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CALCULATIONS OF FATIGUE LIFE OF WELDED CONSTRUCTION ELEMENTS MADE OF ALUMINUM ALLOY AW-5754

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Abstract: *The paper presents the results of calculations of fatigue life based on the analytical method SLD (safe life design). The calculations were carried out for three different variable-amplitude loads with an average value $\sigma_m = 0$ MPa, which were characterized by different values of the spectral load factor: load I – $\xi = 0{,}7004$, load II – $\xi = 0{,}4684$, load III – $\xi = 0{,}3419$. Fatigue life was determined for a welded structural element made of aluminum alloy, for which an S-N diagram was adopted in accordance with the recommendations of the standard EN 1999-1-3:2007+A1:2011 The linear hypothesis of Palmgren-Miner fatigue summation was used in calculations. The obtained results allow to conclude that the applied calculation method can be used at the initial stages of construction due to the speed of calculation and the adoption of general assumptions in the S-N chart. A significant impact on fatigue life results in the form of operating load, which is characterized by the spectral filling factor ξ.*

Keywords: AW-5754 aluminum alloy, fatigue life, life calculations, loads spectrum, standard EN 1999

1. Introduction

Calculations of fatigue life of machine construction elements are carried out in terms of: stress (Szala, Ligaj, 2016), strain (Szala, Ligaj, 2016) and energy (Ligaj, 2014). Each of the above mentioned approaches requires the use of fatigue durability graph, accepting the fatigue failure additive hypothesis and defining load conditions. Obtaining the results of calculations consistent with the results of experimental tests under the same load conditions requires the use of detailed data on the fatigue properties of the material and / or construction element. These properties allow for the implementation of analytical or numerical calculations at different levels of accuracy, and the assumed level of accuracy depends on the level of implementation of the construction process.

At the initial stage of construction, analytical methods are used that use generalized fatigue characteristics, usually in stress terms. Examples of this type of characteristics are presented in the works (EN 1999-1÷3: 2007, FITNET). In the preliminary calculations, the S-N diagram determined in the conditions of R = -1 loads, the linear Palmgren-Miner fatigue additive fatigue hypothesis and the one-parameter load spectrum are used.

Calculations and experimental tests of structural elements with original constructional and material features require the use of non-standard methods. This applies to elements of cutting assemblies, elements of food industry machinery (Flizikowski et al., 2015), adhesive joints (Wirwicki, Topolinski, 2013).

The aim of this paper is to calculate the fatigue life of a welded structural element under conditions of variable-amplitude loads using the SLD (safe life design) method.

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2. Calculation of fatigue life

2.1. Material for research

In the tests, the aluminum alloy EN AW-5754 (designation according to DIN: AlMg3, according to ISO: AlMg3, Werkstoff no.: 3.3535, according to PN: PA11) was purchased in the form of a sheet 4 mm thick in the H22 state of cure. This alloy is characterized by high resistance to corrosion in seawater and industrial atmosphere. It is characterized by high fatigue strength. It is designed for elements joined by welding. EN AW-5754 is used for structural components of transport, for welded constructions, pressure vessels, piping elements, pneumatic and hydraulic lines, for pillars and road markings. Table 1 presents the results of tests of mechanical properties under tensile loads.

Tab. 1: Static properties of aluminum alloy EN AW-5754 under tensile loads.

	Static properties of aluminum alloy EN AW-5754					
	$R_{p\,0,2}$	R_m	E	G	A_{50}	ν
	MPa	MPa	MPa	MPa	%	---
1	2	3	4	5	6	7
Average value	142.0	220.0	70500	26500	22.0	0.33

2.2. Properties of the structural element

Calculations of fatigue life were made for a welded element (Fig. 1). The parameters of the fatigue life chart are: m_1 = 4.3 and m_2 = 6.3. The category of fatigue for an element is 45 ($\Delta\sigma_c$ = 45 MPa (for N_c = $2 \cdot 10^6$ cycles) (data according to EN 1999-1÷3: 2007 + A1: 2011).

a) b)

