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INVESTIGATIONS OF FATIGUE STRENGTH OF SANDWICH PLATES

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The results of investigations of mechanical properties of the polyvinyl chloride foam and the epoxide composite reinforced by glass clothes and their fatigue life are presented. The fatigue life and the dependence of the structure degradation on the number of cycles of the sandwich plate subject to bending are also given. The plate was composed with the core made of the polyvinyl chloride foam and the face sheets of the epoxide composite reinforced by glass clothes.

Key words: mechanical properties, fatigue investigations, fatigue life, structure degradation, sandwich plate, polyvinyl chloride foam, epoxide composite reinforced by glass clothes UKD symbols.

1. Introduction

In the last years there was an increase of interest in the modern constructional materials such as sandwich constructions (sandwich plates). They are characterized by: very advantageous ratio of weight to the stiffness and the strength, good vibration damping and good insulation properties. Due to the mentioned advantages, sandwich constructions find greater and greater application in air- and car-industries as well as in the shipbuilding, the railroad engineering and the building. The faults of the constructions are: increased technological requirements and lack of the resistance to the action of concentrated forces (proper nodes for carrying these forces should be used).

Using sandwich structures on elements of real constructions requires a proper knowledge of these material properties at different loadings and environments. It seems to be purposeful to make theoretical and experimental investigations of sandwich constructions made of elementary components (face sheets-core).

2. The subject of investigation

The test pieces of sandwich construction shape (sandwich plate) consisting of face sheets made of the epoxide-glass composite with the thickness of 1 mm and the core of the polyvinyl chloride foam were taken into investigation. The epoxide-glass composite was made of the Epidian-53 resin and the glass cloth STR-58 of home production, with the same number of weft and warp fibres. The face sheet was made of two layers of the cloth.

The polyvinyl chloride foam is the part of the core of the investigated sandwich plate, type PChW-1-115, density 115 kg/m^3. Test pieces, their shapes and dimensions being presented in Fig. 1, are made of the sandwich plate with the dimensions 150×200 mm. Whereas, in Fig. 2 the test piece made of polyvinyl chloride for fatigue investigations is presented. The pads of aluminium alloy PA-2 for strengthening the places to which the load is transmitted were used.

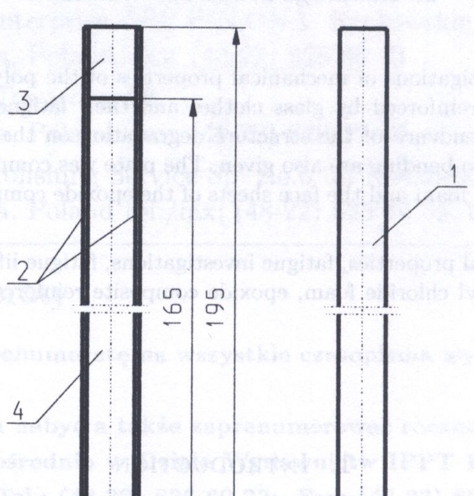

Fig. 1. The shape and dimensions of the test piece used in testing; 1 – test piece, 2 – face sheet, 3 – pads of aluminium alloy, 4 – core.

In static investigations the basic mechanical properties of polyvinyl chloride foam, presented in Table 1, and epoxide composite strengthened by glass clothes, presented in Figs. 3–5, were described. The angle ϕ in these figures is the angle between the direction of the loading and the direction of cloth warp.

