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FATIGUE LIFE TESTS OF THICK BONDLINE ADHESIVELY-BONDED JOINTS UNDER CONSTANT AMPLITUDE LOADING CONDITIONS

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Abstract: *The study presents the test results of thick bondline adhesive-bonded joints in variable load conditions at loading cycle asymmetry coefficient R = 0. The study included the following samples: G1 group (without aging), G5 group (samples stored for 4 weeks in water at 20 ºC) and G7 group (samples stored for 1 week in water at 20 ºC, and sealed air-tight for 1 week in a water and moisture barrier film at 70ºC). Fatigue life results for G1 and G5 samples do not show significant differences for each load level indicating that the ageing conditions used for G5 samples did not affect the fatigue life. The comparison of the S-N curves for G1 and G7 samples shows significant differences indicating that the ageing conditions used for G7 samples resulted in an increase in fatigue life compared to G1 samples without ageing). Significant differences can be observed depending on the load level.*

Keywords: adhesive joint, rail vehicle, aging of adhesive joints, fatigue life, S-N curves

1. Introduction

Gluing permits obtaining joints in which no installation stresses occur, which lowers internal tensions in large-size rail structures, including, among others, rail car bodies. One of the more frequent application of gluing technology in presently manufactured rail vehicles is fixture of external plastic or metallic plating to metal frame, and installation of internal equipment of cars. Fatigue research of thin sheet metal for similar applications were conducted by Tomaszewski and Strzelecki (2016). When fixing skin plates to the car framing, the glued joint must perform several functions. The primary function is stable and reliable joining of the elements. Another function is eliminating inaccuracies in making of the car framing, and adequate mutual amortization of the glued elements, so that any tensions from the framing occurring while driving are not transferred onto the car plating. For this reason, thick-layer glued joints are applied in framing-plating type connections. The joint obtained must feature adequate elasticity in order to correctly perform its functions. During operation of the vehicle, these types of joints are exposed to variable load, and to the effect of variable atmospheric conditions, including temperature, humidity, saltiness, sunlight. Therefore, the glues applied for these types of joints must feature resistance to the factors mentioned.

Adhesive-bonded joints in operating conditions may be subject to loads, including high variability σ_m and σ_a cycles. The variability range σ_m and σ_a is determined by various factors and the operating conditions.

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The nature of operating loads significantly affects the fatigue life of machine components and is related with the number of cycles at high amplitude σ_a, stress variability range $\Delta\sigma$ and the course of the changes.

The purpose of the study was to evaluate the fatigue life of thick bondline adhesive-bonded joints aged in variable loading conditions at cycle asymmetry coefficient R = 0.

2. Method and results of tests

The material glued was a sheet of 1.6 mm thickness made of X2CrNi12 steel (PN-EN 10027-1: 2007). The shape of the sample resulted from the guidelines of PN-EN 1465:2009 standard. Strips of length 100 and width 20 mm were cut from the sheet. The strips were degreased (BETACLEAN 3350 degreaser), and then ground with fine-grained sand paper (granulation 180) at the area to which the joint will be applied. Then, they were degreased with the same product again. For gluing, the strips were placed in a special shape that ensures proper positioning of the plates relative to each other, and thus the required shape and dimensions of the joint (according guidelines of DVS 1618:2002). BETAMATE BTR glue was used for gluing. Gluing was performed in strictly controlled conditions, i.e. 20 ºC temperature and 23% humidity. Then, the samples were left in holder used to gluing for 7 days in the same conditions. This procedure is required during gluing in instruction DVS 1618:2002 – the aim is to dry the adhesive. Next the samples were aged. The shape of a ready sample is presented in Figure 1. After aging, the samples were kept for 2 hours in ambient temperature (DIN 54457), after which the tests were performed. Examples of tests in static conditions are presented in the paper (Mackowiak, Ligaj, 2017).

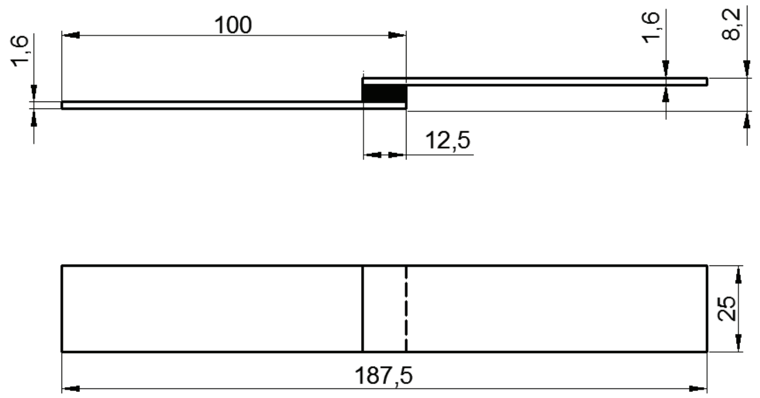

Fig. 1: Shape and dimensions of the test specimen.

The specimens were aged according to the guidelines specified in DIN 54457 and ISO 9142. Sample aging methods are specified in Table 1. The specimens made were divided into three groups. Nine specimens were tested in each group.

Tab. 1: Specimen aging method (Topoliński, Ligaj, Mazurkiewicz, Miterka, 2017).

