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TECHNOLOGICAL RESIDUAL STRESSES IN AMORPHIZED DETONATION COATINGS

The results of experimental studies of the distribution of technological residual stresses in amorphous-crystalline detonation coatings are presented. The effect of residual stresses on friction indices is also determined. The distribution, depth and value of residual stresses were determined by a mechanical destructive method. The diagrams of the distribution of macrostresses across the depth of the sprayed coatings, as well as depending on their thickness, were created and studied.

It is shown that annealing, as a type of heat treatment, is one of the most accessible and effective methods for production. Annealing can change the value and pattern distribution residual stress in the studied coatings.

The main technological directions for improving the quality of amorphous-crystalline coatings by minimizing their residual stresses are formulated. [dx.doi.org/10.29010/086.4]

Keywords: *amorphous-crystalline materials; detonation coating; residual stresses.*

Introduction

Provide the reliability of quality and competitiveness of machines and mechanisms with coatings is associated with the decision of a set of technical problems, most of which are due to the effect of technological residual stresses [1].

Technological residual stresses arise during the processes of coating formation during the hardening of parts or reconditioning. Their pattern, sign and distribution have important impact on operational properties. Residual stresses can gradually reduce surface strength, which leads to malfunctions of moving mates as a result of wear, or actively stimulate the causes of destruction processes. For the mechanics of a deformed solid, despite the formal understanding of the basic physical processes that cause residual stresses in the sprayed coatings, the formation of technological residual stresses is a difficult process. Especially note the case when the change in the volume of material is concentrated in the surface layer.

Residual stresses have been investigated for a long time. An extensive theoretical and applied material has been accumulated on various aspects of their operational impact [2]. However, the development of technology, the emergence of new structural materials, in particular, amorphous-crystalline, and the increasing requirements for their quality, confirms the actual of the problem of residual stresses.

In addition, the field of research of technological residual stresses that arise in the conditions of detonation gas spraying is not sufficiently developed and researched, both in our country and in the world.

Problem Formulation

The aim of the article is to study using the system analysis of the patterns of distribution of technological residual stresses in amorphous-crystalline detonation coatings and to determine their effect on operational properties [3].

Modern technology fundamentally allows the use of several methods and instruments for determining (measuring) residual stresses. The results obtained in the work are based on the mechanical method.

Methods

The experimental values of technological residual stresses in amorphous-crystalline coatings were determined by a mechanical destructive method, which is the most developed and reliable [4]. The study by a mechanical method made it possible to determine the nature of the distribution, the depth of occurrence and the value of residual stresses using the NI-1 device (IPMS NAS of Ukraine). This device allowed us to register changes in the sample deflection boom in the process of continuous etching of the sprayed layer. An aqueous solution of ortho-phosphoric and sulfuric acids was used as the electrolyte. The samples had the form of plates with a thickness of not more than 2.5 mm. Surfaces that were not etched were protected with a mixture of paraffin and rosin.

Mechanical method for determining residual stresses. From the surface of the samples by electrochemical method, which does not make its own stresses and does not heat the surface layers, strained thin surfaces are removed. At the same time, the occurring deformations are measured, the thickness of the removed layer is determined, and according to the theory of elasticity, the residual stresses in the samples are calculated.

The sign of the residual stresses is determined by the sign of the tangent of the angle of inclination of the tangent, which is defined to the recorded deflection curve at a point. When the logger is moved to the right, the tensile stresses (with the «+» sign), and when the logger is moved to the left, the stresses are compressive (with the «–» sign). The deflection of the sample is positive if directed towards the removed layer.

The studies have determined stresses of the first kind — macrostresses, which arise in detonation coatings as a result of the interaction of various technological factors during its formation.

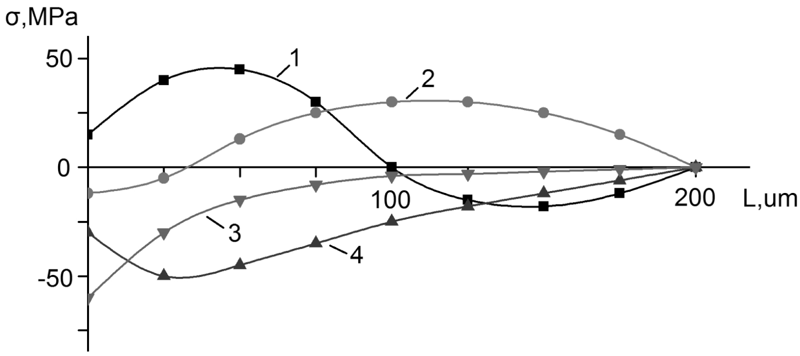

Fig. 1. Diagrams of distribution of macrostresses over the depth of the surface layer of coatings:
1 — based on nichrome doped with Al and B; *2* — based on titanium doped with Al and Fe; *3* — amorphous-crystal composition Zr-Al-B; *4* — based on an alloy of tungsten carbide with cobalt