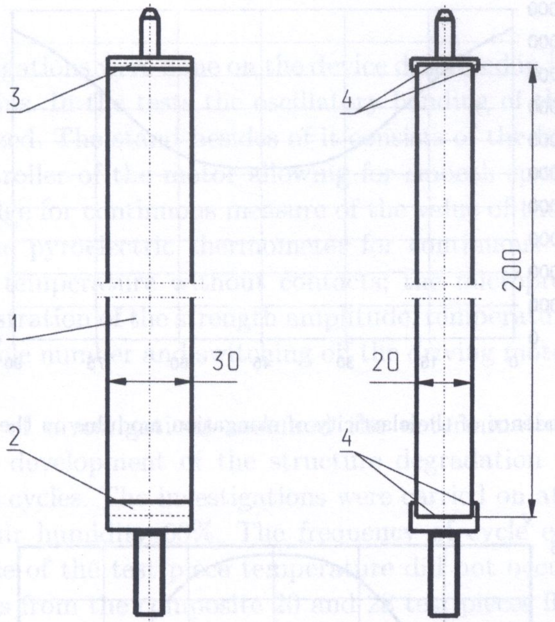

FIG. 2. The shape and dimensions of the test piece for fatigue investigations; 1 – polyvinyl chloride foam, 2 – lower holder, 3 – upper holder, 4 – adhesive layer.

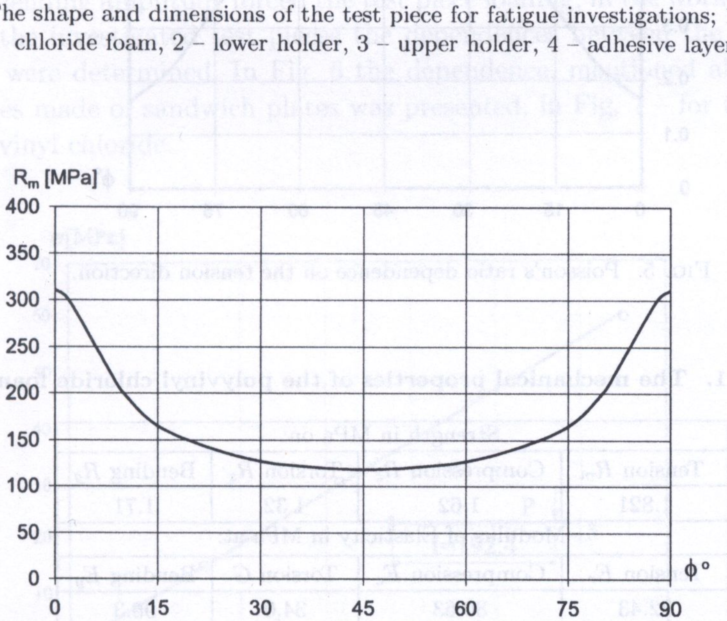

FIG. 3. Tensile strength dependence on the direction of the loading.

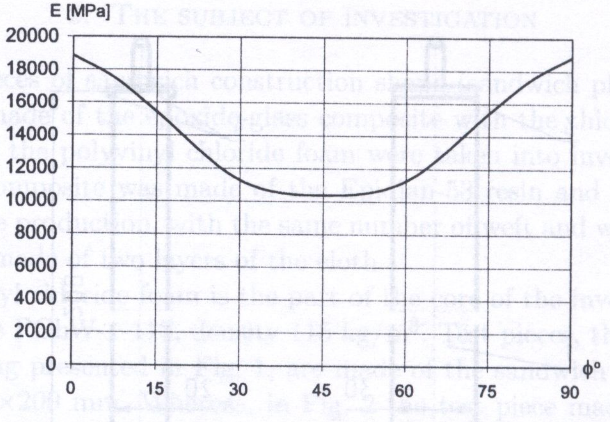

FIG. 4. The dependence of the elasticity of elongation modulus on the tension direction.

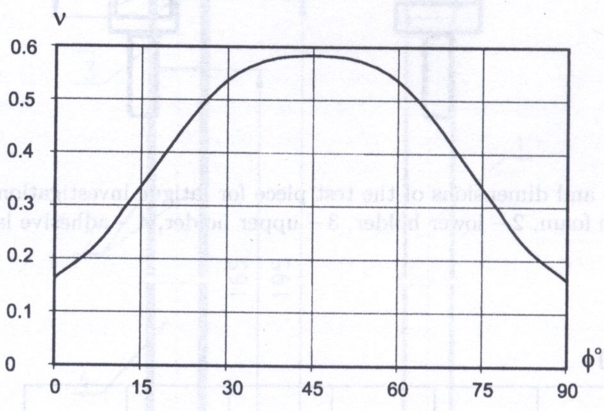

FIG. 5. Poisson's ratio dependence on the tension direction.

