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Surface Reinforcement of Carbon Composites with Microstructural Metal Materials

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Abstract—Surface reinforcement of carbon composite with sheet metal is considered in this work. To increase conjunction strength on metal, a microrelief obtained via deformation cutting is used. All samples with microrelief show high strength in exfoliation and shock tests with a changing damage mechanism from adhesion to cohesion.

Keywords: carbon fibre reinforced plastic, polymeric composite, CFRP, reinforcement, adhesive bonding, deformation cutting

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INTRODUCTION

Polymeric composite materials (PCMs) exhibit a series of advantages in comparison with metals and their alloys, this favoring their wide application in aerospace engineering, automobile manufacturing, and other fields. However, such disadvantages as low hardness and wear resistance, low impact toughness, and low heat resistance, among others, necessitate using metallic functional joints, which require specific material properties.

In many cases, only the PCM surface layer is responsible for the operation of its product. This concerns the friction parts, the joints that undergo cavitation or erosion wear, collapse contact loads, and other items. In fact, the connection of parts made of polymeric composite materials with metallic parts is one of the most complicated and little-known questions [1]. Surface reinforcement of PCM with metal sheets is an effective method of improving the functional characteristics of composite joints. As an example, one can adduce antierosion sheathing of rotor blades with a PCM metal sheet [2].

Thin-sheet metallic (corrosion resistant and carbon steels, titanic and aluminum alloys), as well as polymeric (ultrahigh molecular polyethylene, fluoroplast and others), materials can be used for surface reinforcement of PCM. In most cases, the sole method for affixing thin-sheet materials to the PCM surface is a glue joint or application of the reinforcing layer directly during the polymerization of the PCM binder [3, 4].

Modern glues are subjected to high adhesion to PCM with the thermoreactive matrix (glass, carbo-, or organoplastics), but their adhesive bonding with metals or thermoplastic polymers is insufficient. The PCM compound and corrosion-resistant austenitic steels with low adhesion are particularly difficult. Today, to provide strength of the metal–PCM, the metal surface undergoes etching, sand blasting, chemical activation, and so forth. More reliable compounds allow one to make the fixing microelements on metal via punching combs, pin milling or pressing, welding, and so forth (Fig. 1) [5].

An urgent task is miniaturization of fixing elements and providing their high-quality placing that is a difficult engineering problem.

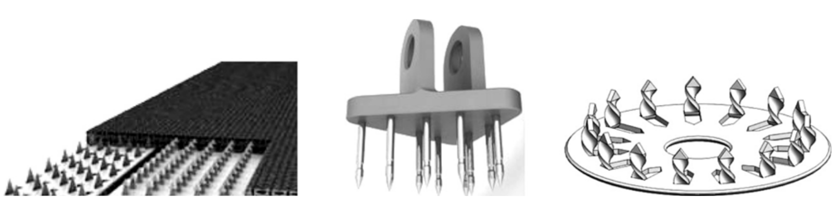

Fig. 1. Fixing microelements for connection of metal with PCM [5].

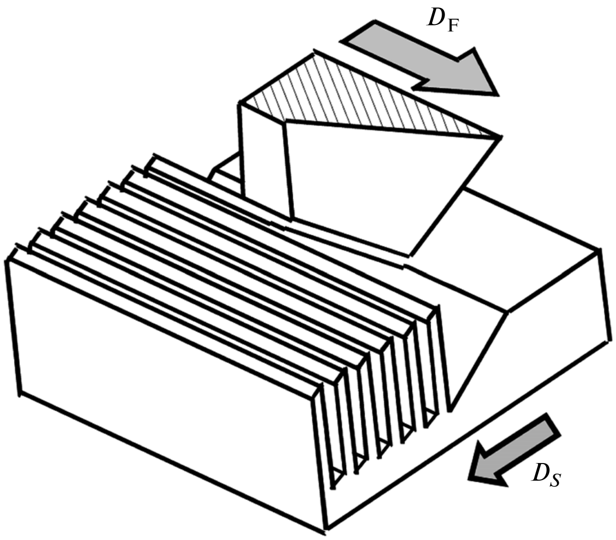

Fig. 2. Principle of deformation cutting.

