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STUDYING THE POSSIBILITY OF COMPENSATION OF UNDESIRABLE MANUFACTURING WARPING IN COMPOSITE ARTICLES FOR AIRCRAFTS

Abstract: The object of the research is the possibility of improving the quality of articles made of composites by means of pre-polymerization treatment of the wet package with intensive pulse loading. Processes of composite articles manufacturing lead to either residual thermal and shrinkage stress appearing or undesirable spatial deformations. Analysis of the impregnation process of dry reinforcing material with a binder makes to develop measures for above-mentioned effects reduction. It was concluded to apply intense impulse loading (shock waves) to composite package after impregnation stage. Conducted experiments with angular composite profile with a doubler on one of the caps shown positive results.
Keywords: residual stress, reinforcing material, composites.

Technological heredity is implemented in the manufacturing of products from composites and their connection with metal tips at various stages of technological transformations [1]. It can be both useful and harmful. Among the harmful properties of polymerized parts, it is possible to include the appearance of residual stresses that lead to undesirable deformations of parts (warping). In metal-composite joints, under definite manufacturing conditions, a violation of the monolithic structure of the composite can be observed in the form of a local decrease in the volume density of the reinforcement or bubbles.

Evaluation and analysis of the value of temperature and shrinkage deformations of profiled parts shows the mechanism of formation of adhesive shrinkage deformations and violation of monolithicity.

The formation of a spatially cross-linked structure of profiled products made of composites is accompanied by an increase in material density, chemical shrinkage, and the appearance of residual adhesive and thermal compressive stresses, which lead to their significant warping. The general dependencies for estimating shrinkage and temperature deformations are given in [1]. Known methods of managing residual stresses and deformations are reduced to the imposition of a force field on the technological object, tensioning of fittings, pressing. They also use layer-by-layer hardening, control of energy input and output to the reactive mass. This is realized by changing the temperature of the medium surrounding the surface of the product. It is necessary to know the level of emerging residual stresses or deformations after each stage of the forming process for their practical implementation.

When considering the problem of managing residual stresses and deformations in composite products, it is worth paying attention to the possibility of controlling these parameters by changing the structure of the composite package: reinforcement angles of monolayers; number of monolayers; sequence of their stacking; application of monolayers of different materials in one package of composite, etc.

Practical quantitative recommendations for technologists regarding the influence of these parameters on the stress-strain state of a thin-walled composite product are practically absent in the literature.

Therefore, **the goal of research** is to improve the quality of parts from composites and metal-composite joints by using additional impulse action during their formation.

Methods of research. Theoretical methods of mechanics of materials are used to estimate the amount of thermal grooves (twisting) of profiles.

A comparison with the experimental results of compaction of the forming material with explosives is used to evaluate the effectiveness of the preliminary impulse loading of the forming material.

Accepted assumptions. The degree of warping of the profiles was evaluated assuming the absence of shrinkage of the binder. When evaluating the effectiveness of the impulse load, the identity of the amplitude-time characteristics of the explosion of explosive substances and the electrohydraulic load was assumed.

Results and discussions. The model for estimating the amount of deformations of a thin-walled composite profile is proposed in [3, 4]. It makes it possible to obtain dependencies for the component values of the complete deformation of the profile (longitudinal elongation, linear movement in the vertical and horizontal planes, and twisting) on the physical and mechanical characteristics of the materials of the monolayers that make up the composite package. In general, these dependencies are complex mathematical functions that have a number of local and global extrema.

A angular profile with an profile with doubler on one of its shelves was considered [2]. When analyzing the behavior of such dependencies, it is worth remembering that the mathematical dependencies issued by the model may have areas that do not make physical sense. Conclusions (for example, about the possibility of controlling the twist angle of the profile) should be made only based on extremes, which makes physical sense. When designing an object of composite, the recommendations for the designer to reduce the amount of the profile twisting should be compared with similar parameters obtained during the strength analysis of the profile.

In the general case, if the recommended angles of reinforcement of the parts of the composite profile do not coincide, then it is necessary to make some intermediate decision.

The deformations of the profiled product calculated in this way may be less than those that actually occur during their manufacture. This can be explained by the need to account for shrinkage stresses caused by surface tension forces on the contact surfaces of the matrix and reinforcement.

Formation mechanism and estimation of residual temperature stresses. When filling the capillaries of the channels that occur between the outer surfaces of the armature (Fig. 1), surface tension forces play an important role. In general, the surface of the armature can be wetted to varying degrees. In the ideal case, such a ratio of brands of reinforcement material is chosen that would be sufficiently wetted by the specified brand of binder. The length of penetration of the liquid phase into the capillary channels, in general, depends on the pushing pressure and the number of repeated loads [1].

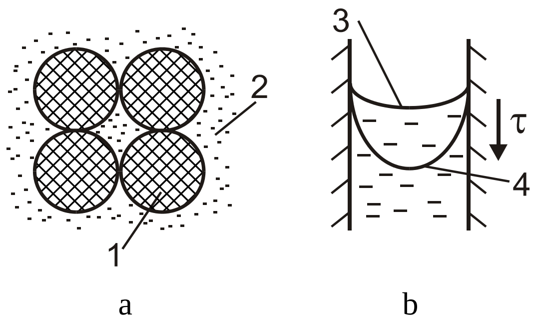

Fig. 1. Cross-section of the CM: a – transverse; b – longitudinal; 1 – armature; 2 – matrix; 3 – position of the liquid boundary; 4 – position of the matrix border during solidification

The simplest physical model of the occurrence of shrinkage stresses caused by surface tension forces was considered (see Fig. 1). Threads of armatures located next to each other will form channels of complex shape and small size. When impregnation, they must be filled with a liquid compound. If they wet the surface of the fibers (for which special measures are taken), the border of the compound has a concave shape. Its chemical shrinkage occurs and its border increases in curvature in the process of hardening.