Table 1. The mechanical properties of the polyvinyl chloride foam.

Strength in MPa on:			
Tension R_m	Compression R_c	Torsion R_s	Bending R_g
1.821	1.62	1.32	1.71
Modulus of Elasticity in MPa at:			
Tension E_r	Compression E_c	Torsion G	Bending E_g
92.43	80.63	34,0	98.3
Poisson's ratio at:			
Tension ν_r		Compression ν_c	
0.262		0.260	

3. The methods of investigations

Fatigue investigations were done on the device described in [1] at the constant amplitude of strains. In the tests the oscillatory bending of the cycle character $R = -1$ was realized. The stand besides of it consists of the following elements: the thyristor controller of the motor allowing for smooth speed regulation, the extensometer bridge for continuous measure of the value of the strength loading the test piece, the pyroelectric thermometer for continuous measuring of the tested test piece temperature without contacts; the microprocessor controller SAJA for the registration of the strength amplitude, temperature and time as the function of the cycle number and switching off the driving motor after damaging the test piece.

The program of investigations assumed the determination of the fatigue, stability and the development of the structure degradation with the number of sandwich plate cycles. The investigations were carried on at the temperature of 18±1°C and air humidity 60%. The frequency of cycle equal to 4 Hz, by which the increase of the test piece temperature did not occur, was stated. 21 test pieces, linings from the composite 20 and 28 test pieces from the sandwich plate were taken into the fatigue investigations of the core material.

The bending amplitude forced the test piece loading, in the workstand, therefore for the investigated test pieces the dependences between the stresses and bending were determined. In Fig. 6 the dependence, mentioned above, for the test pieces made of sandwich plates was presented, in Fig. 7 – for test pieces of the polyvinyl chloride.

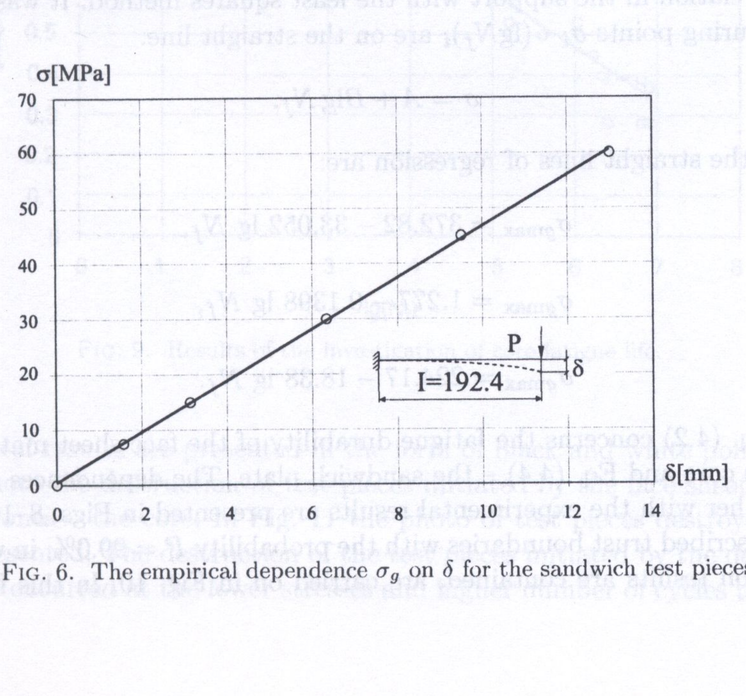

FIG. 6. The empirical dependence σ_g on δ for the sandwich test pieces.

