UDC 620.17:678.686:004.9:621.9
DOI 10.36910/10.36910/6775-2313-5352-2025-27-2
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DEVICE FOR AUTOMATED TESTING OF EPOXY COMPOSITE COATINGS FOR THE STRENGTH OF ADHESIVE BONDS

Modern industry in Ukraine involves complex extreme operating conditions for various mechanisms and machines in the open air, including cyclical temperature changes. In this area of research, the creation of effective protection systems is perspective. From a scientific point of view, the use of adhesive-strength coatings made of various materials depending on their functional purpose is interesting in this area of research, which determines the use of different methods for their formation. The most technologically advanced in terms of forming protective coatings from these materials, operation and restoration are epoxy composites with a wide range of functional characteristics. One of the main characteristics mentioned is the strength of the adhesive bonds of such coatings to the working surfaces of parts. The strength of adhesive joints is determined by the amount of separation of cylindrical metal samples glued together. The accuracy of determining these characteristics depends significantly on the accuracy of the direction of force application relative to the adhesive joint. This indicator is influenced by the total error in the technological chain, in the system: "fixed gripper on a tensile testing machine (fastening error) - the shank of one of the cylindrical samples on the side of the fixed gripper of the tensile testing machine (manufacturing error of the shank relative to the axis of the cylindrical sample) - cylindrical sample on the side of the movable gripper (error of mutual positioning of two cylindrical samples in the adhesive joint area, error of manufacturing the shank of the specified cylindrical sample and error of its fastening on the movable gripper). The development of a device that will reduce the total error in the aforementioned system will increase the accuracy of determining the adhesive characteristics of coatings, including when testing multilayer coatings on metal surfaces.

Keywords: *multilayer coatings, epoxy composites, shank fastening error, mutual positioning accuracy of samples, adhesion characteristics.*

Introduction. Current industrial development determines the problem of designing various mechanisms and machines with increased reliability and durability under various operating conditions without a significant increase in the amount of materials used in their manufacture and repair [1-4]. Improvements in performance are mainly achieved by applying protective coatings made of composite materials with different functional purposes [5-7]. Various methods are used to form these coatings [8-11]. Epoxy composite materials and coatings based on them with controlled structural organisation have also proven themselves well in solving this problem while simultaneously expanding the functional characteristics of various products that operate, in most cases, in extreme conditions [12-14]. An example is the operation of parabolic antennas in different climatic zones, namely in marine climates, at temperatures where frost occurs, various atmospheric precipitation, etc. When the product is in 'sleep' mode and not in operation, frost, ice, and snow accumulate on the surface of the antenna. These factors increase the time required to prepare the product for operation of the parabolic antenna. The problems highlighted necessitate the creation of a heating system for the working surface of the product. In this case, the most effective solution is to use surface-distributed resistive electric heaters. When designing such products, multi-layer coatings with different functions are used: electrical insulation, electric heating, and thermophysical. The most technologically feasible way is to place such coatings on the back side of the antenna. A coating layer is used when spraying aluminium oxide and forming subsequent epoxy composite layers [15-16]. Reliable operation of the heating system is ensured by adhesive-mechanical interaction in the composite material of the layers both at the phase boundary in the 'matrix-filler' system and between the layers and in the 'aluminium base-multilayer coating' systems.

In view of the above, research aimed at creating an adhesion-strength gradient coating consisting of layers of sprayed aluminum oxide and subsequent layers of epoxy composites is scientifically and technically important when creating an antenna heating system [17-18]. To solve this problem, it is necessary to study the effect of their structural parameters, including nanostructural formations, on their adhesion characteristics.

The aim of the work. The aim of the work is to develop a device to ensure the accuracy of mutual positioning of cylindrical samples glued together by self-centring during the process of testing the strength of adhesive joints.

Research materials and methods. The samples are made of steel (Figs. 8-9). The strength of adhesive bonds to this material is known and, under this test scheme, is σ = 55-60 MPa for epoxy binders (ED-20, CYD128, E-51). The strength of adhesive bonds when using a binder based on E-7 epoxy resin manufactured in China is 74-78 MPa.