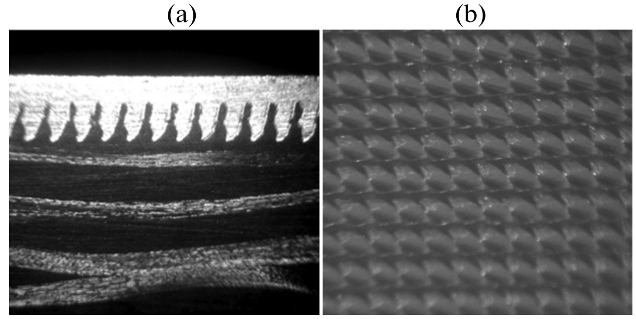

Fig. 3. (a) Cross section of reinforced carbon composite before tests and (b) view of microstructural studded surface.

DEFORMATION CUTTING AS A METHOD FOR PREPARING THE SURFACE FOR GLUING

An existing increase in strength and reliability of both glue conjunction and compound obtained via polymerization of the binder can be enriched via regular small-step micro- or macrorelief with a high height-to-pitch ratio. The preparation of the deep micro- and macroreliefs via deformation cutting (DC) is the most promising method.

The DC method is based on simultaneous cutting of the surface layers and their plastic deformation [6, 7]. The cut layer is not removed completely from the blank, being linked with it from its narrow side. A set of the cut surface layers that retains the continuity of its connection with a blank forms a developed macrorelief in the form of finning on the treated surface (Fig. 2). This technology allows one to obtain macrorelief on plastic materials such as copper, aluminum, and their alloys; titanium; steels; and thermoplastic polymers [8].

DESCRIPTION OF SAMPLES FOR MECHANICAL TESTS OF SURFACE-REINFORCED CARBON COMPOSITE AND THEIR SYNTHESIS

The tested samples were carbon composite slabs with a thickness of 4.2 mm with one-side surface reinforcement with thin-sheet material made of corrosion-resistant austenitic 316L steel (the closest Russian analog is 03Kh17N14M3 steel). Steel slabs with initial thicknesses of 0.6 and 0.76 mm were used. Carbon composite was connected with steel during the PCM synthesis via vacuum infusion. To obtain carboplastic, carbon fabric with a density of 400 g/m^2 with Toolfusion®1A/1B Airtech epoxy resin impregnation was used. No posthardening was carried out at high temperature.

Both smooth steel slabs and slabs with microrelief of two types obtained with DC were used for surface reinforcement: simple tilted finning (Fig. 3a) and finning with gaps on the tops of the fins that looks like a micropin structure (Fig. 3b) [9]. The gaps on the tops of the fins were obtained via finning of a slab with shallow incisions (ca. 0.1 mm). The incisions served as stress concentrators at which the fin formed by DC was ruptured. The incisions were prepared by a profile roller with a tooth pitch of 0.6 mm. For all samples, fin pitch S was 0.4 mm. The microrelief height varied over the range of 0.45–0.7 mm, the fin tilt was 7°–13°, and the interfin gap of microrelief was 120–220 μm. The deforming cutting was implemented on a 16K20 screw-cutting lathe using the devices in the form of a drum on which the processed steel strip was stretched.

The geometrical microrelief parameters for the studied samples are shown in Table 1.

Three types of tests were conducted: one for impact toughness and two for exfoliation (with an indenter and tensile testing machine). Each test was performed on two identical samples with averaging results.

DETERMINATION OF METAL–CARBON COMPOSITE STRENGTH CHARACTERISTICS OF SURFACE REINFORCED PCM

The impact toughness test was implemented on a Walter+Bai AG PH150 pendulum hammer at shock energy of 50 J. The samples were slabs without cuts with dimensions of 55 × 12 × 4.2 mm. The shock of the pendulum was from the metal side. The scheme of the tests is shown in Fig. 4a.