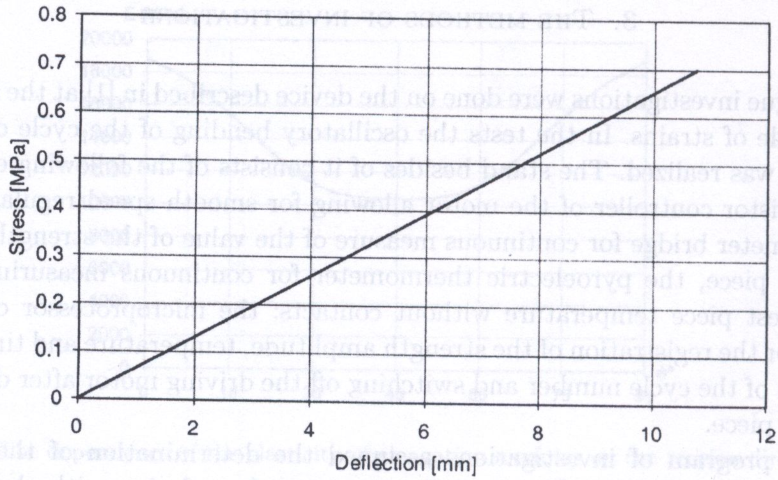

FIG. 7. The dependence on the maximal stresses and bending for test pieces made of the polyvinyl chloride.

4. Determination of durability on the principle of the experimental results

The results obtained from the fatigue investigations of the face sheet, the core and the sandwich plate presented in semi-logarithmic co-ordinates, could be approximated by a straight line. This dependence was determined by the linear correlation in the support with the least squares method. It was assumed that measuring points $\sigma_i - (\lg N_f)_i$ are on the straight line:

$$\sigma = A + B \lg N_f. \tag{4.1}$$

This way the straight lines of regression are:

$$\sigma_{g\max} = 372.82 - 33.052 \lg N_f, \tag{4.2}$$

$$\sigma_{g\max} = 1.277 - 0.1398 \lg N_f, \tag{4.3}$$

$$\sigma_{g\max} = 224.17 - 18.38 \lg N_f. \tag{4.4}$$

The Eq. (4.2) concerns the fatigue durability of the face sheet material, Eq. (4.3) – the core and Eq. (4.4) – the sandwich plate. The dependences (4.2) and (4.4) together with the experimental results are presented in Figs. 8–10.

The described trust boundaries with the probability $P = 99.0\%$, in which the investigation results are contained, are carried on in Fig. 10. In this figure the

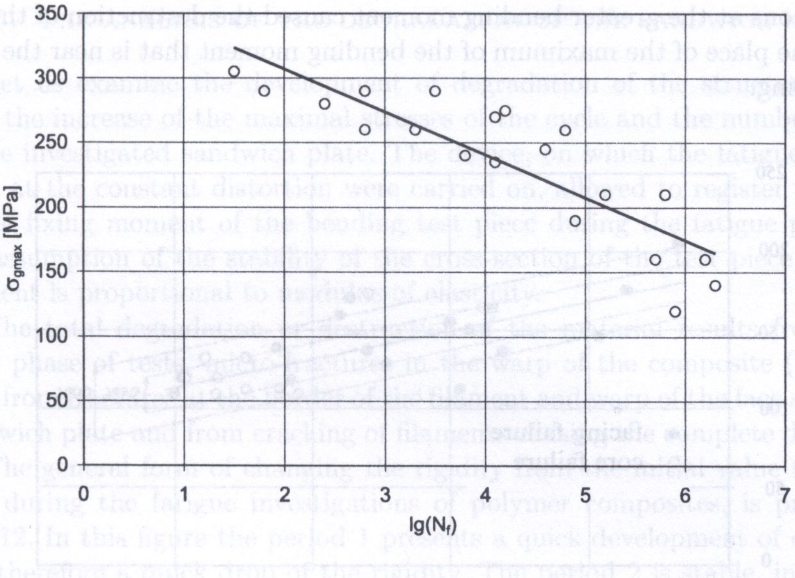

FIG. 8. Results of the investigation of face sheet fatigue life.