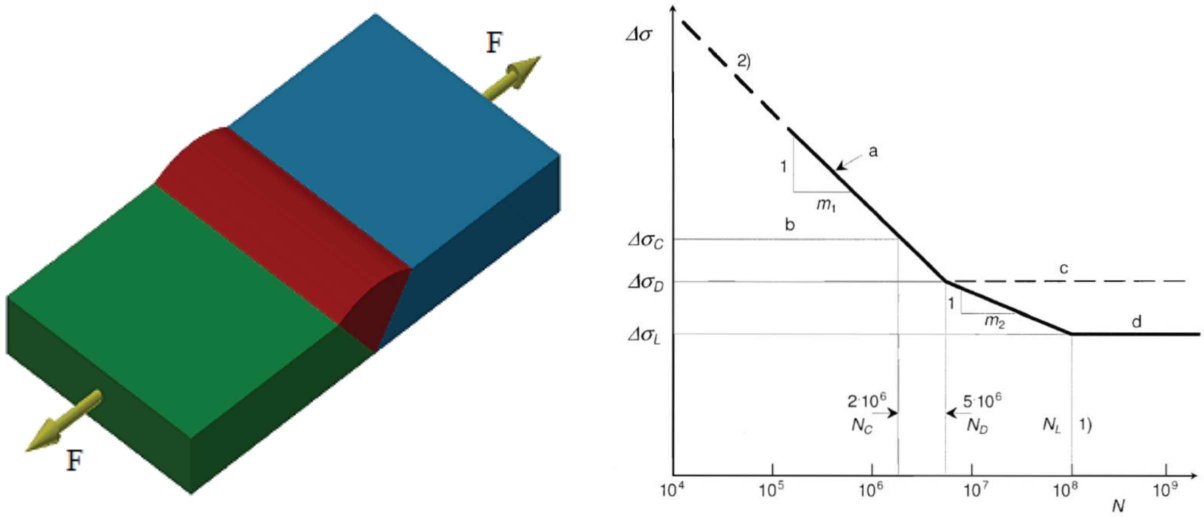

Fig. 1: The shape of the structural element with a butt weld connecting simple elements (a) and a schematic representation of the fatigue life diagram (b) based EN 1999-1÷3: 2007.

The calculations were carried out for variable-amplitude loads with a constant mean value $\sigma_m = 0$, which were presented in the form of block load spectra. For the accepted spectra, the fill factor was determined from the formula (1):

$$\xi = \sum_{i=1}^{k} \frac{\sigma_{ai}}{\sigma_{a\,max}} \cdot \frac{n_i}{n_c} \tag{1}$$

The value of the spectral duty factor is for:

- spectra I – ξ = 0.7004,
- spectra II – ξ = 0.4684,
- spectra III – ξ = 0.3419.

Fatigue calculation results for individual spectra are presented in the tables: 2, 3. and 4.

Tab. 2: Parameters of the I load spectra and fatigue failure result Di

Stage number in the spectrum	Spectrum I: ni cycles	Spectrum I: σ_{ai} MPa	The slope of the straight line graph m_1 and m_2	N_i	D_i
1	80	80	$m_1 = 4.3$ $N_D = 36.4$ MPa	168496	$4.748 \cdot 10^{-4}$
2	100	75		222387	$4.497 \cdot 10^{-4}$
3	120	70		299190	$4.011 \cdot 10^{-4}$
4	100	65		411469	$2.430 \cdot 10^{-4}$
5	200	60		580510	$3.445 \cdot 10^{-4}$
6	300	55		843909	$3.555 \cdot 10^{-4}$
7	400	50		1271390	$3.146 \cdot 10^{-4}$
8	30	45		2000000	$1.500 \cdot 10^{-5}$
9	35	40		3318784	$1.055 \cdot 10^{-5}$
10	40	35	$m_2 = 6.3$ $N_D = 36.4$ MPa	9742470	$4.106 \cdot 10^{-6}$
11	45	30		25730702	$1.749 \cdot 10^{-6}$
12	50	25		81154854	$6.161 \cdot 10^{-7}$
n_c	1500	---		D =	0.00262
ξ	0.7004				