The insert made of different materials (steel, titanium, aluminium) is coated with a coating of different materials (ceramics, cermets) with a thickness of 200-250 μm by gas flame spraying. When using the method of detonation spraying on a steel insert (Steel 45), the theoretical strength of the adhesive joints can be less than or equal to σ for ED-20, CYD128, E-51 - 55-60 MPa, for E-7 - 74-78 MPa.

Destruction happened at the junction of the system insert - detonation coating for detonation spraying. Thus, this approach to testing the strength of adhesive bonds will allow determining the adhesive characteristics of different materials coated by different methods. Since the tensile adhesion tests are performed in an automated mode using a tensile tester and a computer that records not only the adhesion characteristics but also the elastic modulus and the amount of coating deformation, it is necessary to ensure that the load and the direction of movement of the grippers are aligned. For this purpose, we propose a device design that will provide these indicators with the smallest error.

Discussion of research results. The device belongs to the technical field of devices and instruments for improving the accuracy of determining the adhesive characteristics of epoxy composite coatings [19-20]. The design of the device is based on the task of self-centring to reduce the total error accumulated in the technological chain in the system 'sample - device - tensile tester'. This total error has the following components:

- manufacturing errors, installation in one of the cylindrical parts of the sample when the shank is fixed in the fixed gripper of the tensile machine;
- manufacturing error in the installation and fixing of the shank of another cylindrical sample on the side of the moving gripper of the tensile machine.

The development of a device that will reduce the total error in this system will improve the accuracy of determining the adhesive characteristics of coatings to metal surfaces, including when testing multilayer epoxy composite coatings using a tensile tester with the results and test process recorded on a computer.

The sample is made in the form of two cylinders of specimens glued together. An epoxy composite material is placed at this joint to test the strength of the adhesive bond. The device (Fig. 1-9) is equipped with hinged fixing axes, with their horizontal longitudinal optical axes perpendicular to each other in the projection onto the horizontal plane, and two grippers between the tensile machine holders. A sample consisting of two cylinders glued together by a butt is equipped with two cylindrical axes, and the first gripper has a flat protrusion placed between the jaws of the tear opener holder, and on the opposite side of the first gripper there is a groove perpendicular to the larger side of the flat protrusion with a flat protrusion of the next second gripper placed therein, which is fixed relative to the first gripper by a cylindrical axis. It should be noted that the second gripper has a groove perpendicular to the flat protrusion in the vertical plane on the side opposite to the protrusion, with a flat protrusion of the test specimen placed therein and fixed therein by a cylindrical axis. The holes for the fixing axes of the first and second grippers are perpendicular to each other, and the groove of the second gripper has a protrusion of the test specimen, which is fixed relative to the second gripper. axis. The holes in the projection of the second gripper and the projection of the test sample are made with a diameter larger than the diameter of the fixing axes by an amount equal to the amount of the gap between the end surface of the projection of the second gripper and the bottom surface of the recess of the first gripper. Accordingly, the end surface of the protrusion of the test specimen shank and the bottom surface of the recess of the second gripper can be fixed with the axis of the second gripper with the protrusion of the specimen. The dimensions of the groove of the first and second grippers are larger than the width of the projections of the second gripper and the projection of the test piece placed in the groove of the second gripper, with the possibility of rotational movement along the fixing axes of the first and second grippers. It is possible to move the second gripper along the fixing axis of the first gripper and the test sample along the fixing axis of the second gripper, and the holes in the body of the first and second grippers are made with a diameter equal to the diameter of the axes.

The technical concept of the device is presented in the kinematic diagram in Fig. 1 and the structural diagrams in Figs. 2-7. The device consists of a first gripper 1 with a flat protrusion 2 for placement in the holder of the breaking machine. On the opposite side, there is a groove 3 located parallel to the larger side of the flat protrusion 2. The second gripper 4 is located in the groove 3 of the first gripper 1 with protrusion 5. The first gripper 1 and the second gripper 4 are fixed to each other by axis 6 through holes 7 and 8. In the second gripper 4, on the side opposite the protrusion 5, there is a groove 9 located perpendicular to the flat protrusion 5.

