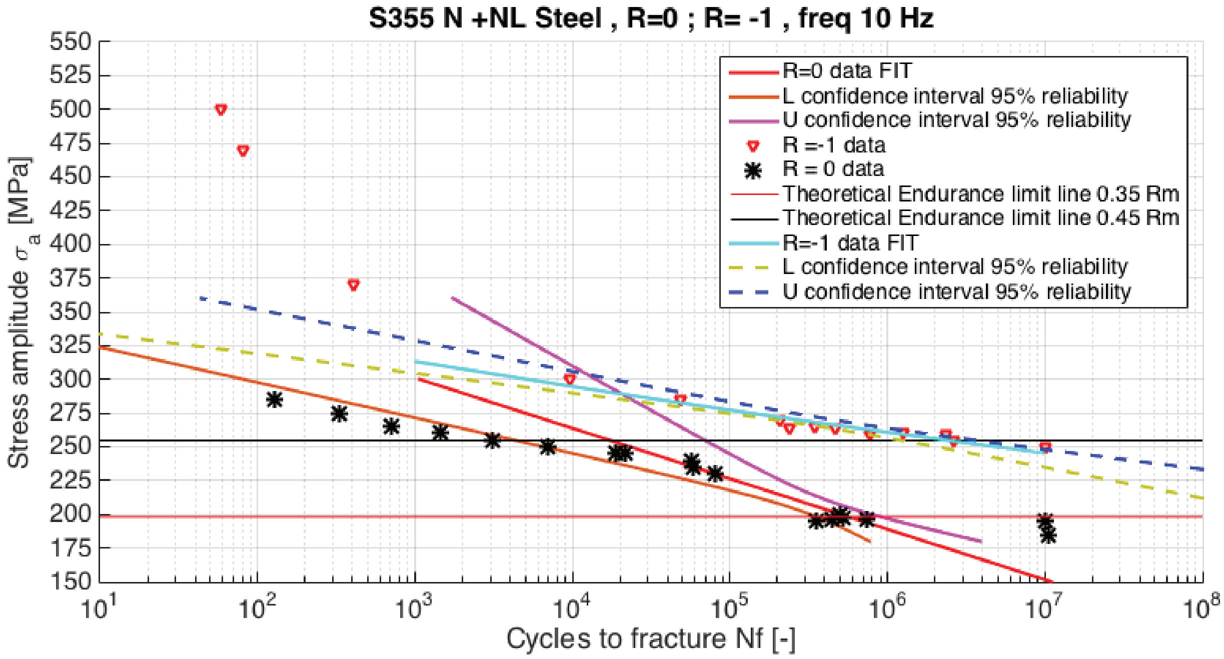

Figure 4 S-N curves and their confidences intervals, for R=0, R=-1

Figure 5 shows the S-N curve with maximal stress on y axis.