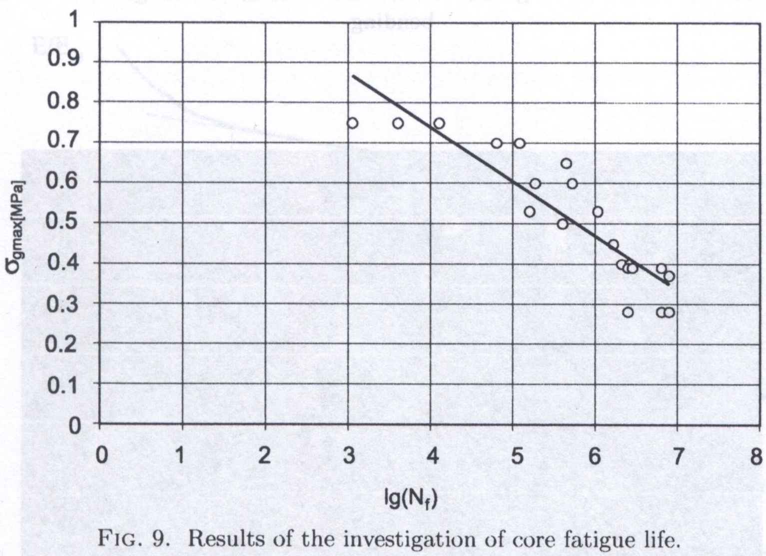

FIG. 9. Results of the investigation of core fatigue life.

experimental results are presented in the form of black and white points. Black points denote the destruction of test pieces initiated by the face sheet, whereas the white ones – the core. In Fig. 11 the photo of test pieces destroyed during tests is presented. The destruction of the test pieces initiated by the destruction of the core occurred at the lower stresses and higher number of cycles to destroy.

Investigations at the greater bending moment caused the destruction of the face sheet at the place of the maximum of the bending moment that is near the place of restraining.

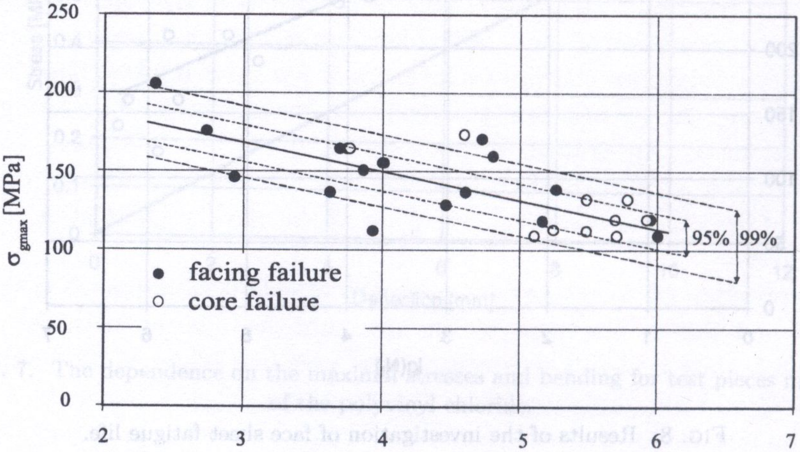

FIG. 10. Results of the investigation of sandwich structure for fatigue life in oscillatory bending.

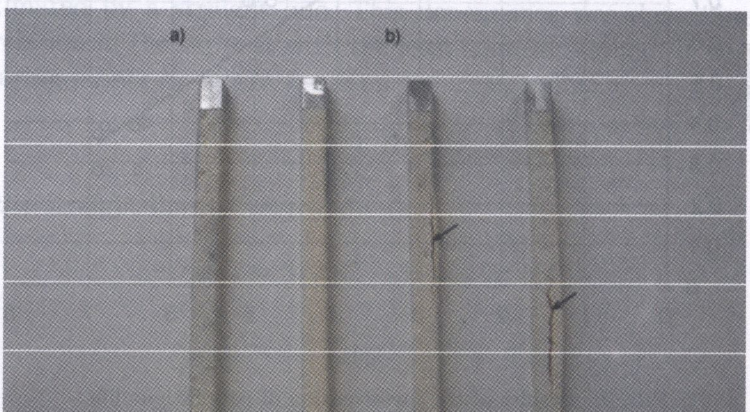

FIG. 11. The photo of test pieces destroyed after investigations.