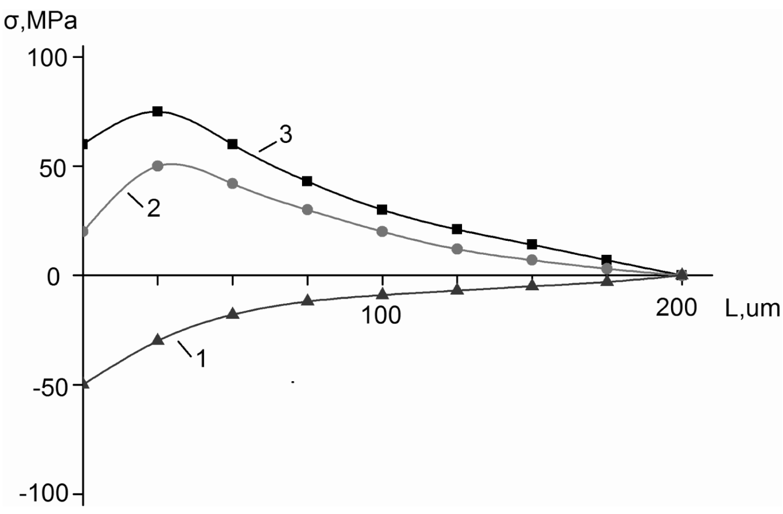

Fig. 2. Diagrams of distribution of macrostresses across the depth of Zr-Al-B coatings, depending on the deposition thickness:
1 — 150 μm; *2* — 250 μm; *3* — 350 μm

Results and Discussion

When testing amorphous-crystalline coatings, the patterns of distribution of residual stresses over the depth of the surface layer were determined and analyzed. For comparison with the obtained results, diagrams of the distribution of macrostresses of detonation coatings are presented, which are sprayed with powders — nichrome (type ПХ20Н80) doped with aluminum and boron; titanium doped with aluminum and iron; amorphous-crystal composition Zr-Al-B and hard alloy tungsten carbide with cobalt.

Fig. 1 shows the diagrams of the distribution of macrostresses across the depth of detonation coatings.

Researchers have found that the stress distribution pattern across the thickness of the sprayed layers is very dependent on the initial powder mixtures. In some powders, there are more compressive stresses, and in others, stretching with greater approximations to absolute values. From the point of view of operational properties, amorphous-crystalline coatings of the Zr-Al-B system (curve *3*) have the best stress distribution, on the surface of which there are compression stresses up to 70 MPa, monotonically decreasing in thickness and approaching zero at a depth of about 150 μm. In the coating based on titanium (curve *2*), the stresses are small, which is due to the absence of active thermal diffusion processes causing a change in the volume of the sprayed material.

In the coating on the basis of nichrome (curve *1*) tensile stresses were found, reaching values of up to 20 MPa at the surface and at a depth of up to 75 μm passing into compressive. This is due to the formation of solid solutions based on nickel and chromium, which make it possible to relax well the stresses resulting from thermal gradients, which is confirmed by structural and phase researches.

Fig. 2 presents diagrams of the distribution of residual stresses of amorphous-crystalline Zr-Al-B coatings, depending on their deposition thickness. With an increase in the thickness of the coatings, the value of the residual stresses drastically changes to tensile values, and with increasing depth, their value decreases to zero. Thus, the value of the residual stress depends on the thickness of the sprayed coatings.

One of the most accessible and effective in terms of the production of technological operations to minimize residual stresses is heat treatment, namely, annealing. As a result of annealing, the value and pattern of distribution of residual stresses changes. The correlation of changes in the pattern of distribution of residual stresses due to heat treatment becomes greater with increasing annealing temperature. Annealing of the studied samples was done at temperatures of 300 °C and 400 °C.

The pattern of distribution of residual stresses after annealing at 300 °C is shown in Fig. 3. The value of the stresses is much redistributed. The stresses in thick coatings have decreased sharply. The depth of residual stresses mainly corresponds to the thickness of the coatings. The field of distribution of residual stresses, after annealing at 400 °C, changes even more. The value of the stress continues to decrease, and their distribution becomes compressive.

