The influence of coating technologies on stress-strain characteristics of the sample at periodic loading

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Abstract. The article is devoted to the research on influence of coating technologies on stress-strain characteristics of a heterogeneous sample (the substrate-coating system) at periodic stress-controlled loading. The comparison of stress-strain characteristics of samples with three types of surface layer showed that the coatings lead to the change in stress at which inelastic phenomena appear in the material. Apart stress-strain characteristics of samples, microrelief on the samples’ surface and formation of a slipband in the grain structure of the coatings were studied in the experiment. It is stated that cold dynamic spraying, which is performed by centrifugal acceleration of particles in vacuum, makes it possible to obtain a coating with better strength and stress-strain characteristics in comparison with cladding.

1. Introduction

There are well-known modern innovative technologies that allow applying metal particles on a detail and creating coatings not only on flat surfaces, but also on surfaces of complex geometrical shapes. Such technologies include, for example, dynamic spraying. This method uses kinetic energy to create a firm joint of the coating to the substrate and has been already used in aircraft engineering, machine manufacturing and production of oil and gas refining equipment [1]. The current trends in the development and improvement of the technology are focused on reducing the temperature and increasing velocity of spraying particles [1-3]. It allows avoiding oxidation of particles, obtaining a better adherence of coating to substrate and a hardened layer of the substrate from cold work hardening after particles hit.

If aluminium powder is used as the sprayed material and applied it to the details’ surface made of aluminium alloys as an electrochemical protection, it is possible to obtain a coating identical to cladding layer by chemical composition.

The cladding layer obtained by the classical method is highly corrosion-resistant and widely used in industry. The thickness of the cladding layer usually varies from 1.5 up to 10% of the semi finished product’s thickness. However, such a coating makes the fatigue-resistance lower which is confirmed by experimental studies [4]. It is stated that the fatigue resistance of the cladding sheets made by classical method can decrease by 35% [5].
For the quantitative analysis of the coating technology influence on the mechanical properties of a sample a comparative analysis is needed. Standard samples with different types of coatings can be analyzed that allow defining the stress-strain and fatigue-resistance characteristics of a sample.

The purpose of the research is an experimental study of the influence of aluminium coating technology on the regularities of inelastic stress of samples made of the D16T (1163) alloy.

2. Samples, equipment, methods

To perform a comparative analysis of the technology effect on the mechanical properties of the semi-finished product, three parties of smooth samples were made of the D16AT aluminium alloy. The samples had a rectangular cross section of 12x10 mm² and a gage length of 50 mm, which made it possible to fix extensometers for measuring longitudinal and transverse stresses.

The first sample party had a cladding layer made of a commercially pure aluminium brand AD1. The thickness of a cladding layer was determined by TU 1-92-161-90 and for this alloy was no more than 4% (Fig. 1a).

From the surface of the samples of the second party the cladding layer was removed by dimensional chemical etching. The chemical etching was carried out in sodium alkali (15% NaOH) at the temperature of 80°C followed by neutralization in a solution of nitric acid (30% HNO3), washing in cold running water and drying in a warm air steam. The cladding layer removal rate was 50 micron/min. This made it possible to remove the coating without deforming underlying basic material and without creating residual stresses or hardening the surface (Fig. 1c).

The samples of the third party had a coating made by cold dynamic spraying (Fig. 1b). To fulfill the conditions of the comparative experiment, the cladding layer was etched off the surface of the third party, and the coating of the required thickness was made by cold dynamic spraying. The protective coating was made by the cold dynamic spraying machine [6].

The modes under which the metal particles were sprayed were selected experimentally and were as follows: the rotational speed of the gun - 27600 rpm, depth of the vacuum in the chamber - 2x10^-1 Mmhg. The coating time - 8 minutes. Aluminum powder ASD-1 was used as the sprayed material. The fraction of the sprayed powder - 20 ... 30 microns.

The thickness and coating homogeneity obtained by cold dynamic spraying was controlled by transverse microsections using a scanning electron microscopy equipment Hitachi S-3400N (shown in Fig. 2a), b). With the help of Back Scattered Electron Detector the image was obtained in the composite contrast which makes it possible to separate visually the substrate and coating. This method allows defining the elements in the surface layer and equitability of particles over the entire substrate surface.
The performed analysis of the cross-section microstructure shows that the coating thickness for the D16T alloy is uniform and lies in the range from 95 to 120 microns.