A test sample 10 is placed in groove 9 with a flat protrusion 11 and fixed with a cylindrical axle 12, which is placed in the hole 13 of the protrusion 11 of the test sample 10 and the hole 14 of the second gripper 4. The holes 7 and 8 for the fixing axes 6 and 12 in the flat projections 5 and 11 of the second gripper 4 and the test sample 10 are made with a larger diameter by the amount of the gap h. The longitudinal optical axes of holes 7 and 14 for fixing pins 6 and 12 of the first 1 and second grippers are perpendicular to each other. The test sample 10 with a projection 11 is placed in the groove 9 of the second gripper 4 and fixed relative to the second gripper 4 by the fixing axis 12. The gaps between the end surface 15 of the protrusion 5 of the gripper 4 and the surface 16 of the bottom of the groove 3 of the gripper 1 and, respectively, the surface 17 of the protrusion 11 of the test sample 10 are made equal to the gap h. A hole 13 is made in the projection 11 of the test sample 10. On the opposite side of the projection 11 of the test sample 10, there is a projection 18 that can be placed in the holder of a tensile testing machine during testing. The test sample consists of two parts (Fig. 5). An adhesive is placed between them. It is not shown in the structural diagram, as it is not a structural element.

It should be noted that a gap h is provided between the inner side surfaces 19 of the groove 3 of the gripper 1 and the side surfaces 20 of the gripper 4 of the protrusion 5. Also, a gap h is provided between the inner side surfaces 21 of the groove 9 of the second gripper 4 and the side surfaces 22 of the protrusion 11 of the test specimen 10. The gap provides for the possibility of rotational and axial movement along the axes 6 and 12 of the second gripper 4 and the test specimen 10. The openings 7 and 14 in the gripper bodies 1 and 4 are made equal to the diameter of the axes 6 and 12. It should be noted that the surfaces of the axes 6 and 12 and the holes 8 and 13 are made with a roughness Ra = 0.16 μm and heat-treated to 45-50 HRC. Before a series of tests, it is necessary to apply lubricant to the surface of the fixing axes 6 and 12 to improve the mutual movement of the mated parts during the process of self-centring during testing. The value of the gap h was selected for design reasons and is 4-5 mm. This gap h ensures the self-centring of the test specimen 10. It should be noted that the fixture assembly ensures that the guaranteed gap h is maintained between the surfaces 22 and 23 of the grippers 1 and 4, the surfaces 24 and 25 of the gripper 4 and the test sample 10.

The proposed device is implemented as follows. The device is assembled in several consecutive stages. The flat protrusion 5 of the gripper 4 is placed in the groove 3 of the first gripper 1. Next, the hole 8 of the gripper 4 is aligned with the holes 7 in the body of the gripper 1 and fixed with the fixing axis 6. In this case, due to the gaps h between the corresponding surfaces (described above), the second gripper 4 can move along the fixing axis 6 and rotate around the optical axis of the fixing axis 6. Next, a flat protrusion 11 of the test sample 10 is placed in the groove 9 of the second gripper 4, aligning the hole 13 with the holes 14 in the gripper body 4 with the fixing axis 12. The specified test sample 10 can be displaced along the fixing axis 12 and rotated around the optical axis of the fixing axis 12. The device is ready to be placed in the holders of the tensile testing machine.

The device assembly (Figs. 1, 2, 7) is placed vertically between the jaws of the upper holder of the tear opener with the flat protrusion 2 of the gripper 1. This holder is capable of vertical movement at a given speed. A schematic diagram of the joint formation for testing the strength of adhesive joints is shown in Fig. 8-9.

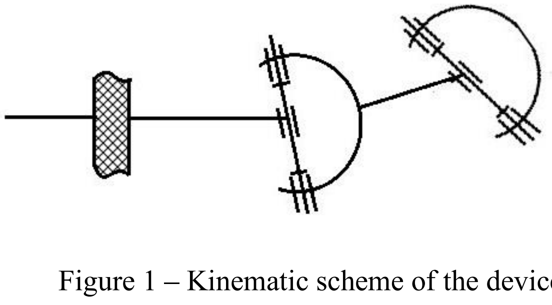

Figure 1 – Kinematic scheme of the device

The test material insert is coated, for example, by detonation spraying. Next, an epoxy coating is formed. The material is vacuumed before forming the joint. Next, the joint is formed under load for 24 hours, heat-treated if necessary, followed by testing. Next, the test specimen 10 is placed between the jaws of the lower fixed holder of the tensile machine by the projection 18. Next, switch on the tensile testing machine. The test is started. The results of movement at the required speed and force are set on a computer using the developed program. Next, the test results are analysed.