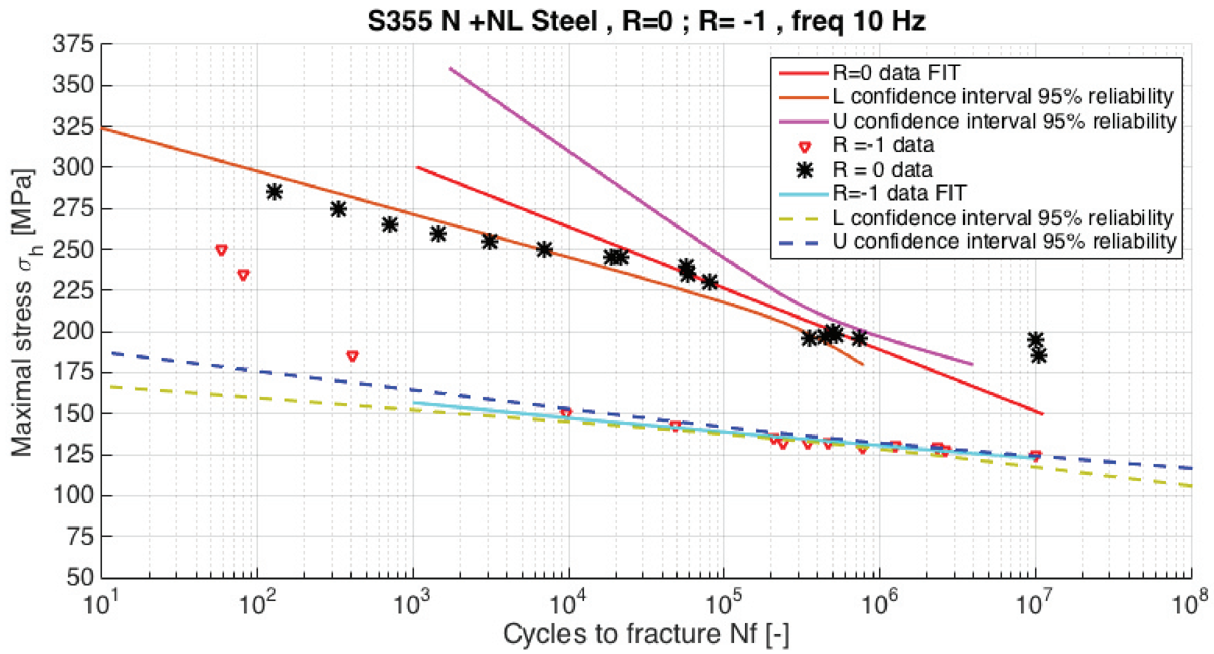

Figure 5 S-N curve, with maximal stress on Y axis, for R=0, R=-1

5. EVALUATION

To calculation of coefficients and confidence intervals were used CSN and ASTM standards. From the comparison approaches of these two standards is result that are almost identical. Statistical methods reported in the literature allow the evaluation of files of fatigue tests and determination of confidence intervals and tolerance. Mentioned statistical methods are designed for a small number of tests and thus the cases of experimental practice. [5]

For the evaluation of the results was essentially used least squares approximation method. Values for approximation were selected from a are of 10^4 -10^7 cycles to failure. Subsequently, was conducted an approximation of the measured points. For the approximation in high cycle fatigue (Wöhler curve) was elected following equation, generally known as Basquin equation [2]:

$$\sigma_a = \sigma_f{}' \cdot (2N_f)^b \ , \tag{1}$$

where σ_f is the fatigue strength coefficient and b is the exponent of fatigue strength.

In the same manner they were assembled curves for double-sided confidence intervals of the approximated curves. For reliability calculations were used tables of critical values of Student distribution for θ degrees of freedom confidence level $\alpha = 0.05$. All the calculated values and the resulting approximations are shown in **Figures 4 and 5**. As a computational tool was used Matlab software. Evaluation sided confidence intervals were performed according to [5] and below equation:

$$\log N = a + b \cdot \sigma, \tag{2}$$

where the unknown constants a and b were calculated by least squares approximation method. **Table 3** below shows a list of these constants.

Table 3 Calculated values of equation 2

R ratio	a	b
0	11.0513	-0.026738
-1	2.5835	-1.5761

Basic output - therefore calculating of the Basquin equation values are shown below in **Table 4**.

Table 4 Calculated values of Basquin equation

R ratio	σ_f	b
0	504.142	-0.0667
-1	399.878	-0.0478

6. CONCLUSION

Shifting values of the mean stress from positive field to zero, therefore, the change of load ratio from R = 0 to R = -1, causes shortening of the fatigue life and decrease the fatigue strength limit. This can be deduced from the **Figures 4 and 5**. In the case of plotting coordinate system N_f against σ_a not allow see in which stress state the material is from to quasi-static test point of view or whether the tip, the maximal stresses are over the yield strength or not. Therefore, it is more than suitable to use in obtaining the value of the maximal stress which is entirely clear in where area is the material / sample loaded. Of course, the influence value of the mean stress is described by Goodmann, Gerber, Soderberg [10], but the classic S-N curve is not quite noticeable.

It can also point to empirical coefficients of determination of fatigue limit, which is given as a multiple of the ultimate strength. For materials with a ultimate stress up to approx. 800 MPa is generally mentioned coefficient $0.35R_m$ above this threshold of strength is featured $0.45R_m$ [4]. Coefficient $0.35R_m$ is valid for cycle asymmetry R = 0, but due a change to R = -1 is changed to ~ $0.43R_m$.

Results of experimental measurements provide a change of fatigue properties of steel S355 N + NL in changing of load ratio. These data are very useful for the design of constructions. Knowledge of impact of these changes in stress allows a sufficiently dimensioning and refine calculations of the newly proposed structures.

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