![Microstructure Image](image_url)

**Figure 2.** The microstructure of the aluminum powder coating on the surface of the D16T alloy with an increase in 100 (a) and 1000 times (b), respectively, made by cold dynamic spraying.

To determine the stress-strain characteristics of samples from three parties, they were tested on the universal servo-hydraulic test machine Instron 8801 according to a program reported in [4]. The loading program was a sequence of blocks with stepwise increasing stress amplitude. Each block contained 100 cycles of harmonic loading with a frequency of 1 Hz of constant amplitude and zero average stress in the cycle. The amplitude of the loading for each stage increased by 1000 N. The increase of total stress tensor-component was measured by standard extensometers: No. 2620-601 Dynamic Extensometer, Transverse / Diametral Extensometer No. W-E-404-F.

The methods of defining stress-strain characteristics described in [7] made it possible to determine the stress-strain state at which irreversible changes in the sample occur preceded the destruction.

3. The main results

Figure 3 in the coordinates: $\varepsilon_{y, \text{max}}$, $\varepsilon_{y, \text{min}}$, $\varepsilon_{x, \text{max}}$, $\varepsilon_{x, \text{min}}$ versus $\sigma_{x, \text{max}}$, $\sigma_{x, \text{min}}$, represents the experimental diagrams of the D16T samples stress: 1 with a cladding layer, 2 without a cladding layer, 3 coated by cold dynamic spraying under a symmetrical stress cycle, allowing determining the characteristics of the limiting stress cycle. Here: $\varepsilon_{y, \text{max}}$ and $\varepsilon_{y, \text{min}}$ are the longitudinal and transverse stresses, respectively, at the maximum stress in the cycle $\sigma_{x, \text{max}}$; $\varepsilon_{x, \text{max}}$ and $\varepsilon_{x, \text{min}}$ are longitudinal and transverse stress, respectively, at the minimum stress in the cycle $\sigma_{x, \text{min}}$. 
Figure 3 shows that on the diagram of transverse stress $\varepsilon_{y\text{max}}$, $\varepsilon_{y\text{min}}$ for the sample with a cladding layer 1 at amplitude 80 MPa, nonequilibrium stress processes are activated.

Figure 3 shows that the stress diagrams for 2 and 3 are close in the entire loading interval. The sample coated by cold dynamic spraying (curve 3) has identical stress-strain characteristics as the uncoated sample 2, and tends to unilaterally accumulate transverse and longitudinal stress.

The comparative analysis of the tensor components ratios of the samples stress with cladding samples and samples coated by cold dynamic spraying (1 and 3) reveals that when the ultimate stress (80 and 250 MPa, respectively) is reached, nonequilibrium stress processes are activated in the material, which are followed by a change in the shape and volume of the sample surface.

As follows from the diagrams, the inelastic behavior of a sample without a cladding layer and a sample coated by cold dynamic spraying comes out at a stress amplitude in the 250 MPa cycle; a sample with a cladding layer - 80 MPa. It shows that the D16T alloy surface treatment by cold dynamic spraying with aluminum powder ASD-1 does not impair the ability to resist stress during periodic loading in comparison with the uncoated D16T sample.

The research of the samples’ surface using optical microscopy before and after loading shows that the localization of the microrelief and formation of slipbands in the grain structure of the coating (Fig. 4) take place in the surface layer of the sample with cladding [8]. That does not happen in the surface layer of samples from other parties (uncoated and coated by cold dynamic spraying).
Figure 4. Microstructure of the D16T alloy surface with a cladding layer before (a) and after (b) periodic loading.

4. Conclusions

It has been experimentally proved that cold dynamic spraying makes it possible to create a coating that, in comparison with the classical method of protecting the samples surface with a cladding layer, increases the stress-strain characteristics of the material under symmetrical periodic loading. It allows predicting that the fatigue-resistance of samples coated by cold dynamic spraying does not decrease, but increases in relation to samples with cladding.

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