Research Article

Experimental Study Of Plates With Polymer Coatings For Resistance Under Compression

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Abstract. Polymer coatings are widely used in various fields of technology to protect structural elements from corrosion, to provide electrical insulation, to control the frictional characteristics of surfaces, for decorative purposes, etc. [1]. Reliable identification of the mechanical properties of coatings is an important task from the point of view of ensuring their strength and wear resistance during operation process [1-8]. Here, the mechanical properties of epoxy-polyester-based coatings used for corrosion protection of structural elements of aviation equipment are determined. On the basis of a sequence of experimental studies and theoretical calculations, the elastic modulus of the coating material, the residual stresses acting in it arising from the use of heat treatment in the process of coating deposition [9-13] and the adhesion strength of the coating to the substrate under conditions of complexly stressed heating are determined. The results obtained can be used both to assess the strength and durability of the coating material, and to assess their influence on the mechanical behavior of protected thin-walled structures.

Keywords: Polymer coatings, strength, compression, modulus of elasticity.

1. Introduction

When carrying out strength calculations of large-sized structures, the effect of coatings can be neglected if the wall thickness of the products significantly exceeds the thickness of the coatings and the rigidity of the coatings is much lower than the rigidity of the structure material. However, if the thickness of the coating is comparable to the thickness of the structural element and if the coatings have sufficient rigidity, then their effect cannot be neglected under certain loading conditions. From the point of view of strength calculations, thin-walled metal structural elements with polymer coatings can be presented in the form of two- or three-layer plates (depending on whether the coating is applied on one or both sides) with a tougher middle metal layer and much more pliable outer layers-coatings [10-11]. At present, not many experimental and theoretical works are known in which the analysis of the macroscopic mechanical behavior of such structural elements is carried out taking into account the effects of the influence of residual stresses. It is worth noting a wide variety of works in the field of obtaining and studying the properties of composite materials [14-35] and the study of functional-gradient thin-walled structures with coatings (for example, [11, 36-38]). However, in such structures it is usually assumed that the rigidity of the surface layers is higher compared to the inner region. These are structures such as, for example, metal products with ceramic coatings or hardened near-surface zones. Thin-walled structures with a rigid middle layer and pliable thin outer layers have received little attention. In linear problems of statics, in fact, as experiments show, the effect of thin coatings can be neglected. In more specific problems, for example, under conditions of finite deformations, nonlinear elasticity, in problems of stability and vibration loading of thin-walled structures with coatings, neglecting the effect of coatings can lead to calculation errors [39-62].

The subject of research is to determine the mechanical characteristics of the modulus of elasticity, residual stresses and adhesive strength of epoxy-polyester coatings, and their effect on the mechanical behavior of metal substrates during stability tests at room and elevated temperatures.

2. Experimental studies and theoretical calculations

In stability tests, samples were used from rolled sheet steel grade 08PS with a constant thickness of 0,7 mm and, depending on the batch, of various lengths and widths (with or without coating).

The length of the working zone for specimens with a length of 240 mm was 132 mm, and for specimens with a length of 120 mm - 86 mm. The samples were tested at a constant speed of 0,5 mm/min. Mechanical grips were used for all samples. The tests were stopped after the appearance of a clearly pronounced nonlinear section on the load-displacement diagram, while the loss of stability of the sample was visually always observed somewhat earlier.

The tests were carried out at room and elevated temperatures of 70°C. Before testing at elevated temperatures, the sample was kept in the chamber for 10 minutes. It was found that when testing samples with coatings at an elevated temperature, it is necessary to additionally tighten the grips of the testing machine after heating the sample. Otherwise, the test results turned out to be significantly underestimated. The appearance of such an effect should be explained by the influence of the effect of thermal expansion of the coatings, which leads to a weakening of the force in the grippers during heating. In samples without coatings, no such effect was found, and they were tested without additional tightening of the grips.

The theoretical values of the critical buckling load $P_{кр}$ were found on the basis of the well-known formula from the theory of bar stability for the case of vertical load action and rigid pinching of the bar ends []:

$$P_{кр} = \frac{4\pi^2 EJ}{l^2},$$

where $l = 86$ mm - rod length, E – Young's modulus, J – moment of inertia of the cross-section of the bar.