Samples with a cladding metallic layer without microrelief exfoliated completely from carbon composite, whereas the samples with microrelief exfoliated exclusively by the carbon composite layers

Table 1. Parameters of microrelief of the plated slab for the tested samples

Sample number	1	2	3*	4	5	6*
Thickness of initial steel sheet, mm	0.76	0.76	0.6	0.76	0.6	0.76
Fin height, mm	0.65	0.67	0.45	0.53	0.6	0.7
Interfin gap, mm	0.19	0.16	0.22	0.13	0.12	0.13
Fin tilt, deg	8	13	8	13	7	8
Residual sheet thickness, mm	0.26	0.37	0.38	0.37	0.28	0.53

* With gap at the top of fins.

Table 2. Destruction energy of samples in tests on impact-testing machine

Sample number	1	2	3	4	5	6	Cladding without relief	Without cladding
Fracture energy (A_n), J	11.5	11	7.3	10.4	11.1	9.1	7.2	4.1

(Fig. 4b). The damage energies of the tested samples are shown in Table 2. The maximum fracture energy of the samples with microstructure samples of the plated slab was $A_n = 11.5$ J, which resulted in a specific viscosity value of $a_n = 228$ kJ/m^2. The increase in the specific shock viscosity of 5.2 and 11 of the samples in comparison with the carbon composite samples plated with the microrelief-free sheets was 53–60%.

During exfoliation tests with the indenter, the samples were plated carbon composite slabs with sizes of 25 × 30 × 4.2 mm. At the slab's center, a hole with a diameter of 8 mm was cut from the CRFP side with a slot drill until contact was made with cladding metal. The cylindrical punch indenter was introduced into the obtained hole with a vertical milling machine at a rate of 50 mm/min without rotation. The sample was maintained at a 9257B Kistler (Switzerland) dynamometer platform relied on unplated carbon composite, as is shown in Fig. 5a. The sensibility threshold of the dynamometer was 0.01 N. For these tests, the indicator of strength of the glue conjunction was the maximum peel removal force necessary for exfoliation of metal from carbon composite.

Tests on the plated slabs without microrelief resulted in complete adhesive exfoliation of metal at a minimum effect on the indenter. Cohesive damage to carbon fabric with its residuals on the plated metallic slab was detected for all samples with microrelief (Fig. 5b). The exfoliation forces of the samples are shown in Table 3. The maximum load of the plated layer exfoliation (1254 N) was found for sample 6 with 0.7 mm-high microrelief with cracks on the top of the fins.

All samples also underwent strength tests at 90° exfoliation. The test scheme is depicted in Fig. 6. The tests were done on a multipurpose Instron 600-DX hydraulic testing machine. The metal–carbon com-