Excessive capillary pressure helps to spread the reinforcement fibers and reduce the density of their arrangement. But the main thing is that the reduction of the curvature radius of the distribution boundary during approval leads to the appearance of shrinkage stresses t, which are added to temperature stresses.

After stopping the pulse action, the boundary of the liquid phase can go down (Fig. 1, b), but at static (relatively low) pressure, which is applied to the part during polymerization, the liquid phase will more easily fill the capillary channel to a greater length and solidify at a greater depth.

The formation mechanism of non-monolithicity during the formation of point metal-composite joints. When forming integral panels or units from composites, point joints of metal parts (formed bolts, nuts, washers and fittings) with the main part made of composite are used quite often (Fig. 2).

When local transversal microelements are introduced into the regular structure of the composite, it is disturbed in the form of non-monolithic zones. These zones are filled with gas (or binder) and practically do not perceive the active load. It is possible to assume that reinforcement fibers will cross in the space between local elements. This generally leads to a noticeable loss of the load-bearing capacity of the connection. The degree of violation of the regular structure with the non-oriented position of the passage channels for fibers is greater than with the linear arrangement of microelements.

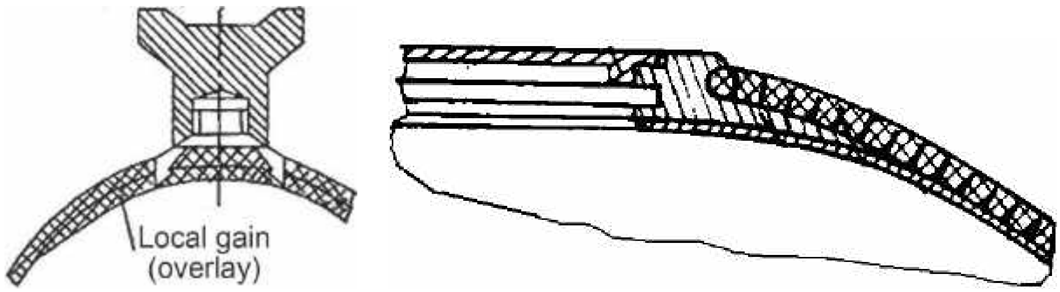

Fig. 2. Examples of assembled units in which metal-composite joints are implemented

In order to partially fill such zones with fibers (due to their bending) or with a liquid phase, it is necessary to apply intense impulse pressure to them during molding.

To increase the infiltration degree, it is suggested to press the composite layers with shock waves. The effectiveness of the process was confirmed experimentally [4]. But a single impulse load contributes to the seepage completeness, but it is difficult to significantly reduce shrinkage stresses.

Significant relaxation of shrinkage stresses and residual stresses of a different nature can be facilitated by intense transmission through the reactive volume of stress waves generated during the polymerization reaction [1]. Due to the macro-continuity of the composite volume reacting with the wave, the direction of transmission of the compression waves, in the first approximation, can be chosen arbitrarily. A possible schematic diagram of the device for implementing this model is shown in Fig. 3.

Devices for generating powerful compression waves, for example, using an electro-hydraulic discharge has long been known [5]. Multi-electrode generators of pressure waves allow controlling the frequency and intensity of the load with such waves in wide ranges.

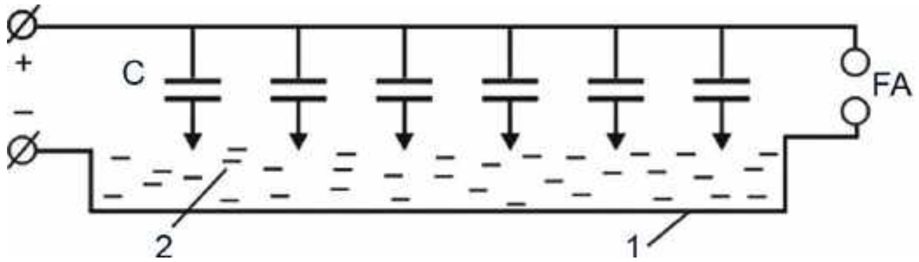

Fig. 3. Schematic diagram of the device for removing the residual stresses in profiled products from composites during polymerization: 1 – external elastic surface of the shape setting tool; 2 – operational interval; C – capacitor bank; FA – forming arrester

The device works in the following way. When high voltage is applied, capacitor batteries are charged. After closing the arrester, which forms the field of discharges, electrohydraulic discharges occur at the discharge working intervals. The time of energy release in each of the intervals is controlled, and the load intensity is directly proportional to the square of the capacitor charging voltage. Thus, the forming tool surface is loaded with compressive pulse bursts that are transmitted to the reacting volume.

The limits and conditions of the applied solutions are determined by the dimensions of the available equipment, the complexity of the geometry of the connection structure, the strength and rigidity of its elements, and the features of the operating conditions of the product.

The prospect of further research is the development of practical recommendations for the designer (technologist) regarding the selection of geometric and physical-mechanical parameters of thin-walled composite profiles, taking into account strength limitations and limitations on minimum warping.

Conclusions. As a result of the conducted research, the calculation of the stress-strain state of thin-walled composite profiled parts shows that thermal stresses lead to the appearance of significant total twisting of the product. Chemical shrinkage and surface tension forces increase torsional deformations.

It is found that changing the reinforcement angle (which is different from 0°) of the profile with doubler on the angular profile and the number of monolayers in the profile with doubler allow to reduce the twisting angle of the profile.

It is established that the transmission of bundles of compression waves throughout the volume of the composite being polymerized can reduce residual stresses. The intensity of such influence is determined by the level of technological residual stresses arising in the product.

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