Classification of Composite and Steel Plates Joints in Hybrid Structures with External Type of Reinforcement by Composite Materials

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Abstract. The article provides a brief classification of existing joints of composite and steel elements with each other. Three types of connections are considered: mechanical, adhesive and combined connections. Their main advantages and disadvantages that limit their widespread use are indicated. One of the main advantages of composite materials is the variety of their physical and mechanical characteristics, which are determined at the stage of composite fabrication. In view of this feature, the use of composite materials as part of hybrid structures can provide an effective use of the physical and mechanical properties of materials. The main requirement for hybrid structures is to ensure the joint operation of all used dissimilar materials.

1. Introduction

Hybrid structures - structures consisting of several dissimilar materials, arranged in a special rational way along the length and cross-section of the structure, ensuring their joint work [1-2].

The materials that make up hybrid structures can be divided according to their functional purpose into load-bearing materials that absorb most of the internal forces acting in the structure, as well as auxiliary materials - which compensate for the shortcomings of load-bearing materials due to their rational placement in the structure.

By the type of reinforcement with auxiliary materials, 2 types of hybrid structures should be distinguished - with external and internal reinforcement. Often, in structural schemes of hybrid structures with an external type of reinforcement, plates are used to reinforce the load-bearing material. Rational for the case of a hybrid structural system is the use of a steel bearing base, for example, an I-section, reinforced with composite plates of a special shape [3-4].

Composite materials - a solid product consisting of two or more materials that differ from each other in shape and / or phase state, and / or chemical composition, and / or properties, bonded, as a rule, by a physical bond and having an interface between compulsory material (matrix) and its fillers, including reinforcing fillers [5-6].

One of the main advantages of composite materials is the variety of their physical and mechanical characteristics, which are determined at the stage of composite fabrication. In view of this feature, the use of composite materials as part of hybrid structures can provide an effective use of the physical and mechanical properties of materials [7-8].
The main requirement for hybrid structures is to ensure the joint operation of all used dissimilar materials. In the case of hybrid structures with internal amplification systems, ensure the specified requirement by:

1) rational arrangement of these materials along the length of the structure, preventing any displacement of materials relative to each other;
2) anchoring materials reinforcing the structure to the supporting material, for example, using the shape features of the system elements;
3) using glued or bolted joints.

In the case of hybrid structures with an external reinforcement system, this requirement can be met only by attaching the reinforcing material to the carrier [9-10].

Here are 3 types of connections between reinforcing composite plates and steel bearing sheets:
- mechanical connections;
- adhesive joints;
- combined connections.

2. Mechanical connections
Mechanical connections include the connection of dissimilar materials using bolts, screws, pins, rivets, studs. Figure 1 shows some of the possible options for mechanical joints of composite and steel plates. The main advantages of bolted connections include their simplicity and speed of installation. There is also a wide variety of connections using various elements (bolts, rivets, etc.), for each of which a calculation method has been developed and tested [11-12].

The main disadvantages of mechanical connections include:
- uneven distribution of stresses in materials;
- damage to the surfaces of the materials to be joined;
- most of the connections are not tight.

A feature of the use of mechanical joints for connecting composite and steel sheets with each other is the need to make a hole in the composite material - the use of suitable nozzles for drilling is required, followed by machining the holes as needed [13-14].

In some cases, when using mechanical joints, the composite material experiences significant shear forces at the joints due to the perception of a part of the shear stresses in the structure. The most effective shear forces are perceived by a fiber-reinforced composite with reinforcement in several directions, less effectively - by a composite with a unidirectional arrangement of reinforcing fibers [15-16].
Reducing the influence of shear forces can be achieved as a result of: 1) making a larger number of bolted connections connecting the composite and steel; 2) reinforcement of the composite in the places of the holes with metal thin-walled plates mounted in the body of the composite; 3) the use of curved fibers reinforcing the composite material [17-18].

3. Adhesive connections
Adhesive joints - used to create sealed joints between composite and steel plates. The advantages of this type of connection are:
- even distribution of stresses in steel and composite plates, along the entire length of the hybrid structure;
- no damage to the surfaces of the materials to be joined;
- provided that the adhesive is applied over the entire area of the composite plate, the adhesive joints are tight;
- provided that the adhesive is applied over the entire area of the composite plate, the adhesive joints are hermetically sealed;
- during thermal expansion, the difference in deformations of dissimilar materials can be partially perceived by the adhesive seams.