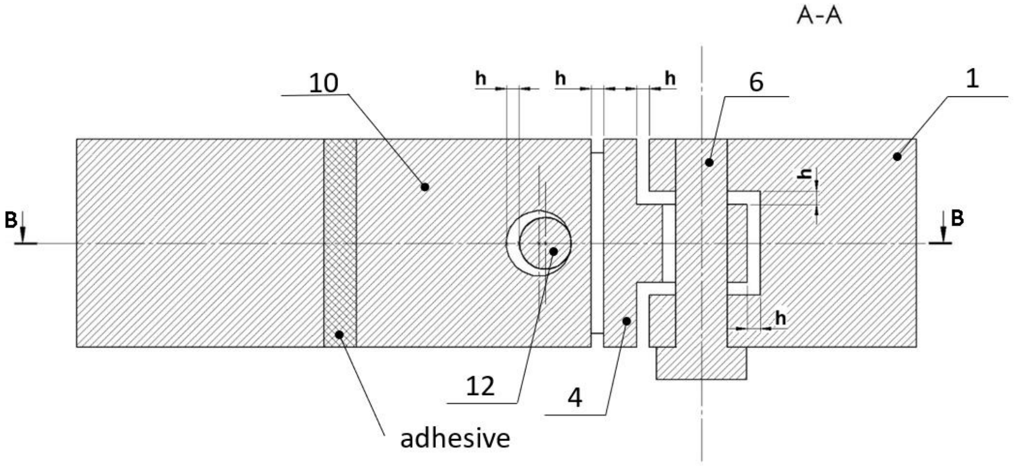

Figure 2 – General view of the device with longitudinal section A-A for a better view of the design.

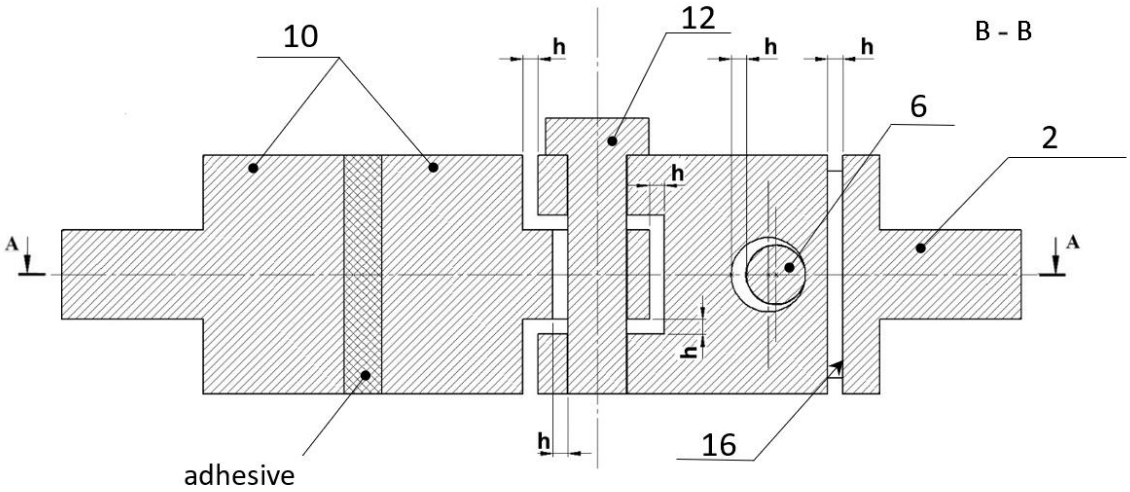

Figure 3 – General view of the device with longitudinal section B-B for a better view of the structure.

