UDC 691
DOI 10.36622/VSTU.2022.53.1.004

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INFLUENCE OF THE SELF-HEATING TEMPERATURE ON THE CYCLIC DURABILITY OF COMPOSITE MATERIALS

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Statement of the problem. Various methods of accelerated testing are used to determine the endurance of polymer composite materials. One of these methods is the temperature method which has its own limitations. Thus the possibility of its application for epoxy polymer materials should be established.
Results. The article suggests a formula for identifying the value of the fatigue life of an epoxy composite material. The reliability of the values calculated using this formula is experimentally established. It is proved that the intensity of the temperature increase depends on the loading speed.
Conclusions. The reliability of the calculations according to the suggested formula for calculating the fatigue life indicators is confirmed by comparing the results with the experimental data, the values are quite closely correlated allowing the formula to be used while calculating the endurance for samples made of epoxy composite.

Keywords: polymer composite material, endurance limit, self-heating temperature, cycle asymmetry coefficient.

Introduction. There are currently several endurance test methods [8, 12—20]. One of such methods is the temperature method [1, 2, 6]. It can be employed for metals and a number of plastics. Also, the temperature method can be made use of in endurance testing of polymer composite materials [3, 5, 10, 11].

The objective of the study is to reduce labor costs for fatigue testing of specimens made of epoxy composite material by identifying the fatigue resistance using a formula that includes the self-heating temperature index. This possibility is due to low values of the thermal conductivity coefficient, an increase in hysteresis losses with a linear nature of the hysteresis stress, and low softening temperatures of the epoxy composite materials tested for cyclic loading.

1. Applied materials and test methods. For the manufacture of samples, polymer concrete mixes based on epoxy and furan-epoxy resins were used. Epoxy resin ED-20 (GOST 10587-84) was used as a binder. It is a highly viscous liquid.

Dynamic viscosity at the temperature of 25 °C is 12—25 Pa/sec. The content of epoxy groups is 19.3—22.0 %. Gelatinization time with a hardener is no less than 4—5 hours. The density of the resin is 1.16 g/cm^3 and the flash point is 270 °C. Epoxy resin ED-20 is a condensation product of epichlorohydrin and definolpropane, has a yellowish color; produced by Ltd. Khimprom, Ufa.

To plasticize and reduce the viscosity of the resin, a benzene-toluene-xillene fraction was used which is an intermediate product in the production of crude benzene. Its chemical composition in % by weight is the following: benzene — 72—75; toluene — 8—10; xylene, solvent — 3—4; naphtholin — 5—6; polymers — 1—3; acid tar — 1—2; the remainder — 1—10.

The plasticized epoxy resin has a density of 1.23 g/cm^3 and a viscosity B3-4 — 180 seconds.

Epoxy resin ED-20 is cured with polyethylenepolyamine (STU 49-2529-62).

For enhancing the composition strength, deformability and durability, aggregates were introduced into its composition: crushed granite, quartz sand and filler — andesite flour. Crushed stone density — 2.7 g/cm^3, average density — 2.5 g/cm^3, porosity — 3.75 %, compressive strength — 150 MPa, frost resistance — 100—150 cycles, water absorption — 0.22 %. Chemical composition: SiO2 — 53—80 %, Al2O3 — 11.21 %, TiO2 — 0.35—2 %, FeO — up to 1 %, FeO3 — 1.5 %. The size of crushed stone grains ranged from 5 to 10 mm.

Quartz sand with medium fraction was used (GOST 8736-77). The density is 2.6 g/cm^3, average density is 1.5—1.6 g/cm^3. The chemical composition is SiO2 — 97.3 %, CaO — 0.77 %, R2O3 — 0.16 %, others — 0.96 %. The size of sand grains is from 0.63 to 1.25 mm [4].

Andesite flour had a density of 2.6 g/cm^3 and a specific surface area of 0.28 m^2/g.

The production technology of the samples from polymer concrete mixes was carried out in compliance with the recommendations [9]. The mix was put into molds manually. Both metal and wooden molds were used, but treated with paraffin paper, which made free stripping possible, and further protected the samples from swelling through the course of holding and testing. The mix was compacted on a vibrating platform with a standard vibration frequency. After molding, the samples were kept for a day at a temperature of 18—20 °C, and then for 24 hours they were subjected to dry heating in a heat chamber at a temperature of 80 °C. The temperature rise was carried out at a rate of 0.5 °C per minute.

After the heating was complete, the heat chamber was turned off, and the samples were slowly cooled making it possible to avoid shrinkage cracks.

In order to identify the internal self-heating of polymer concrete samples, chromel — aluminum thermocouples, insulated with glass fiber and located inside the samples so that it was possible to detect temperature changes over the cross section and height of the sample, were used.