5. The analysis of the degradation of the sandwich plates

Let us examine the development of degradation of the structure together with the increase of the maximal stresses of the cycle and the number of cycles of the investigated sandwich plate. The device, on which the fatigue investigations at the constant distortion were carried on, allowed to register the change of the fixing moment of the bending test piece during the fatigue process. At the assumption of the stability of the cross-section of the test piece, the fixing moment is proportional to modulus of elasticity.

The total degradation or destruction of the material results from, at the early phase of tests, micro-fractures in the warp of the composite (resin), and then from fractures at the border of the filament and warp of the face sheet of the sandwich plate and from cracking of filaments causing the complete destruction.

The general form of changing the rigidity from the initial value to the final one, during the fatigue investigations of polymer composites, is presented in Fig. 12. In this figure the period 1 presents a quick development of destruction and therefore a quick drop of the rigidity. The period 2 is stable, in which the speed of the elasticity module is constant and in the period 3 the rigidity changes violently, leading to the final destruction.

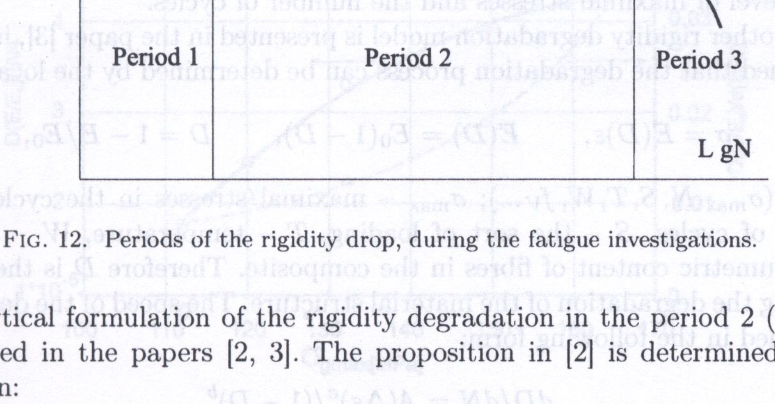

FIG. 12. Periods of the rigidity drop, during the fatigue investigations.

Analytical formulation of the rigidity degradation in the period 2 (Fig. 12) is proposed in the papers [2, 3]. The proposition in [2] is determined by the expression:

$$N_f \cdot S^m = C. \tag{5.1}$$

C and m are constants, N_f is the cycle number for destruction, S is the parameter dependent on σ or ε. The most frequently the stresses referred to modulus

(σ_0/E_0) are denoted as S, where E_0 is the initial elasticity modulus. The dependence dE/dN from the linear part of the diagram (Fig. 12), determines the speed of the rigidity drop. In the general form the dependence can be taken as $E/E_0 = f(N)$. The rigidity drop in dependence on the number of cycles N can be described by the straight line equation:

$$E/E_0 = AN + B. \tag{5.2}$$

Differentiating Eq. (5.2) with respect to the cycle number, the rigidity drop is obtained:

$$d\left(\frac{E}{E_0}\right)\Big/ dN = A(\sigma). \tag{5.3}$$

A is the only function of stresses, so we can write:

$$\frac{d(E/E_0)}{dN} = -K\,(\sigma/E_0)^m = A(\sigma). \tag{5.4}$$

Integrating Eq. (5.4) we obtain:

$$\int\limits_0^{E/E_0} d(E/E_0) = \int\limits_0^N -K(\sigma/E_0)^m dN, \tag{5.5}$$

$$E/E_0 = 1 - K(\sigma/E_0)^m N. \tag{5.6}$$

Equation (5.6) presents the current degradation of the rigidity in dependence on the level of maximal stresses and the number of cycles.

