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ANALYSIS OF STRENGTH CHARACTERISTICS OF COMPOSITE MATERIALS UNDER VIBRATION LOADS AT HIGHER TEMPERATURES

Keywords: organic-inorganic composites, material strength, yield point.

Abstract: This paper focuses on the analysis of mechanical properties of organic-inorganic polymeric hybrid material Multimetall "Stahl 1080" containing metallic particles. This material is designed for the regeneration of used metallic parts made of steel, cast iron, or composite materials. This type of material provides a 100% contact with the surface of the filled material, attenuation of vibration loads during the operation under strains, as well as protection against corrosion and tribological wear. The analysis concentrated on the behaviour of the material under vibration loads at higher temperatures.

Analiza charakterystyki wytrzymałościowej materiałów kompozytowych na drgania w wysokich temperaturach

Słowa kluczowe: organiczno-nieorganiczne kompozyty, wytrzymałość materiałów, granica plastyczności.

Streszczenie: W artykule zaprezentowano analizę właściwości mechanicznych materiału hybrydowego polimerowego organiczno-nieorganicznego Multimetall "Stahl 1080" zawierającego cząstki metaliczne. Materiał ten został zaprojektowany w celu regeneracji zużytych metalicznych części ze stali, żeliwa lub materiałów kompozytowych. Ten typ materiału zapewnia 100% przyleganie do powierzchni pokrywanego materiału, tłumi drgania, jak również chroni przed korozją i zużyciem tribologicznym. Analizę skoncentrowano na badaniu oddziaływania na materiał drgań w wysokich temperaturach.

Introduction

The increasing interest in highly resistant construction materials enhances the search for new materials that would meet these strength requirements. The organic-inorganic composites are the most advanced and versatile materials today. Generally, composites can be classified in view of the material from which the matrix has been made or the substance used for the reinforcing phase. The matrix can be made of Metal Matrix Composites (MMC), Ceramic Matrix Composites (CMC), or Polymer Matrix Composites (PMC) [1]. The type of substance used for the matrix significantly determines the useful properties of the composite. The fillers are usually made of inorganic metal powders and their oxides, and other inorganic compounds, i.e. amide fibres, glass fibres, and steel fibres obtained in various ways. The use of powder as a reinforcement phase increases the strength of the material and allows for transmitting bigger loads [1].

Among the most advanced groups of materials are polymeric compounds having a metallic organic structure. These compounds are formed by ions or metal clusters coordinated by ions with organic ligands. This group consists of organic-inorganic hybrid compounds. The metal-organic connection in these materials is disturbed by inorganic bridges or the linking of successive organic ligands to the metal-ligand matrix. Compounds, which are formed as a result of connection of metallic centres by various types of organic compounds, play the role of bridges. They have high mechanic properties, stemming from this particular structure, based on the connection of organic and inorganic phases [2].

The structures of hybrid materials linking inorganic and organic parts into a uniform whole in at least one dimension can be divided into the following two basic groups: (a) coordination polymers or porous Metal Organic Framework (MOF) with connections of metal–ligand–metal type, and (b) hybrids of metal oxides containing infinite matrices of metal-oxygen-

-metal connections as a basis of their structure. In the case of organic-inorganic crystalline hybrids, bivalent magnetic metals are connected by the added carboxyl or nitrogen groups, whereas single hydrogen atoms or organic chains make the organic part. These types of compounds are based on an organic polymer; therefore, the ultimate properties of the material depend on its thermal and mechanical properties. Advantageously, particular components of the polymer can be easily shaped and connected. Apart from this, the polymers are thermally and mechanically stable. All such compounds are intensely investigated and numerous publications referring to this issue can be found in literature [1–9].