The dimensions of the samples for mechanical testing were assigned in compliance with the recommendations [7].

Fig. 1 shows the dimensions of the test specimens and strain gauge equipment. For tests with a short-term and repeatedly applied load, samples of 40 × 40 × 160 mm and 100 × 100 × 400 mm in the shape of prisms as well as beams of 40 × 80 × 1000 mm in size were made.

Fig. 1. Dimensions of test specimens and strain gauge equipment

2. Identifying the self-heating temperature. While performing endurance tests, the self-heating temperature was recorded using a self-recording device on a chart tape. This tool is connected to a temperature sensor which is in contact with the sample to be tested. The self-heating curve was recorded using electric and automatic potentiometers of the EPP type. The test results are self-heating temperature curves as shown in Fig. 2 depending on the coefficient of asymmetry of the load application cycle.

Fig. 3 shows the self-heating temperature curves of epoxy composite materials whose analysis shows that while examining more than 30—50 thousand cycles, the curve can be conditionally divided into three sections. The first section of the OA of a typical self-heating temperature curve (Fig. 4) is characterized by a rapid rise in temperature in the initial period of the study. The second section AB is a section of linear rise. The third section of the HP is characterized by a rapid increase in the temperature of self-heating prior to the destruction. In this case, destruction occurs at the end point D of the section. The coordinates of this point correspond to the temperature T_r and the number of loading cycles N_k where the sample is destroyed.

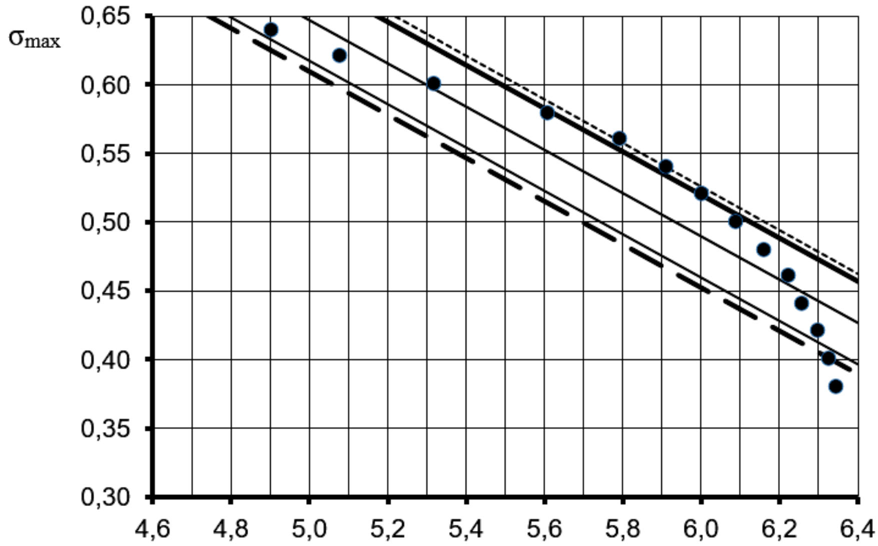

Fig. 2. Endurance line of epoxy composites under cyclic compression

Point E in Fig. 3 is the point of intersection of the tangents to the sections of the curve AB and VD. It is this point, and not point C, which is that of intersection of the extended straight section AB with the ordinate Dn_k which is suggested being taken as the foundation for determining the fatigue life in terms of identifying the value of the critical self-heating temperature T_{sk}. In this case, the value will be slightly higher than its true one, but constant within the measurement accuracy for any level of loading, which is proved by the experiments. Therefore according to the geometric relationships of the self-heating curve (Fig. 3), the fatigue life equals:

$$N_k = A\ ctg\alpha\left(T_{ck} - T_c\right),$$

where A is the scale factor which is identified according to the diagram behind the curve; T_c is the temperature cut off by the continuation of the rectilinear section of the curve on the temperature axis; α is the elevation angle of the straight section.