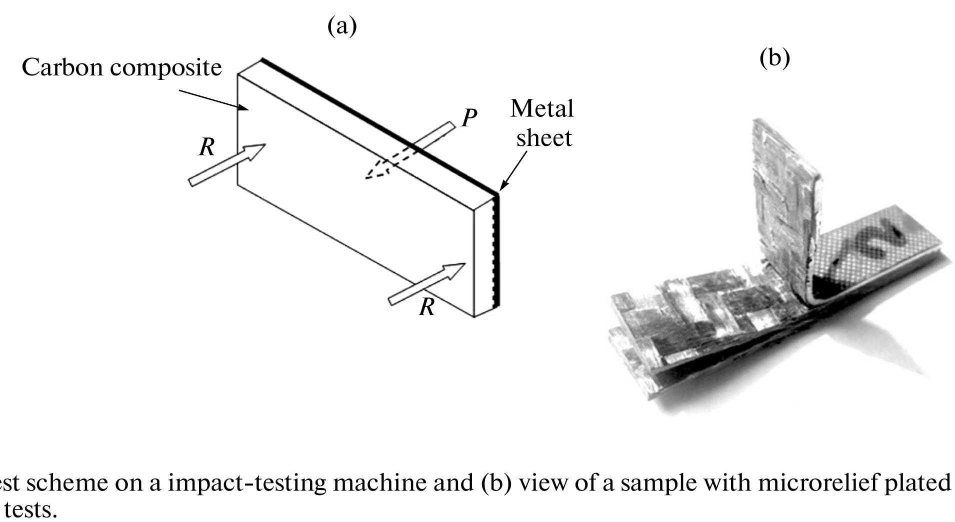

Fig. 4. (a) Test scheme on a impact-testing machine and (b) view of a sample with microrelief plated layer obtained via DC after tests.

(a) (b)

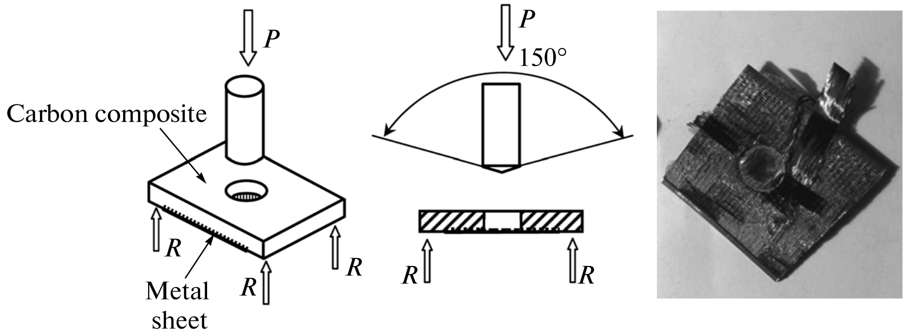

Fig. 5. (a) Test indenter exfoliation scheme and (b) view of a plated steel slab with microrelief after exfoliation.

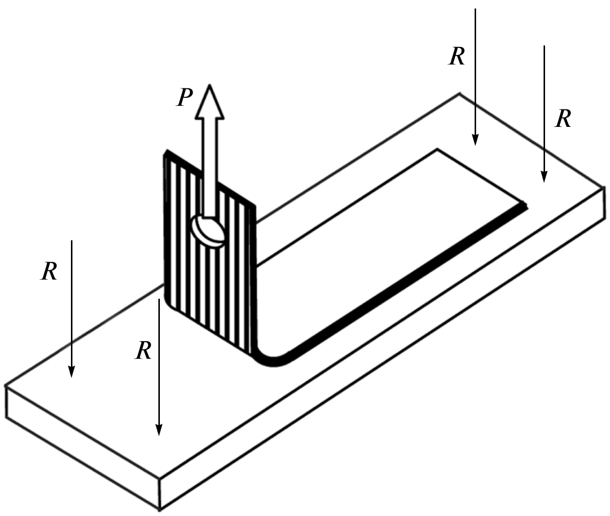

Fig. 6. Scheme of 90° exfoliation tests of samples.

(a) (b)

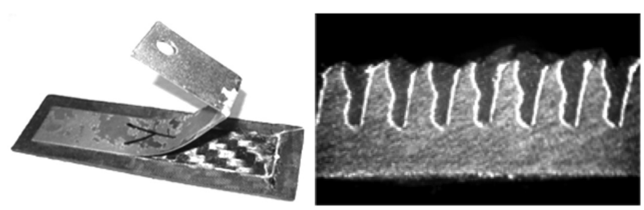

Fig. 7. External view of samples after 90° exfoliation tests: (a) plated slab with microrelief; (b) cross section of a plated layer with microrelief.

posite contact zone had a size of 25 × 100 mm. The samples were stretched with a rate of 25 mm/min and an average breaking force recorded. The loading was then recalculated in the "per unit length" force measured in Newtons per 1 mm of a sample width (or in kN/m).