Tab. 3: Parameters of the II load spectra and fatigue failure results Di

Stage number in the spectrum	Spectrum II: ni cycles	Spectrum II: σ_a MPa	The slope of the straight line graph m_1 and m_2	Ni	Di
1	2	80	$m_1 = 4.3$ $N_D = 36.4$ MPa	168496	$1.187 \cdot 10^{-5}$
2	15	75		222387	$6.745 \cdot 10^{-5}$
3	31	70		299190	$1.036 \cdot 10^{-4}$
4	45	65		411469	$1.094 \cdot 10^{-4}$
5	56	60		580510	$9.647 \cdot 10^{-5}$
6	69	55		843909	$8.176 \cdot 10^{-5}$
7	92	50		1271390	$7.236 \cdot 10^{-5}$
8	120	45		2000000	$6.000 \cdot 10^{-5}$
9	165	40		3318784	$4.972 \cdot 10^{-5}$
10	200	35	$m_2 = 6.3$ $N_D = 36.4$ MPa	9742471	$2.053 \cdot 10^{-5}$
11	290	30		25730703	$1.127 \cdot 10^{-5}$
12	415	25		81154855	$5.114 \cdot 10^{-6}$
n_c	1500	---		D =	0.00069
ξ	0.4684				

Tab. 4: Parameters of the II load spectra and fatigue failure results Di

Stage number in the spectrum	Spectrum III: ni cycles	Spectrum III: σ_a MPa	The slope of the straight line graph m_1 i m_2	Ni	Di
1	1	80	$m_1 = 4.3$ $N_D = 36.4$ MPa	168496	$5.935 \cdot 10^{-6}$
2	0	75		222387	0
3	1	70		299190	$3.342 \cdot 10^{-6}$
4	0	65		411469	0
5	1	60		580510	$1.723 \cdot 10^{-6}$
6	9	55		843909	$1.066 \cdot 10^{-5}$
7	25	50		1271390	$1.966 \cdot 10^{-5}$
8	40	45		2000000	$2.000 \cdot 10^{-5}$
9	50	40		3318785	$1.507 \cdot 10^{-5}$
10	60	35	$m_2 = 6.3$ $N_D = 36.4$ MPa	9742471	$6.159 \cdot 10^{-6}$
11	70	30		25730703	$2.720 \cdot 10^{-6}$
12	1243	25		81154855	$1.532 \cdot 10^{-5}$
n_c	1500	---		D =	0.00010
ξ	0.3419				

The linear hypothesis of Palmgren-Miner fatigue additive calculation, which is described in formula (2), is used in calculations:

$$D = \sum \frac{n_i}{N_i} = 1{,}0 \tag{2}$$

On the basis of the calculations made for the fatigue failure D, the fatigue life of the structural element was calculated in the conditions of variable-amplitude load for the assumed load spectra.

The fatigue strength calculation results are:

- spectrum I - $\xi = 0.7004$, $D = 0.00262$, $\lambda = 1/D = 382.4$, $N = \lambda \cdot n_c =$ **573 567 cycles**,

- spectrum II - $\xi = 0.46842$, $D = 0.00069$, $\lambda = 1/D = 1450.3$, $N = \lambda \cdot n_c =$ **2 175 433 cycles**,

- spectrum III - $\xi = 0.3419$, $D = 0.00010$, $\lambda = 1/D = 9941.4$, $N = \lambda \cdot n_c =$ **14 912 130 cycles**.

3. Conclusions

In the calculation of fatigue life, the analytical method SLD (safe life design) was used. This method is based on the calculation of fatigue failure cumulation using standard fatigue life data. The welded element with full butt weld made of aluminum alloy was calculated. The obtained results of calculations show the effect of the value of the spectral load factor on the fatigue life of the structural element. As the value decreases, the value of fatigue damage decreases. The value of coefficient ξ is determined by the number of cycles with high amplitudes σ_{ai} in the operational course of loads.

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