Specimen number	Group number	Aging method	Static destructive force		Number of specimen for fatigue test
			F_{max}(Av)	SD	
1	2	3	4	5	6
1	G1	Specimens not aged	1401.6 N	*156.3 N*	9
2	G5	Specimens stored for 4 weeks in water in 20 ºC temperature	1370.6 N	*158.9 N*	9
3	G7	Specimens stored for 1 week in water in 20 ºC temperature, then tightly closed (using foil not permitting air and humidity) in 70 ºC temperature (so-called cataplasma test)	1125.4 N	*138.2 N*	9

SD – standard deviation

Fatigue tests of adhesive joints were carried out under of force control. The load sequence of the structural element during tests is constant-amplitude loads with the cycle asymmetry coefficient R = 0. A detailed research program was showed in Table 2.

Based on the test results for thick bondline adhesive-bonded joints in variable load conditions at cycle asymmetry coefficient R = 0, the following fatigue life equations were determined:

- for G1 samples: $\log \tau_a = -0.1615 \log N + 0.7417$,
- for G5 samples: $\log \tau_a = -0.1664 \log N + 0.7489$,
- for G7 samples: $\log \tau_a = -0.1679 \log N + 0.7442$.

Tab. 2: The program of fatigue testing under constant-amplitude conditions.

Specimen number	Group number	Specifics and levels of loads during testing		
		Coefficient R	Amplitude of load F_a [N]	Average amplitude shear stress τ_a [MPa]
1	2	3	4	5
1	G1	0	1000	3.20
2			600	1.92
3			400	1.28
4	G5	0	1000	3.20
5			600	1.92
6			400	1.28
7	G7	0	1000	3.20
8			600	1.92
9			400	1.28

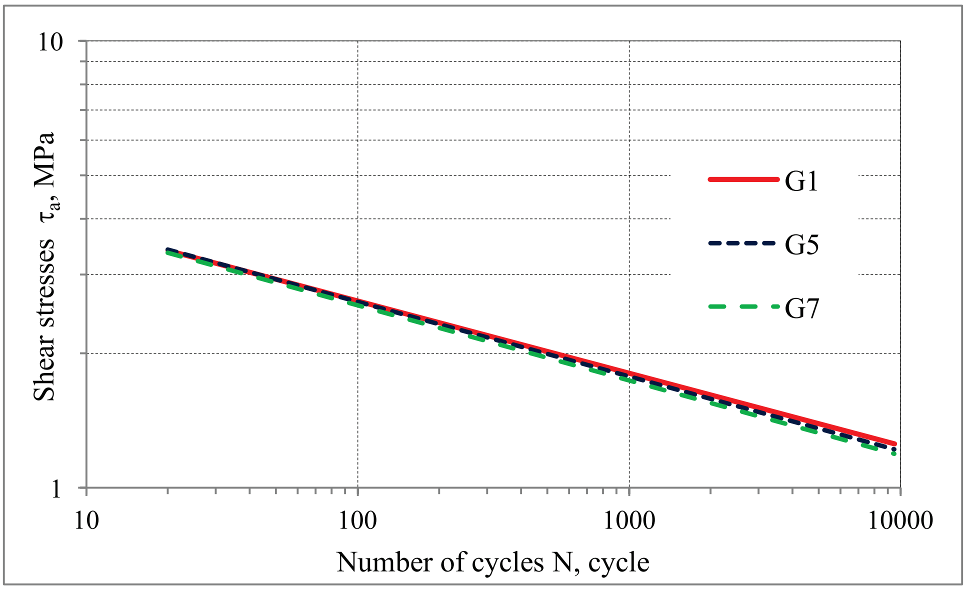

Fig. 2: S-N curve fatigue life.

Differences between the fatigue life diagrams developed on the basis of experimental tests were analyzed on the basis of the values of relative life difference δ calculated from equation:

$$\delta = \frac{N_{G\_i} - N_{G1}}{N_{G1}} \cdot 100\% \qquad (1)$$

where:

N_{G1} – number of cycles till fatigue crack for group G1.

N_{G_i} – number of cycles till fatigue crack for groups G5 and G7.

Tab. 3: Values of relative differences in fatigue lives δ.

Average amplitude shear stress τ_a [MPa]	Relative differences in fatigue life	
	$\delta_{G5\text{-}G1}$	$\delta_{G7\text{-}G1}$
3.20	0.09%	-9.0%
1.92	-8.8%	-19.3%
1.28	-15.2%	-26.6%

The results of experimental tests for specimens G1 served as the point of reference for the analysis. Values of relative differences in fatigue lives δ_N (Tab. 3) define quantitatively the mutual the position of fatigue characteristics.

3. Conclusions

The experimental test results for thick bondline adhesive-bonded joints in variable load conditions at cycle asymmetry coefficient R = 0, show high coincidence of the results between G1-G5 and G1-G7 samples. Its indicate, that the ageing conditions used for G5 samples (stored for 4 weeks in water at 20 ºC) and G7 sample (stored for 1 week in water in 20 ºC temperature, then tightly closed) did not affect at the differences in fatigue life compared to G1 group. Analysis of the test results shows that the difference in the fatigue life value increasing with the decreasing in the amplitude of load. The differences should be considered as small, contained within the confidence interval for the fatigue life chart for G1 samples. This form of results can be explained by the area of experimental research, contained with the scope of quasi- and low-cycle fatigue. High levels of stress amplitude lead to large strains that cause changes in the adhesive structure. Along with the decreasing in the stress amplitude value, the deformation decreasing, which increasing the durability. If the values of strain are smaller, the properties of adhesive have a greater impact on fatigue life, which change also under the influence of the aging process.

In the aim determine of the cause of the differences in results, further studies at lower load levels within the high-cycle fatigue range or test with stepwise increasing amplitude will be carried out according to the procedure described by Topolinski et al., 2012 and Wirwicki et al., 2013.

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