One of the advantages of composite materials, as noted earlier, is the variety of their physical and mechanical properties, which depends on: тип применяемого связующего;
1. the type of fibers used (fiberglass, carbon fibers, basalt fibers, etc.);
2. the nature of fiber reinforcement (unidirectional, in two and three directions);
3. the ratio of the binder and reinforcing fibers used in the manufacture of the material;
4. the method of manufacturing the composite material.

The indicated advantage of composite materials is a significant disadvantage in the case of using adhesive joints of steel and composite plates. This is due to the fact that the features of the interaction of the adhesive composition with the composite surface differ for different types of composites. For this reason, for each application of adhesive joints, it is necessary to search for the optimal adhesive composition suitable for the selected composite material.

This disadvantage is aggravated by the fact that the use of a new adhesive composition requires additional mechanical tests, which establish the nature of the destruction of the adhesive joint along the following boundaries: a) steel - adhesive mass; b) glue mass - composite material; c) along the cross section of the glue mass. In addition, the disadvantages of adhesive joints include the high difficulty of performing installation work, the need for special equipment.

However, the adhesive type has the potential to become one of the main types of joints in steel and composite plates in the future. This is justified by the fact that composite materials are increasing their share in the building materials market, regulatory documents have been adopted that determine the calculation methods for building structures made entirely of composite [19-20], which regulate the types of composite materials recommended for use. Gradually, the nomenclature base of composite materials will expand, which will entail the development of new adhesives with appropriate tests. In this case, the difficulties associated with the choice of adhesives for new types of composites will be eliminated.

4. Combined connections
Connections of this type are characterized by the fact that their bearing capacity depends on several factors, which are determined by the design features of the connection. As a rule, combined joints are joints, the joint operation of which is ensured by a special configuration of materials. Below are several types of combined connections.

A nodal connection (see Figure 2) of fiberglass truss profiles has been developed, the main feature of which is a steel composite plate, to which all truss elements are attached (item 1.2). The peculiarity of the composite plate (item 3) is that it consists of a steel gusset with stamped teeth on both sides (item 6), on which fiberglass composite plates are attached (item 5). In this case, the strength of a
connection made of dissimilar materials depends on the strength of adhesion of the surfaces of these materials, the strength of stamped steel teeth, fiberglass plates - at the points of attachment of the teeth, as well as at the points of bolted joints of the truss elements (item 4).

![Diagram of nodal connection](image)

**Figure 2.** Nodal connection: a) general view of the node; b) section of the node along the section 1-1; c) general view of the stamped steel plate; d) view 2-2 of the stamped plate.

Also known is the design solution of the combined connection "FAUSST" (see Figure 3). In the process of manufacturing the composite plate (item 1), steel fibers (item 3) are additionally used, which are located along the border of the composite material. To connect dissimilar materials, the composite and steel elements (item 2) are installed in the design position, after which the outlets of the steel fibers of the composite material are welded to the steel profile. In this way, a combined joint is created, the strength of which depends on the strength of all steel fibers, the stress-strain state of the composite material at the points of attachment of the fibers, the strength of the welded joints and the adhesion strength between the ends of the elements.
In addition, it should be noted a compound with an increased adhesion bond, the use of which makes it possible to achieve high shear strength. Bonding can be achieved by design measures such as winding a reinforcing fiber around a threaded steel rod during the composite fabrication process. The bond strength is determined in this case by the adhesion strength of the composite material to the steel surface, as well as the strength of the composite material itself (at the threaded sections). Increased adhesion bond can also be ensured by special processing of the fibers of the composite material in a special environment, for example, in plasma (see Figure 4).

**Figure 3.** Combined connection type "FAUSST".

**Figure 4.** Joining steel and composite parts: a) composite material; b) steel part; в) the interface between the materials.

5. **The discussion of the results**

The use of adhesive joints is possible when creating permanent joints of steel and composite sheets, however, difficulties arising in the selection of the required adhesive material currently limit their use.

The use of combined connections is also possible, depending on their type and the availability of a complete calculation and design methodology. Nevertheless, the joints of the combined type remain the most complex from the point of view of the structural arrangement among all the types considered, they require high qualifications in the production of work.
6. Conclusions
The most rational option for joining steel and composite plates is mechanical type. The main advantage of this type of connections lies in the availability of a detailed regulatory framework for their calculation and design, as well as in the simplicity and speed of installation of mechanical connections.

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