APPLICATION OF ULTRA-FINE POWDERS OF REFRACTORY COMPOUNDS FOR IMPROVING THE MECHANICAL PROPERTIES OF PLASMA-SPRAYED COATINGS

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Abstract

The results of experimental study of influence of mechanical activation of metal powders with small admixtures of refractory nanoparticles on plasma sprayed coating properties are presented. There were shown the drastic changing the structure and mechanical properties of coatings in other conditions being equal.

1. Introduction

Plasma spraying is regarded as being one of the most promising techniques of obtaining coatings and composite materials. The internal boundaries between splats as well as those with surface of substrate are the key factors to provide proper set of physico-mechanical, functional and service properties during process of spraying. In many respects the above-mentioned properties are determined by both structure of material and stress concentrations being formed within border zones of varying scale level, phase and structural boundaries in heterogeneous non-uniform material of coating, contact areas of either particles or components of coating and substrate as well as those of the components themselves, the boundary between the coating and substrate integrally. The adhesion, porosity, structure and phase composition of plasma-sprayed coating are the basic functional features of its properties. The values of these parameters are essentially affected by unsteady conditions under collision of particles are melted completely/partially or that in solid state with the surface. It is evident that presence of either particles are melted partly or solid ones having been heated promotes a formation of discontinuities resulting in defects and making difficult production of high-quality coating. Existing methods of plasma spraying cannot guarantee required quality of coatings primarily because of high level of their porosity and improper adhesion as well.

Over the last years, in the Institute of Theoretical and Applied Mechanics Siberian Branch of Russian Academy of Sciences promising results were obtained on bulk hardening of metals and alloys with the help of ultrafine (smaller than 0.1 μm in size) mechanically activated powders of refractory compounds [1]. Being given a special treatment in centrifugal planet mills, these powders acquire specific properties due to which, after introducing them into a melted metal, act as highly effective nucleation centers for crystals. Increasing the dispersity of the primary structure and making the grain and extra-phase boundaries more clear, they improve the strength and plastic characteristics of the metal.
Having been injected and well wetted by melt nano-particles are uniformly allocated within the melted substance. There they are centres of nucleation of matrix of alloy, intermetallic and eutectic phases. As a result the fine cast structure of ingot is formed.

Taking into account such an operational experience the experimental investigation of influence of mechanical activation of metal powders being sprayed with admixture of refractory nano-particles on the quality of coating has being conducted.

2. Results and discussion

With this in mind, we undertook an experimental study of the effect of refractory ultra-fine particles on the quality of powder coatings obtained by atmosphere plasma spraying (APS). For this purpose, we prepared compositions of an aluminium bronze powder mixed with 0.05 mass % of an ultra-fine silicon carbide powder. Subsequently, this mixture was given a special treatment in a centrifugal planet mill and then, it was used for APS on aluminium-zinc alloy substrates. The morphology of initial aluminium bronze powder and mechanically activated and modified by SiC ultra fine particles one is presented in Fig. 1.

![Fig. 1. Morphology of aluminum bronze particles of the powder: a, c - initial powder; b, d - mechanically activated and modified powder.](image)

Thorough examination of reference and test samples showed that the internal structure of coatings differed drastically. The former samples contained incomplete melted powder particles and rather irregular inter-splat boundaries, whereas in the latter no such particles were observed. In the latter case, the structure was more monolithic, with more perfect boundaries between splats (see Figs. 2 and 3). The strength of the coating-substrate joint was profoundly increased. For instance, although, during preparation of an angle lap (cutting, grinding) on
reference samples, frequent separations of the coating from substrate happened, no such separations took place in the case of test samples.

![Fig. 2. Coating microstructure in the horizontal plane of sample.](image)

Similar experiments have been executed provided that iron powder was sprayed on steel substrate (steel 3 quality). The ultra-fine TiN-powder has been applied as modification admixture. As clearly seen in photos of cross-sections (see Fig. 4), in this case one can reveal the improvement of quality of coating structure and respectively its mechanical properties i.e. adhesion, density and hardness of coating as well.

According to cited data of electron microscopy the powders having been mechanically treated are melted much better than untreated ones. It is due to accumulation of energy in the form of various defects. This energy is extracted under conditions of plasma flow. The latter results in better melting, gain of density and improving structural and strengthening parameters of coatings. The introduction of refractory ultra-fine particles into the composite material causes a size reduction of phase components of coating structure, with hardness and wear resistance being improved.

Thermal effects of reaction of copper powder and acetic acid have studied the variation of reactivity of mechanically treated powders. It is well known that hydrogen precedes copper in electrochemical series. So copper can not reduce of protons to hydrogen when reacting with any acid. Nevertheless, highly disperse copper produced by either electrochemical method or explosion can react with acetic acid providing the evolving of hydrogen [2,3]. The same happens in our case subject to the restriction that copper powder is mechanically treated in centrifugal planetary-motion high-energy mill. This fact can be justified by occurrence of weakly bound copper atoms after mechanical treatment of powder.
Fig. 3. Coating macrostructure in cross-section of sample at various depths from its upper surface (from the top to coating-substrate interface): a, c, e, g = conventional spraying; b, d, f, h = spraying with admixed ultra-dispersed SiC particles.
Fig. 4. The macrostructure of cross-section of simple iron-ceramic steel's substrate: a - conventional spraying, b - spraying with mechanically activated iron powder with admixture of ultra-fine TiN particles.

As is shown the specific thermal effect of interaction of mechanically treated copper with acetic acid increases monotonically up to 45 kcal/mole owing to accumulation of defects inside of metal under conditions of duration of powder treatment being about 15 min. Here the power input of balls is equal to 55 kW/kg (40 g). After 16 min. of such a treatment there is discovered the relaxation of defects in metal bulk expressed in decrease of specific thermal effect of interaction mechanically activated copper powder with acetic acid till 22 kcal/mole. Consequently, the optimal regime of powder mechanical treatment for providing the maximum reaction ability of powder to be sprayed.

3. Conclusions

The results of preliminary studying the effect of mechanical activation of initial powders with simultaneous their modification by ultra-fine refractory particle of SiC and TiN, other factors being the same are presented. It was shown that coating microstructure is drastically changed. In our opinion, the combined technology proposed is prospective for different applications when it is necessary to improve essentially the mechanical and other properties of coatings to be sprayed.

References