When modeling uncoated plates, we take $E=E_{cm}$– Young's modulus of steel, $J=J_{cm}=bh^3/12$ – moment of inertia of specimens with thickness h and width b. When modeling coated plates, the flexural stiffness of the corresponding bar should be calculated taking into account the additional contribution from the coating layers: $EJ = 2E_n J_n + E_{cm} J_{cm}$, where E_n - modulus of elasticity of the coating, J_n – moment of inertia of coating layers shifted relative to the neutral line of the bar.

In the calculations, the following values of the physical and mechanical properties of materials were used:

Sheet steel 08PS: modulus of elasticity E_{cm} = 190 Gpa; Poisson's ratio μ= 0,3; thermal expansion coefficient $\alpha=12.5*10^6 C^{-1}$.

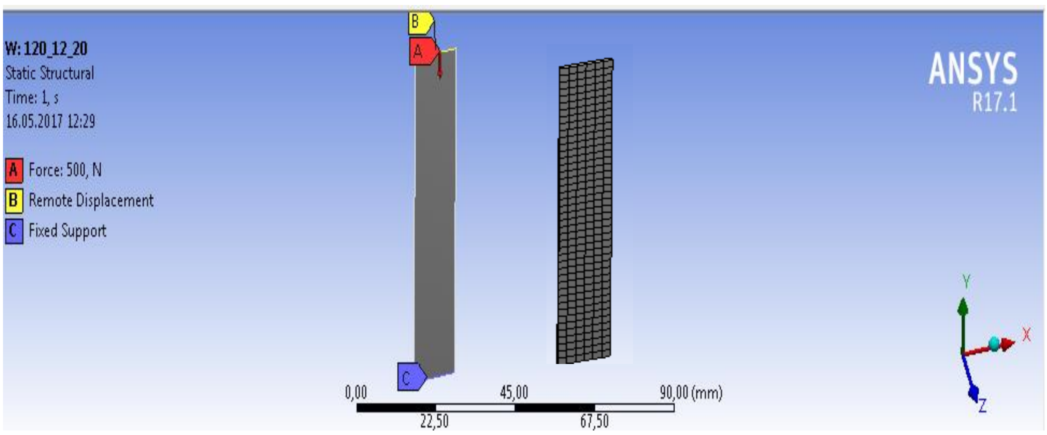
EUROPOLVERI coating: modulus of elasticity E_n =3 Gpa;

Poisson's ratio μ=0,35; coefficient of thermal expansion (CTE)$\alpha=55*10^{-6}C^{-1}$.

In additionally performed numerical calculations, the possible non-rectilinear shape of the sample was taken into account by setting the initial curvature of a given radius. Numerical calculations were carried out in the Ansys Transient Structural module, taking into account finite deformations. The samples were modeled as layered plates. The calculations took into account the effect of residual stresses: the neutral state of the sample was set at a temperature of 150°C (coating polymerization temperature), and the calculations were carried out at a given temperature of 20°C and 70°C. The change in the modulus of elasticity and CTE of materials with a change in temperature was neglected..

The diagrams were obtained as a result of numerical calculations for almost straight samples of 120*12 mm in size with different values of the radius of curvature.

To simulate anchoring similar to the experiment, the boundary conditions were set (Figure 1): on the lower face, the termination conditions were set. On the upper face, the conditions were set for prohibiting displacements in the direction of the width Ox and thickness Oz of the sample, as well as rotation around the direction of the width of the sample Rx. The load was applied to the upper face along the Oy axis in the form of a force.



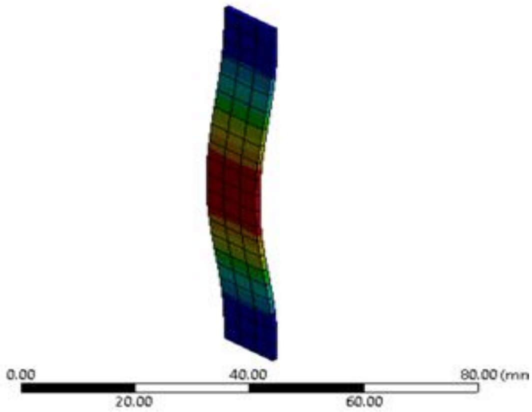


Fig. 1. A finite element model with given boundary conditions and load (top) and a sample that has lost stability (bottom).

3. **Test** results

The results of testing samples at different temperatures are shown in Figure 2. From these results it follows that the presence of a coating leads to a slight increase in the bearing capacity of the plates in the supercritical deformation region. This effect is especially evident for longer and wider samples. For small-sized samples, the effect of changing the critical load of buckling does not actually occur. The effect of temperature on the critical load is also negligible.

