POSSIBILITIESOF ADDITIVE TECHNOLOGIES FOR MANUFACTURING OF GRADIENT MATERIALS WITH RECORD HIGH MECHANICAL CHARACTERISTICS

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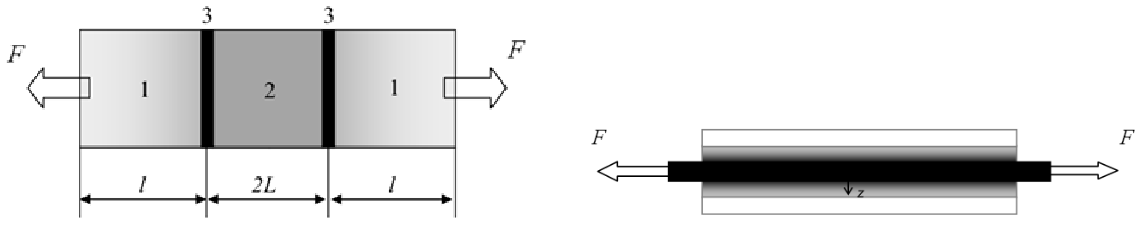
Introduction. The urgency of the problem of creating materials with record high mechanical characteristics is due, first of all, to the needs of the aerospace industry. No less responsible and socially significant is the use of heavy-duty structural materials in medicine, sports, safeguarding equipment, since their use significantly increases the reliability of the functioning of the respective products while significant reducing their size and weight. In the above-mentioned high technology applications, the characteristics of specific strength and rigidity (form stability) are more critical than the material cost, because losses due to major accidents, injuries and lethal outcomes are incommensurable with the costs of manufacturing structural elements.

The aim of the work is to create materials with the highest possible strength and modulus of elasticitybased on optimal modulation of structure and properties of interphase layer.

Methods and results. It seems that this goal can be achieved in the mainstream of two dominant trends in modern composite materials science – the use computer design of materials [1] and application of the principle of additivity (additive technologies)on nanoscale level [2].

More specifically, the possibility of additive (layer-by-layer) formation of a nanosized interphase layer (IL) in the form of a gradient material that is optimal in terms of the load-carrying capacity of a composite as a "matrix-filler" system is considered. The optimal gradient of the structure and properties of the interphase layer for a particular composite modulating this way is proposed to be calculated by methods of computer-aided design of materials. As shown in figure 1, this approach is implemented in the classes of disperse- reinforced (a) and directionally reinforced (b) composites, both on the polymer and on the metal matrix.



a b

Figure 1. Interphase layer of composite with gradient of mechanical properties shown in grey half-tone (uniaxial tension): a) disperse reinforcing (1 – matrix, 2 – filler, 3 – interface layer), b) directional reinforcing.

We have to state that the possibilities of increasing the specific strength and modulus of elasticity of the named composites by choosing a filler in the form of reinforcing fibers and a matrix (binder), as well as reinforcement schemes, are mostly exhausted. The disadvantages of directionally reinforced composites are the low interlayer strength and the "quality" (expressed unevenness) of stress transferring in the "fiber-matrix" adhesion joint. In this connection, the applicants consider the possibilities of optimizing the structure and properties of the least studied component in the form of an interphase layer (IL) formed near the interface, whose role in transferring mechanical stresses between the filler and the matrix is well known.

But in common case, IL is formed spontaneously in the course of complex physical-chemical processes not related to the operational stress-strain state of the composite. Thus, the structure of the

IL, as a rule, does not ensure the uniformity of its stress state, i.e., is not optimal by the criterion of strength. It seems that by controlling the structure of the interphase layer and providing the desired gradient of its deformation properties, it is possible to achieve a significant increase in the efficiency of the transferring of stresses from the filler to the matrix and a radical change in the character of failure.

Thus, optimal gradients of structure and properties, for example, porosity, are characteristic for rationally constructed in course of evolution biological materials – wood, solid (bone and dental) and soft tissues, where the strongest elements, even at the cellular level, are located in the zones of maximum stresses, and relatively low-modulus (damping) intermediate layers of lignin and elastin are localized in such a way as to "absorb" significant strains without destruction.

Expediently organized (modulated) continuous or discrete gradations of the composition of the interphase layer between unlike components (metals, ceramics, polymers) allow redistributing internal stresses and reducing the probability of local fracture and crack formation. Similarly, the level of local stresses that promote the growth of cracks along the interfaces can be regulated by the appropriate distribution along it of the gradients of the elastic and plastic properties of the interphase layer. The effectiveness of using the principles of gradient and deformation compatibility is proved in microelectronics, where thin intermediate layers of variable composition ensure the thermal strength of hetero- and epitaxial layered structures in semiconductor devices.

One of the means to achieve the required gradient of the properties of the interphase layer is the use of nanoparticles introduced into the glaze composition and contributing to the formation of the dendritic structure of the IL. In addition, the introduction of nanoparticles will allow for a more dense packing of the fibrous filler, which also contributes to the strength of the composite.

To synthesize a composite interphase layer reinforced with structurally-forming nanoparticles, solid-phase, liquid-phase (eg, sol-gel) and gas-phase additive technologies can be used. The advantage of solid-phase technologies, in particular, the "ball-mill" process, is the relatively low processing temperature, which avoids undesirable reactions and obtains a qualitative microstructure of dispersed-reinforced materials. However, when using long reinforcing fibers (hardeners with a high aspect ratio), it is difficult to obtain a uniform distribution of the nanoparticles. Only recently there have been reports of the possibility of solid-phase formation of a strong interphase layer as a result of intensive mechanical interaction.

It seems promising to form the aprotic nanocomposite coupling agents in the plasma of amine-like groups using an additional (eg, metallic) cathode that is a source of nanoparticles as well as ion implantation method [3].

Conclusions. The use of additive technologies opens up wide possibilities for increasing the strain-strength characteristics of dispersional and directional reinforced composites by forming an optimal gradient of the material properties of the interphase layers, which ensures the most efficient transfer of mechanical stresses between the rigid reinforcing filler and the elastic matrix.

References

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