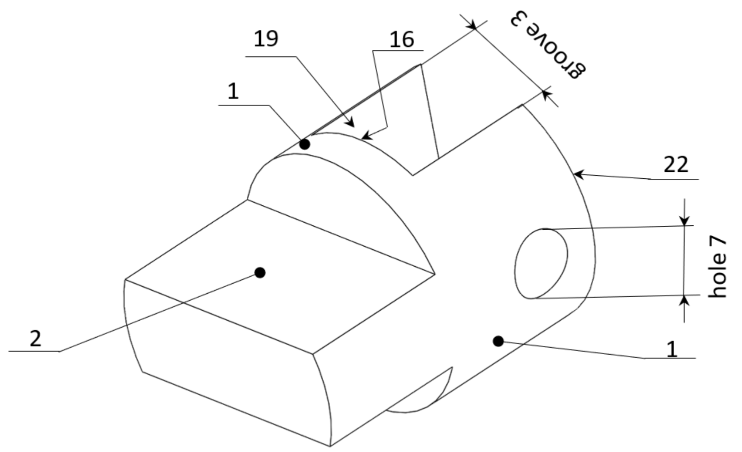

Figure 4 – The first gripper in axonometry.

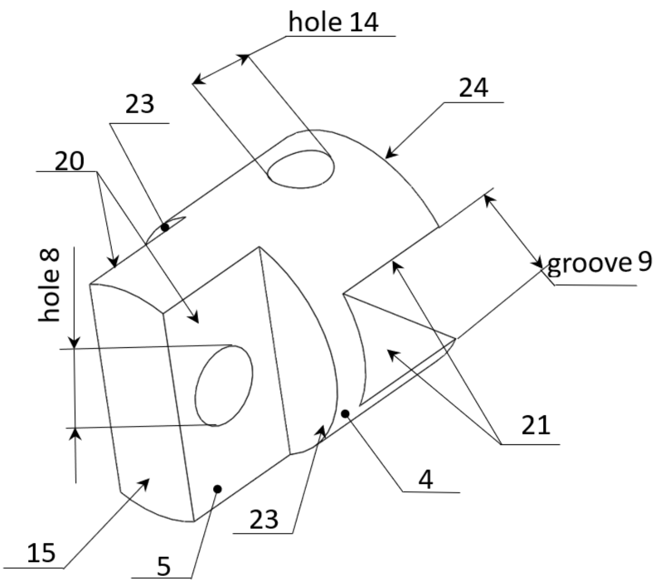

Figure 5 – The second gripper in axonometry.

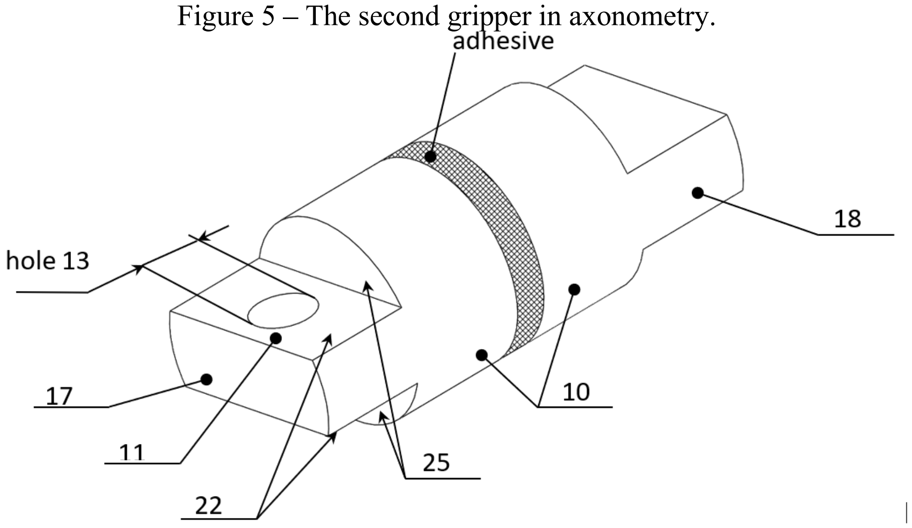

Figure 6 – Sample for testing the strength of adhesive joints in axonometry for a better view of its design with an image of an adhesive bond.

