USE OF UNDERCOATS TO IMPROVE THE ADHESION
OF PLASMA-SPRAYED ANTIFRICTION DEPOSITS
TO THE BASIS METAL

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Undercoats, particularly those of molybdenum and 80% Ni-20% Cr alloy, are widely used in plasma
spraying practice. In recent years, references have appeared in the literature also to the use for this pur-
pose of nickel aluminide [1]. However, it is evident that such matters as the choice of undercoat material
and its optimum thickness have received too little investigation to enable practical recommendations to be
formulated.

In this connection, in the present work a study was made of the effects of molybdenum and nickel
aluminide undercoats on the adhesion of plasma-sprayed deposits containing a solid lubricant [2] to basis
metals. As starting materials for the deposition of undercoats, a molybdenum powder (a 0.056 ± 0.04 mm
fraction) and a composite Al-Ni powder, of the same particle size, produced by the electroless deposition
deposition of nickel on aluminum particles (Fig. 1), were used. Spray deposition was carried out in a modified version
of the plasma unit described in [3], at a current of 600 A, a voltage of 30 V, and a plasma-forming argon
flow rate of 20 liters/min. Deposition was performed on an AK-4 aluminum alloy and Type 45 steel.*

The spray deposition of a composite
Al-Ni powder is accompanied by a reaction
in which intermetallic compounds are formed.
The reaction begins when a particle first ent-
ters the plasma jet and continues on the surface

*AK-4 is aluminum containing small alloying
additions of Cu, Fe, Si, Mg, Ti, and Ni; Type
45 is a 0.45% C steel — Translator.

Fig. 1. Aluminum particle with nickel coating,
× 400.

Fig. 2. X-ray diffraction pictures of:
a) starting powder (Al particle with Ni coating); b) plasma-sprayed layer.
Fig. 3. Microstructure of boundary between plasma-sprayed Al-Ni deposit and basis metal (AK-4 alloy), × 7000.

As a result, the particle remains in the molten condition for a longer time, which enables microwelding to take place between it and the basis metal (metallic bonding). Evidence in confirmation of this contention is provided by data yielded by x-ray structural analysis and metallographic examinations. Figure 2 shows x-ray diffraction pictures of the starting 20% Al-80% Ni powder and of a coating produced from it. The phases NiAl, Ni₃Al, and Ni₂Al were detected in the deposited layer.

As a result of electron microscopical examinations (Fig. 3), it was established that such a deposit firmly adheres to the basis, its material diffusing into the basis metal (AK-4 alloy). Structurally, the coating consists of thin light- and dark-gray layers (microhardness 900 kg/mm²). Between these layers, light-colored inclusions (microhardness 524 kg/mm²) can be observed.

Adhesion tests, performed by the method of separating a plug made of a basis metal from a deposited layer, established that the adhesion of a NiAl undercoat is stronger than that of a molybdenum undercoat (Fig. 4). The relationship \( \sigma_{ad} = f(\delta) \) was found to exhibit a maximum similar to that noted in [4]. Also, as in [4], separation was found to have an adhesional character mainly at thicknesses exceeding those ensuring the highest strength of adhesion (in our case > 0.5-0.6 mm).

The decrease in adhesion strength with increase in coating thickness over this range of sprayed layer thickness is due to a buildup of internal stress in the coating/basis metal system. Internal stress in turn is set up as a result of the presence of a temperature gradient and the difference in thermal expansion between the deposit material and the basis metal.

Certain aspects of the adhesional behavior of the materials investigated, as depicted by the curves in Fig. 4, can be explained in a similar way. Thus, comparison of the thermophysical characteristics of the steel and AK-4 alloy shows that the thermal conductivity of aluminum alloys is about three times that of ferrous alloys. The reaction between a coating (in this case an undercoat) and a basis metal is determined first of all by the temperature in the contact zone between these materials, which rises with decreasing effectiveness of heat removal from the interface, i.e., with decreasing thermal conductivity of the substrate. It is this circumstance that explains why coatings of small thickness adhere more strongly to Type 45 steel than to AK-4 alloy.

However, as the temperature in the contact zone rises during spray deposition, the temperature gradient becomes steeper, and, consequently, the internal stress in the coating/basis metal system increases. Because of this, the dependence of adhesion strength on coating thickness is less pronounced for metals of higher thermal conductivity (in our case AK-4 alloy).

It should be noted that this relationship manifests itself particularly vividly in the deposition of molybdenum, where only the heat absorbed by the particles in the plasma jet is available. When a composite Al-Ni powder is used for spray deposition, the bulk of the heat is generated in the exothermic reaction directly on the substrate. During the coating formation process, a quasistationary heat flow establishes itself between the coating and the substrate. As a result of this, stronger bonds are formed between the spray deposited layer and the basis metal, the temperature gradient is less steep, and the dependence of adhesion strength on deposit thickness is less pronounced (Fig. 4).

To study the adhesion of an antifriction coating in the presence of an undercoat, the plug and the main body of the specimen were covered separately with an undercoat (200 μ thick). The two parts of the spec-