The increasing of effectiveness of the reinforce holes method for fasteners with composite liners

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Abstract. The bearing capacity of a parts or units with a holes for fasteners and mechanical fasteners depends on the stress-strain state and its accompanying stress concentration in the local area of fasteners. In General, it is influenced by a set of operational and structural and technological factors. To replace the use of metal embedded elements, the technology of unloading the zone of point fastening of joints of composite structures is proposed by creating a combined connection with an intermediate element - a composite liner installed by a thermal compression method along the contour of the hole.

1. Problems of formation of fastener holes in composite parts

At the moment, the main method of formation of holes intended for the creation of fasteners and assemblies in the modern aviation and space industry is machining. In particular, for polymeric composites for constructional and functional purposes among the applied methods the formation of holes: drilling, countersinking, reaming, boring, grinding, broaching [1 - 3], the most commonly used drilling and deployment. At the same time, it is known that for polymer composite materials, and especially for fibrous polymer composite materials filled with long-fiber fillers, the formation of holes by local removal of the material, significant reduces the percentage of implementation of high elastic-strength properties of composites, both the material and the structure as a whole. First of all, this is due to the violation of the continuity of the "matrix – filler" system, and the "cutting" of the warp threads, usually directed along the force fields of mechanical loads of the structure as a whole.

From this point of view, it is preferable to lay the formation of holes at the stage of forming and molding plastics. There are many examples of this approach, for example, the use in the molding of special forming equipment, containing in its composition signs that draw the contours of the holes, provide the necessary level of quality of the inner surface of the holes, provide high rates of repeatability of products in the manufacture. This approach is most applicable, however, for products made of injection molding plastics, press-materials (including dispersion reinforced).

In addition to signs, smooth or threaded embedded elements can be used, integrated into the workpiece at the stage of laying out (forming). In the aviation industry, the method of gluing smooth metal bushings, pasted after the formation of a hole machining (figure 1).
Gluing is more often carried out with the help of normal temperature curing glue, the method and the units formed with the help of this connection have a number of restrictions, for example, limited resource (especially in repeatedly demountable joints), heat resistance, low weight efficiency, restrictions on the implementation of special functional properties (radiopacity, electro-uniformity of structures, etc.).

2. Structural and technological solution for the design of holes by installing a composite sleeve thermocompression method

The development of methods for increasing the bearing capacity of the point mechanical connection of composite elements by reducing the stress concentration on the basis of a complex of design and technological solutions [5 - 6], primarily by reinforcing the mounting holes along the entire contour with composite bushings (figure 2), in which the connecting elements are installed, is promising.

2.1 Basic requirements for the method

The basic requirements for the method of installation of the reinforcing element, and the basic principles of its formation. It is shown that the method should provide:

- leveling of existing geometric deviations of the initial hole, which appeared as a result of deviations in the course of the technological process of hole formation by means of mechanical processing or operational resource wear (increase in the diameter of the hole, decrease in its accuracy, deviation from the correct form, for example, ovalization);
- leveling of existing and emerging micro-damages, acquired as a result of machining, appeared or developed during the operation of the product;
- leveling (reducing the impact on the bearing capacity) of defects such as delamination arising from the installation of fasteners and reducing the intensity of their growth during operation;
- development of the appropriate stress concentration in the local area of the holes, including the working conditions of the fasteners, metal fasteners.
2.2 Technological method of forming a composite liner

The technology of unloading of the zone of point fastening of joints of composite structures by creating a combined connection with an intermediate element - a composite liner, installed by thermal expansion resin transfer molding (TERTM) method along the contour of the hole (figure 3).

2.3 Evaluating the effectiveness of the solution

The structural and technological method of reinforcement of holes for fasteners with defects of production and operational origin by installing composite fiberglass bushings is promising due to its high recovery effect for the joints of elements of highly loaded composite structures, in particular for aviation purposes, for which the indicators of strength and reliability are extremely important. The computer simulation and experimental study of the strength properties of the models of composite compounds with different variants of the technological parameters of the installed bushings indicate the possibility of increasing the bearing capacity of even relatively intact samples.

A comparison of the theoretical solution, the results of computer simulation (finite element method), the results of tests of structurally similar samples containing holes of these types and bushings installed in them is shown [7 - 8].

The theoretical justification is expressed in the creation of a model of "hole blunting" as a stress concentrator [9 - 12] (figure 4).
Considering the liner as a "stopper" of cracks due to the presence of an area with a low-modulus material and a local zone of a high-modulus material (carbon fiber panel) from the standpoint of fracture mechanics, taking into account the size of the pre-fracture zone calculated according to the known strength and crack resistance characteristics, the stress concentration ratio for cases without the sleeve and with the liner equal to $\frac{K_{\sigma}}{K_{\sigma}^*} \approx 1.27$ is derived.

For comparative evaluation of stress concentration in the local area by methods of finite element (FEM) analysis in the MSC environment Nastran simulates carbon-plastic panels containing a free hole for fasteners and reinforced with a fiberglass liner (figure 5). 3D models used three-dimensional solid elements - tetrahedron with 4 and 8 nodes.

The model takes into account the reinforcement scheme of the panel–$[0^\circ/0^\circ/\pm 45^\circ/90^\circ/\pm 45^\circ/0^\circ/0^\circ]_{4S}$, typical for the regular zone of the structural element of the airframe and the scheme of reinforcement of the fiberglass liner – the circumferential direction ("spiral").

The liner made of a less stiff composite than combine the design and ensure the compatibility of deformation of the entire mounting system, increase the bearing resistance of the connection and allow to reduce the level of stress concentration in the contact area. Intermediate liners made of less rigid composite than the connected structures ensure the compatibility of the deformation of the entire fastening system, increase the resistance to crumple of the joint and allow to lower the level of stress concentration in the contact zone.

To evaluate the effectiveness of the proposed technology by finite element modeling methods in the MSC environment Nastran comparison of stress-strain state in models of carbon-plastic panels containing a free hole for fasteners and reinforced with a fiberglass liner is performed.

Modeling of operational defects in the area of the hole according to the method of fictitious cracks and finite element calculation of the strength of composite panels with reinforced holes to notches (cracks) confirm these possibilities, because calculations found that for the plates with a cut reinforcement sleeve cylindrical hole in the presence of a crack on the circuit reduces the maximum stress level by 18.7 – 25 %, and for holes with countersink - 31.2 – 37.4 %, and for this type of connection with the liners the presence of cuts has virtually no effect on the level of stress [4 - 6].
3. Conclusion
Structural and technological method of increasing of load-carrying ability of point joints for fasteners with defects of production and operational origin by installing composite fiber-glass liners is promising due to its high reinforce and recovery effect for the connection of elements of high-loaded composite structures, in particular for aviation purposes, which are extremely important indicators of strength and reliability. The computer simulation and experimental study of strength properties of the models of composite compounds with different variants of the technological parameters of the installed bushings indicate the possibility of increasing of load-carrying ability of even relatively undamaged samples.

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