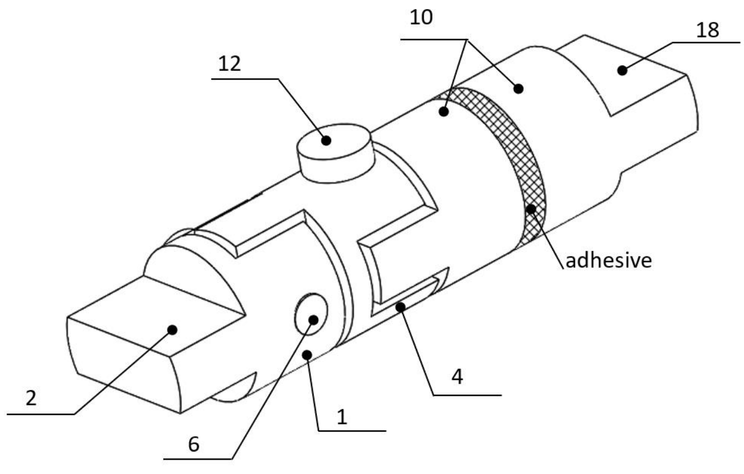

Figure 7 – General view of the device assembly (axonometry).

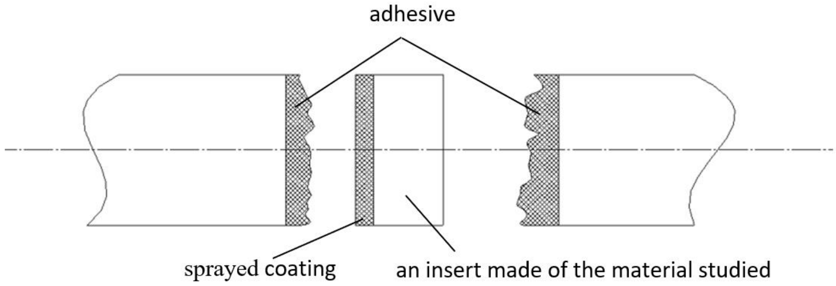

Figure 8 – Scheme of adhesive joint formation.

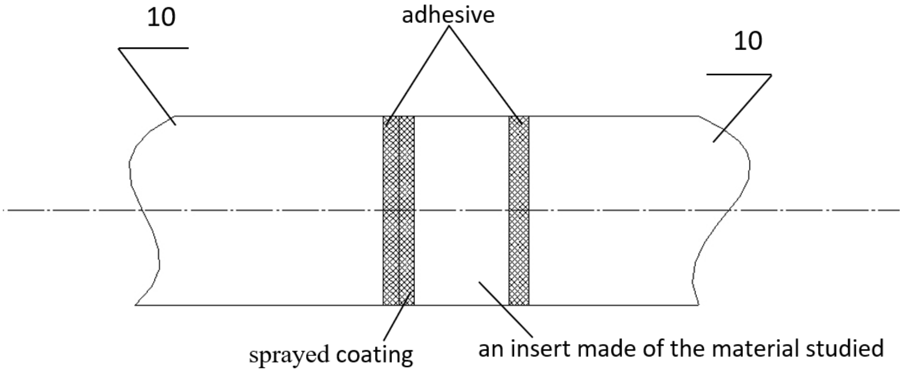

Figure 9 – General view of the joint.

Conclusions. The use of the proposed device will ensure increased testing accuracy by applying a load force along the vertical axis (longitudinal axis) of the device. The use of the proposed device will allow to load the adhesive layer in the test samples evenly. Conditions are provided for adhesive failure of the joint without chipping and its distortion relative to the direction of the applied force. Tangential loads during adhesive joint failure are significantly minimized. This increases the accuracy of adhesive bond strength testing. When installing a test specimen with an adhesive joint, the positioning accuracy is improved while reducing the time required to install the specimen in the working parts of the tensile testing machine. The testing process is simplified and the accuracy of determining the strength of adhesive joints to different materials is increased. A reduction in the error of experimental studies was observed when testing polymer materials based on reactoplasts. In subsequent studies, it is planned to develop similar devices for testing multilayer coatings on various materials.

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Дата першого надходження статті до видання	Дата прийняття статті до друку	Дата оприлюднення
24.10.2025 р	15.11.2025 р.	25.12.2025 р.