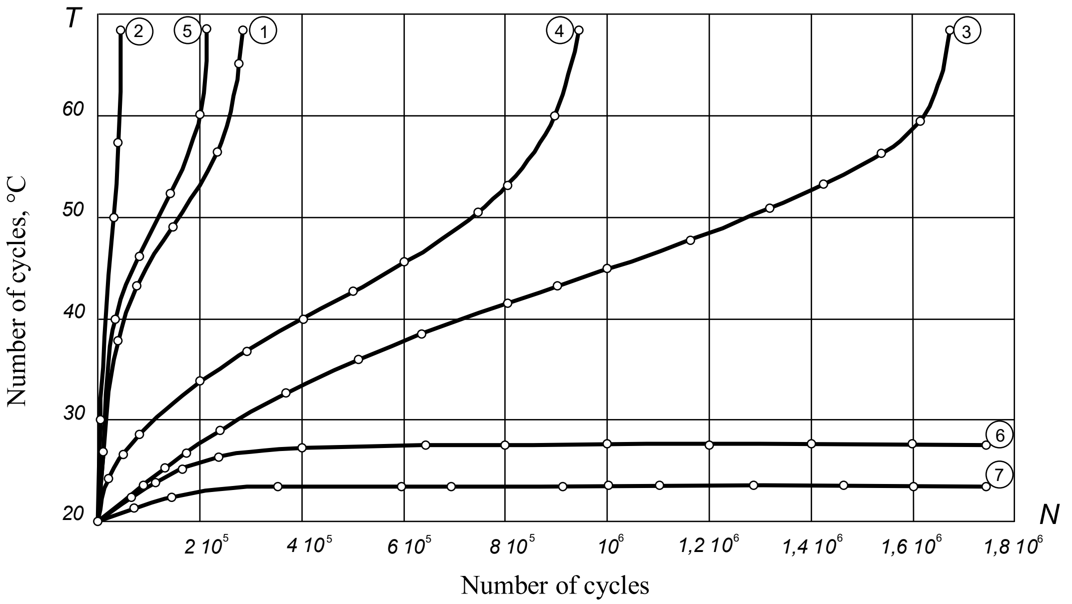

Fig. 3. Self-heating temperature curves of epoxy composite materials at ρ = 0.6:
1 — 0.52$R_в$; 2 — 0.58$R_в$; 3 — 0.42$R_в$; 4 — 0.46$R_в$;
5 — 0.54$R_в$; 6 — 0.4$R_в$; 7 — 0.38$R_в$

Thus having determined the values of the data included in the formula, T_{sc}, T_c and α, it is possible to predict the fatigue life based on the self-heating temperature depending, as shown in Fig. 4, on the coefficient of asymmetry and the magnitude of the applied load. So, at ρ= 0.6, the temperature on the surface of the samples at the moment of destruction is about 70 °C. The higher the loading level is, the more rapidly the temperature rises and the destruction of the sample occurs.

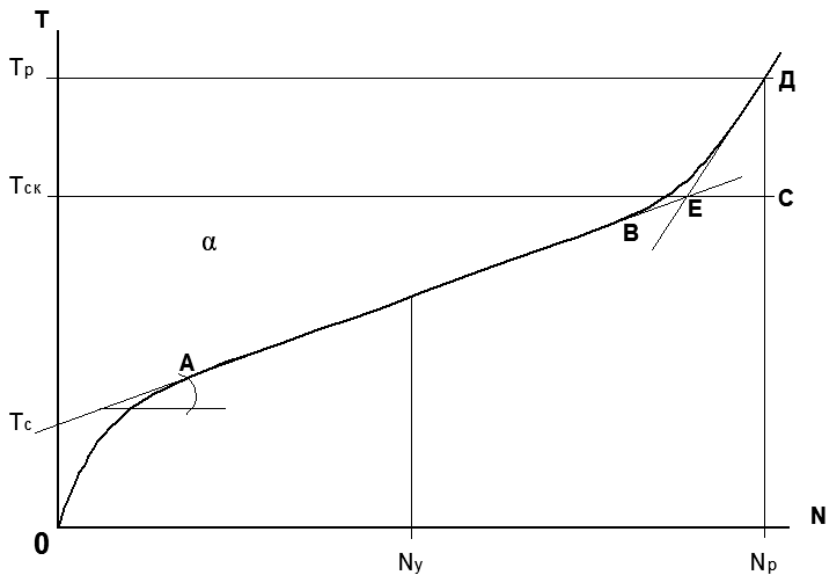

Fig. 4. Typical self-heating temperature curve
for samples of polymer composite materials

A comparative analysis of the experimentally obtained results with similar tests of FAM polymer concrete made it possible to establish that in some cases the temperature of destruction of a polymer composite based on ED-20 resin is 10—15 °C higher than that for FAM polymer concrete, in other cases they coincide.

Conclusions. The analysis of the obtained data made it possible to idenitfy that the deformation and strength indicators do not depend on the self-heating temperature (its value is too low) in cases of stresses occurring that are close in value to the endurance limit.

On top of that, it can be concluded that the rate of destruction of samples depends on the level of loading, and the applied load and the value of the cycle asymmetry coefficient affect the increase in the self-heating temperature.

Hence the reliability of calculations according to the suggested formula for calculating fatigue life indicators is confirmed by comparing the results with experimental data, the values correlate quite well. This formula can thus be employed for calculating the endurance for samples made of epoxy composite and considerably reducing labor costs for a large number of expe-riments.

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