The main emphasis is placed on providing the quality to the worn out materials and restoring regenerated machine parts back to operation with the use of advanced polymeric composites and providing durability to large-size systems operating in higher temperatures and vibration load conditions. The durability of equipment can be increased, and the costs of repairs and idle time can be considerably reduced if tests of mechanical properties of polymeric-inorganic composites are performed. The use of a metal-polymer composite is limited, especially at high temperatures and dynamic strains conditions. To meet the increased requirements regarding the reliability and durability of such materials, scientists try to search for new solutions in the field of material science [1–2].

1. Experiments

The paper describes tests on a new material Multimetall "Stahl 1080" performed in order to analyse its behaviour in the compression conditions at higher temperatures. The previous analyses of the material concentrated on determining the yield point and compressive strength. The tests were performed using a dynamic press with a hydraulic drive [10–17]. The depth of the indention is a representation of the compressive force in the metal-polymer during the test, the width of the indention depends on the diameter of the sample. The experimental results obtained after mathematical transformation of the obtained results revealed that the optimum yield point value corresponds to samples with an excess of a 1mm indention. One of the deficiencies of this type of multicomponent experiments is the limited range of this technique. Thus, the obtained empirical connection approximately gives congruence and the obtained results are not fully reliable because of the error when determining the theoretical yield point value.

Ischenko [12] conducted theoretical strength tests of the metal-polymer layer in hydrostatic compression conditions. The simulation was performed with the use of a computer program for 3D modelling of solids "SolidWorks 2007" involving strength models "CosmosWorks 2006" and finite elements method for calculation (MES) [13].

Present experiments were used for verifying the results of this simulation. Composite samples were prepared fully in compliance with simulated samples, and the loads conditions were based on the results of modelling.

Thanks to good properties of MM 1018 with a range of accuracy of 1/100 mm, the 100% adjustment accuracy was obtained directly on the spot, without demanding any completion of material, i.e. traditional adjustment of maple locks and bridge support to the lower belt of the bridge. Multimetall Steel 1018 has the following properties:

- Levels of gaps from 0 to15 mm;
- High strength at extended loadings, and also in extreme conditions, such as vibrations, and temperature fluctuations from - 40°C to + 90°C;
- Resistant to aging and weather conditions;
- Resistant to gasoline, oils, acids, alkalis, and to the cooling agents;
- Corrosion-resistant, does not rust, and is a non-conductor; and,
- Simple processing, which does not require preliminary preparation and supportive applications.

2. Methodology of research

The samples made of Stahl 1018 composite underwent compressive tests in a Zwick Roell Amsler HB 100. The technical properties of the composite are given in Table 1 [10–11].

The apparatus can be used for the execution of the experiment in the controlled condition at assumed temperatures. A special chamber is used to heat the sample to the required temperature and facilitate compressive tests under vibration load. Elasticity tests and strength tests were also performed for given temperature conditions (20°C to 80°C). The tests can be performed for various sizes and shapes of samples, e.g., at maximum compression load of 100 kN, the maximal piston stroke equals to 250 mm.

The schematic of the experimental setup is presented in Figure 1. A sample (2) made of polymer-based composite was installed in special metallic grips (3), which are fastened to a vibropress (1). The upper, mobile part of the installation oscillated up-and-down at a frequency of 10 Hz (5). The sample is subjected to an alternating force (6): F_1=10 kN, F_2 = 15 kN, and F_3 = 20 kN. The amplitude of vibrations equals 1 kN. Sample (1) is placed in a thermal chamber (4), where the experiments can be carried out at temperatures of +20°C, +40°C, +60°C, and +80°C.