The other rigidity degradation model is presented in the paper [3], in which it is assumed that the degradation process can be determined by the local rigidity:

$$\sigma = E(D)\varepsilon, \qquad E(D) = E_0(1-D), \qquad D = 1 - E/E_0, \tag{5.7}$$

$D = D(\sigma_{\max}, N, S, T, W, f_V ...)$; $\sigma_{\max}$ – maximal stresses in the cycle, N – the number of cycles, S – the sort of loading, T – temperature, W – humidity, f_v – volumetric content of fibres in the composite. Therefore D is the function reflecting the degradation of the material structure. The speed of the degradation is assumed in the following form:

$$dD/dN = A(\Delta\varepsilon)^c/(1-D)^b, \tag{5.8}$$

A, b, c – constants, which are determined on the basis of the experimental results.

From the experimental measurement of the moments of the fixing of the test piece, together with the increase of the cycle number, the dependences of changes of elasticity modules at the bending for different stable stresses of amplitudes equal to: 112, 120, 132, 149 and 166 MPa, were described. From Eqs. (5.1)–(5.6) the dependences of the drop of the elasticity modulus, in dependence on the cycle number and values of stresses assumed in the investigations of the sandwich plate, were computed. The dependences are presented in Fig. 13, where each curve for σ_{max} = const is the average value from three test pieces. These dependences have three periods of the rigidity drop similar to that shown in Fig. 12.

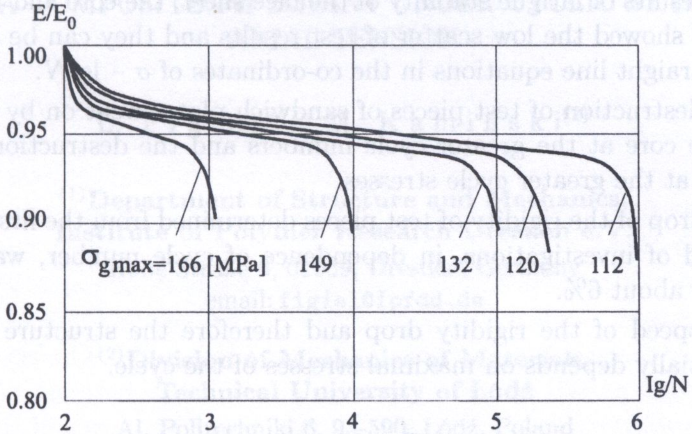

FIG. 13. The dependence of the relative drop of the elasticity modulus on the cycle number for the chosen maximal stresses.

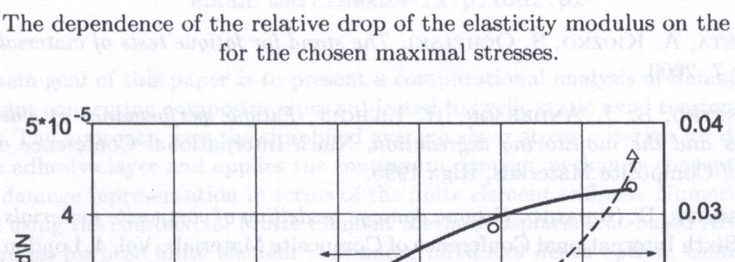

FIG. 14. The speed of changes of E modulus as a function of maximal stresses.

From the relations presented in Fig. 13, using the graphic differentiation of the straight segments of the dependence $E/E_0 - \lg N$, the speed changes of rigidity

$d(E/E_0)/dN$ in dependence on maximal stresses of the amplitude were obtained. The results of these computations are presented in Fig. 14, which follow from the considerable increase of the speed of the decrease of the module together with the increase of maximal amplitude stresses.

6. Conclusions

1. The results of fatigue stability of the face sheet, the core and the sandwich plate, showed the low scatter of test results and they can be described by the straight line equations in the co-ordinates of σ – lg N.
2. The destruction of test pieces of sandwich plates went on by the shearing of the core at the greater cycle numbers and the destruction of the face sheet at the greater cycle stresses.
3. The drop of the rigidity of test pieces determined from the first and second period of investigations, in dependence of cycle number, was small and totals about 6%.
4. The speed of the rigidity drop and therefore the structure degradation essentially depends on maximal stresses of the cycle.

References

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