A multiple increase in the force of metal sheet exfoliation with microrelief was found in comparison with cladding by smooth metallic sheets. Microrelief-free slabs were simultaneously exfoliated from the entire gluing area (with enforcement lower by an order in comparison with the samples with microrelief). For the finned samples, there was cohesive destruction, while no removal of epoxy binder from microrelief was observed (Fig. 7b). The average breaking "per unit length" force was 4.4–9.1 kN/m (Table 4). The highest value was detected for samples 3 and 6 with microrelief in the form of finning with cracks on the top of fins.

Table 3. Exfoliation force of metal plated slab from carbon composite in tests with an indenter

Sample number	1	2	3	4	5	6
Exfoliation force, N	1016	1103	1206	1181	1181	1254

Table 4. Force "per unit length" of 90° exfoliation of metal plated layer from carbon composite

Sample number	1	2	3	4	5	6
Exfoliation "per unit length" effort, kN/m	6.8	5.4	9.1	6.5	4.4	7.3

CONCLUSIONS

(i) The prospects of the use of microreliefs obtained via deformation cutting were demonstrated for surface reinforcement of carbon composite with metal sheets. During bilateral finning of metallic sheets, DC can also be applied in the fabrication of multilayer composites on the basis of thin metal sheets and glue prepreg–metalloplastics [10].

(ii) All samples with microrelief revealed a change in the destruction mechanism from adhesion to cohesion in the exfoliation and shock tests. For samples with microrelief, there was either interlayer destruction by carbon fabric layers (tests on a impact machine) or destruction of epoxy binder on the top of the fins (the exfoliation tests).

(iii) Microrelief obtained via deformation cutting exhibited metal–PCM contact strength in exfoliation to the carbon composite matrix strength.

(iv) In shock tests for samples with microrelief on metal, there was detected an increase in the destruction energy to 60% in comparison with microrelief-free samples on metal.

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REFERENCES

1. I. I. Sorokina and M. V. Astakhov, "The study of the influence of the fastening element shape on the strength of the metal–composite joint," Nauka Obraz. No. 2, 9 (2012).
2. B. N. Slyusar', M. B. Flek, E. S. Gol'dberg, et al., *Helicopter Construction Technology: Technology of Blades of Helicopters and Aircraft Structures from Polymeric Composite Materials* (YuNTs RAN, Rostov-on-Don, 2013) [in Russian].
3. Ya. S. Karpov, *Joints of Parts and Assemblies Made of Composite Materials* (Nats. Aerokosm. Univ. Khar'k. Aviats. Inst., Kharkov, 2006) [in Russian].
4. D. A. Aronovich, V. P. Varlamov, V. A. Voitovich, et al., *Bonding in Mechanical Engineering: Handbook in Two Vol.*, Ed. by G. V. Malysheva (Nauka i Tekhnologii, Moscow, 2005), Vol. 1 [in Russian].
5. A. S. Cherevashchenko, "Structural-technological solutions for metal–composite compounds operating under peeling stress," Probl. Proekt. Proizvod. Konstr. Letatel'nykh Appar., **1** (73), 14–20 (2013).
6. N. N. Zubkov, Doctoral Dissertation in Engineering (Moscow, 2001).
7. N. N. Zubkov, "Features of realization of the method of deformation cutting," Tekhnol. Mashinostr., No. 1, 19 (2001).
8. N. N. Zubkov and A. D. Slepcov, "Production of slotted polymer filter tubes by deformational cutting," Russ. Eng. Res. **30** (12), 1231–1233 (2010).
9. N. N. Zubkov, A. I. Ovchinnikov, A. S. Trofimovich, and A. S. Cherkasov, "Using the pin structures of a new type for cooling of electronic equipment," Vestn. Mosk. Gos. Tekh. Univ. im. N. E. Baumana, Ser. "Mashinostr.," **2** (95), 70–79 (2014).
10. N. F. Lukina, L. A. Dement'eva, A. A. Serezhenkov, et al., "Adhesive prepregs and composite materials based on them," Ross. Khim. Zh. **54** (1), 53–56 (2010).

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