Table 1. Technical characteristics of MultiMetal Stahl 1018

Compressive strength	N/mm^2	max. 160
Tensile strength	N/mm^2	76
Flexural strength	N/mm^2	89
Tensile strength and shear	N/mm^2	22
Elastic modulus	N/mm^2	14000
Coefficient of linear expansion		32x10^{-6} K
Heat resistance		- 40°C / +90°C
Resistance to aging and weathering	min	45
„Work" time / work time with the material 20°C	h	72
Curing at + 5°C	h	24
Curing at + 20°C	g/sm^3	2,4
Specific weight		soft paste
Viscosity	Pa·s	12
Storage packing	kg	1,5+4,5

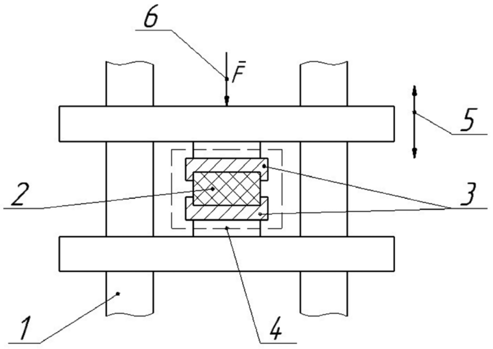

Fig. 1. Scheme of experimental installation; 1 – frame column of testing machine, 2 – sample, 3 – anvils, 4 – adapter, 5 – upper traverse, and 6 – applied load

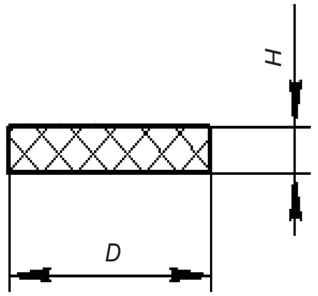

Fig. 2. Scheme of a sample prepared for tests

The behaviour of material at ambient temperature conditions when static and dynamic load are applied is known and has already been described in literature [10–12, 16, 17]. The aim of the experiments is to analyse deformations of composite material under vibration loads in dynamic conditions at higher temperatures (from 20 to 80°C). Experiments were conducted for cylindrical samples of diameter $D = 12$ mm and height $H = 3.5$ mm (Fig. 2). This particular size of the samples was dictated by the fact that layers of this thickness are most frequently used for fixing industrial machines.

Samples were worked according to the following procedure. First, the moulds for the composite were prepared. Syringes (20 cm^3) were used as a mould for the samples to provide proper diameter. The moulds were filled with the material and by pressing the piston to obtain the mass in a compact form, devoid of gas bubbles. Then the material was hardened in ambient conditions for 24 hrs. Afterward, it was removed from the mould and cut into samples of the required height. The surfaces of the samples were treated with abrasive paper and a polisher. The schematic of thus prepared sample is given in Figure 2.

3. Results

The experiments were performed for organic metal material under vibration load at temperatures of 20 to 80°C. The results of experiments are presented in Figures 3 to 8.

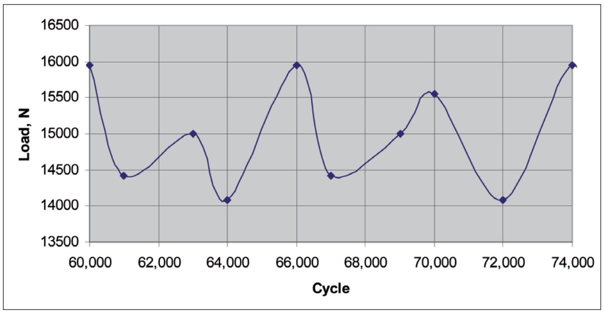

Fig. 3. Fragment of a plot illustrating the control signal for a force of 15 kN at a temperature of 20°C

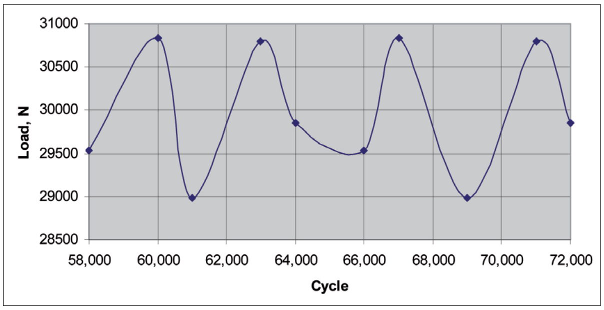

Fig. 4. Fragment of a plot illustrating the control signal for a force of 30 kN at a temperature of 20°C