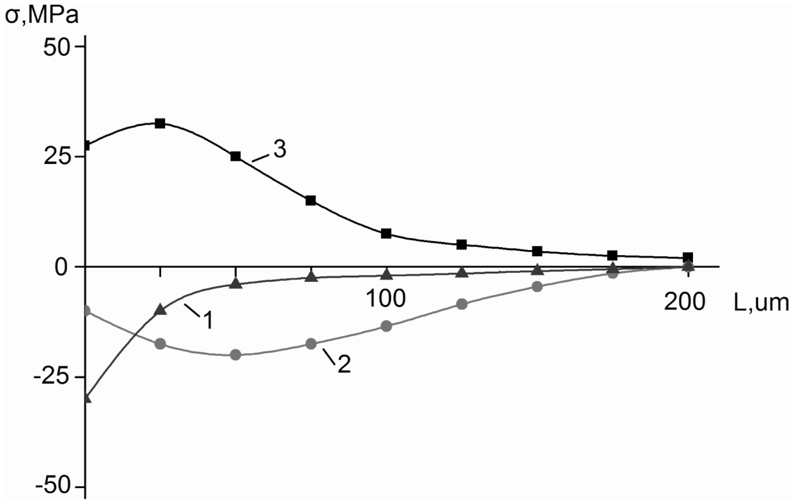

Fig. 3. Diagrams of distribution of macrostresses over the depth of Zr-Al-B coatings after annealing (300 °C):
1 — 150 μm; *2* — 250 μm; *3* — 350 μm

Thus, heat treatment of samples at different temperatures redistributes residual stresses in the coatings. With an increase in the annealing temperature, the pattern of the distribution of residual stresses changes qualitatively. Residual stresses are noticeably reduced, first in thicker coatings, then in thinner ones, and the stresses from tensile stresses pass into compressive stresses.

Being an important indicator of the functioning state of surface layers of coated parts, internal tensile stresses reduce the temporary resistance, and compressive stress can increase fatigue strength. Internal stresses have the same effect on endurance limit.

Thus, on the basis of the tests performed, it can be concluded that residual stresses occur in the surface layers of amorphous-crystalline coatings, which are strengthened by detonation spraying. These stresses, by their absolute value and distribution, have a small effect on the reliability and properties of the coating.

The optimum thickness of the sprayed amorphous-crystalline detonation coatings, corresponding to maximum wear resistance, is 150–200 μm.

With an increase in the thickness of the sprayed coatings, the increase in residual stresses can be significantly reduced by heat treatment. During heat treatment, tensile stresses turn into compressive stresses, which is good for their operating properties.

Conclusions

Residual stresses that occur during the formation of amorphous-crystalline detonation coatings, taking into account their material and specific loading scheme, can be controlled by changing the temperature-kinetic spraying parameters, as well as matching the properties of the components of composite coatings (first of all, their thermal expansion coefficients).

The use of materials with high shear moduli has a significant impact on the value of the residual process stresses. In this case, despite the small stock of plasticity of the coatings, the wear resistance will be high, since the stresses arising in the process of friction do not exceed the permissible ones.

Improving the quality of coatings by reducing the level of residual stresses is achieved by spraying special undercoats layers between the substrate and the coating, which provide a smooth change from the properties of the substrate material to the coating material.

The reduction of residual stresses is achieved through the rational use of amorphous-crystalline coatings with optimal thickness and the use of lubricant.

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ТЕХНОЛОГИЧЕСКИЕ ОСТАТОЧНЫЕ НАПРЯЖЕНИЯ В АМОРФИЗИРОВАННЫХ ДЕТОНАЦИОННЫХ ПОКРЫТИЯХ

Приведены результаты экспериментальных исследований анализа закономерностей распределения остаточных технологических напряжений. в аморфно-кристаллических детонационных покрытиях, и определения их влияния на эксплуатационные свойства при трении. Характер распределения, глубину залегания и величину остаточных напряжений определяли механическим разрушающим методом. Построены и изучены эпюры распределения макронапряжений по глубине напыляемых покрытий и в зависимости от их толщины.

Показано, что одной из наиболее доступных и эффективных в условиях производства является термическая обработка – отжиг, в результате которого можно изменять величину и характер распределения остаточных напряжений в исследуемых покрытиях.

Сформулированы основные технологические направления повышения качества аморфно-кристаллических покрытий путём минимизации их остаточных напряжений. [dx.doi.org/10.29010/86.4]

Ключевые слова: *аморфно-кристаллические материалы; детонационное покрытие; остаточные напряжения.*

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