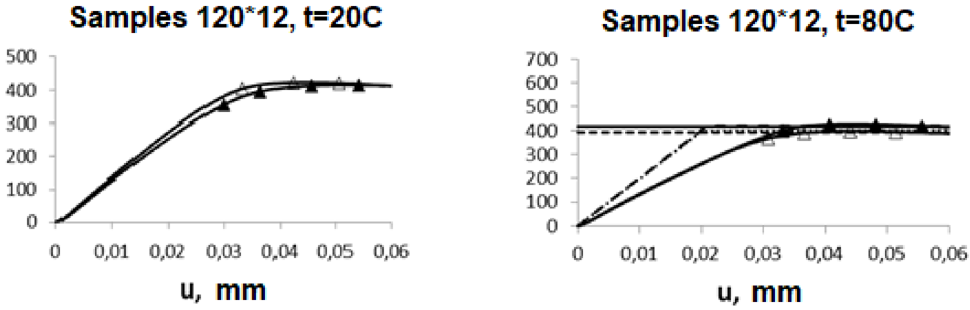


Fig. 2. Results of testing samples for stability at room and elevated temperatures.

4. **Simulation of test results**

Comparison of the results of numerical and analytical modeling of the stability of plates with coatings and experimental data is shown in Figure 3. It is shown that analytical calculations using the Euler formula (horizontal dashed lines) and numerical modeling (dashed diagrams) are in good agreement with each other and are in good agreement with the experiment in critical load forecast. The results of calculations confirm that the presence of a coating does not significantly affect the level of the critical load. The discrepancy between the angle of inclination of the linear section of the experimental diagrams and the diagrams obtained in Ansys is explained by the fact that the experiment was carried out without an extensometer and the displacements were measured by the displacement of the traverse, which led to overestimation of the displacement values.

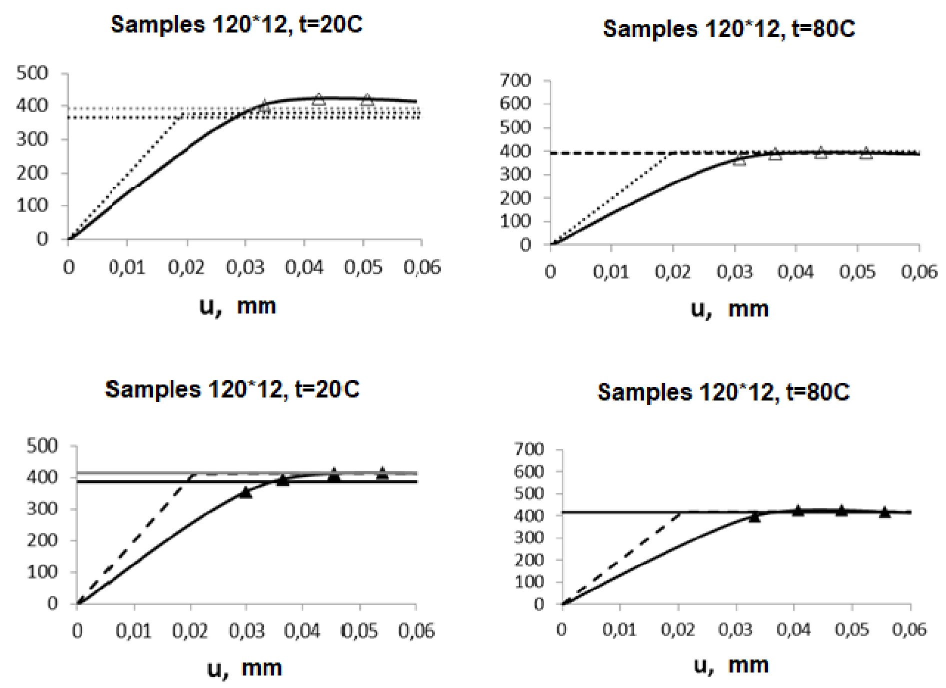


Fig. 3. Results of modeling and testing of 120x12 samples. Top - uncoated samples, bottom - coated.

5. Conclusion

As can be seen from the graphs, the effect of the coating is reduced to an insignificant increase in the critical force, which is confirmed by the classical analysis of the strength of materials and numerical simulation. The best result is obtained by using the Ansys Eigenvalue buckling module.

6. Acknowledgements

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