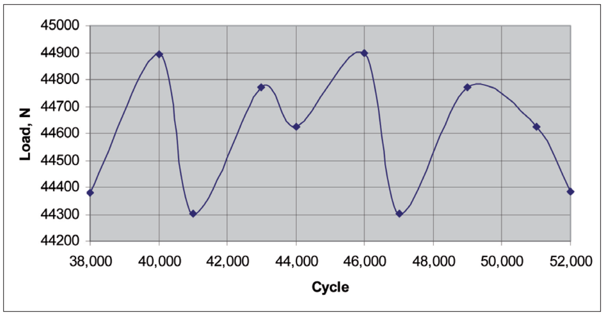

Fig. 5. Fragment of a plot illustrating the control signal for a force of 45 kN at temperature of 20°C

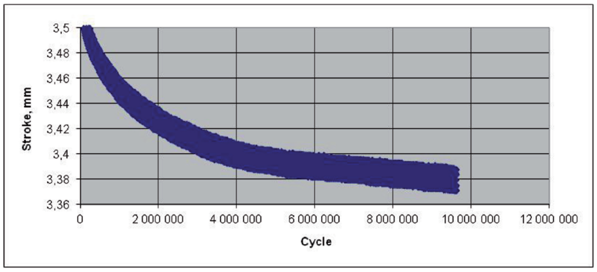

Fig. 6. Plot illustrating change of sample height at a load of 15 kN at a temperature of 20°C

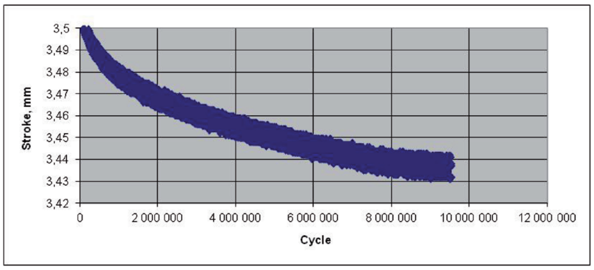

Fig. 7. Plot illustrating the change of sample height at a load of 15 kN at a temperature of 40°C

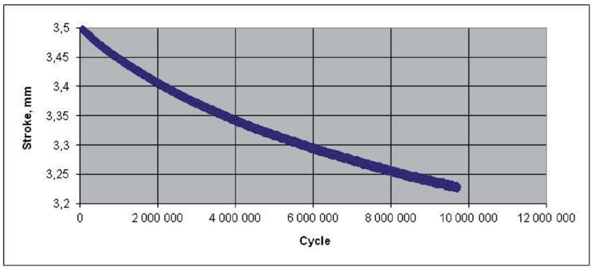

Fig. 8. Plot illustrating the change of sample height at a load of 15 kN at a temperature of 60°C

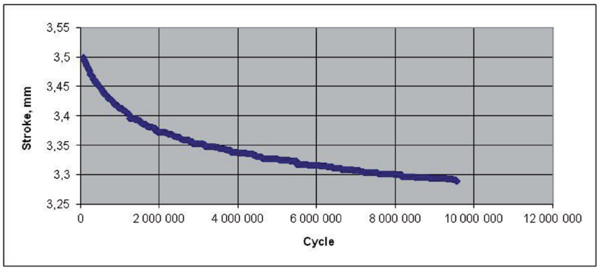

Fig. 9. Plot illustrating the change of sample height at a load of 15 kN at a temperature of 80°C

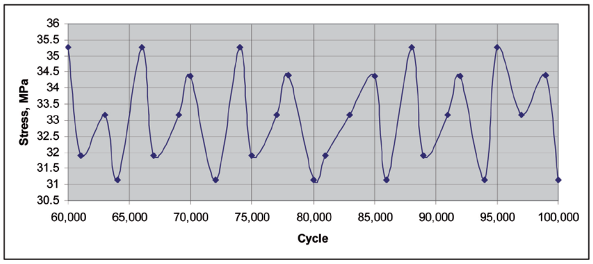

Fig. 10. Fragment of a pressure signal curve for a force of 15 kN at a temperature of 20°C

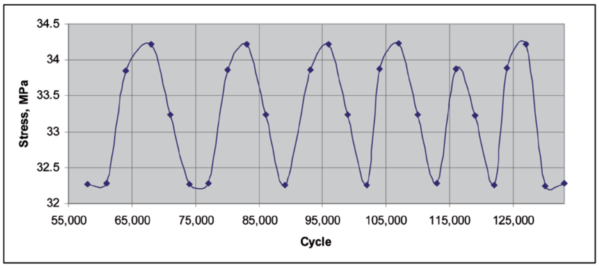

Fig. 11. Fragment of a pressure signal curve for a force of 15 kN at a temperature of 40°C

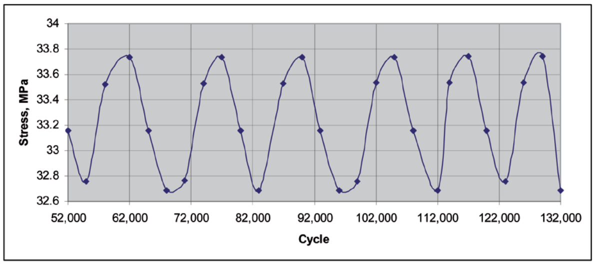

Fig. 12. Fragment of a pressure signal curve for a force of 15 kN at a temperature of 60°C

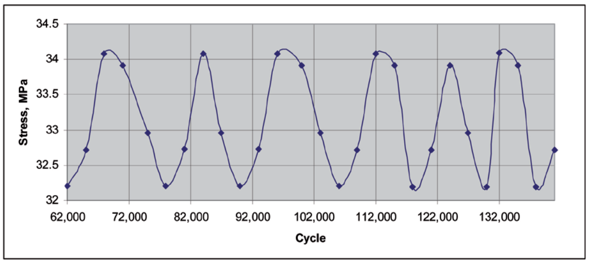

Fig. 13. Fragment of a pressure signal curve for a force of 15 kN at a temperature of 80°C

The analysis of Figures 3 to 5, which show fragments of control signals curve for forces of 15 kN, 30 kN, and 45 kN at ambient temperature, reveals that the change of the force value does not cause the amplitude to be exceeded, regardless the number of cycles. A similar conclusion can be drawn when analysing Figures 10 to13, which represent fragments of plots of pressure signals for a force of 15 kN at ambient temperature and at 40°C, 60°C, and 80°C. At ambient temperature, the strength of the material is higher and the pressure does not always reach its maximum in certain cycles, although the strength of the material decreases with the rising temperature. Even at a temperature of 80°C, the force changes, and the pressure for the sample changes, depending on particular characteristics.

The plots in Figures 6 to 9 show the change in the height of the samples under a load of 15 kN at temperatures of 20°C, 40°C, 60°C, and 80°C. The material is observed to slightly bend, depending on the number of cycles. The sample is more liable to vibratory loads at low temperatures, and after 3000 cycles, the change of its height is not continued. This cannot be observed at high temperatures. It further means that the material can be liable to attenuation caused by vibrations during work and then operate steadily for the next 7000 to 8000 cycles.

Conclusions

A number of experiments were performed on samples made of composite material Multimetall "Stahl 1080." The material was tested in conditions resembling actual ones. The samples were subjected to dynamic loads at ambient and higher temperatures. The sample turned out to be most liable to loads at low temperatures. At higher temperatures, susceptibility to material flowing increases mainly due to the lower strength of the organic bridges in its structure. Application of the composite mainly depends on the condition required by casting technology, but generally, it should be pointed out that, for high-pressure die casting processes such material should not be used.

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