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SPUTTERING OF PROTECTIVE CoCrAl COATINGS ONTO GAS TURBINE BLADES[1])

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Deposition of metal coatings using a d.c. planar magnetron has been investigated. The alloy films prepared in this way have been studied by scanning electron microscopy and X-ray diffraction. Adhesion was tested by temperature cycling.

I. INTRODUCTION

The use of gas turbines in air and marine transport has accelerated research of Ni-based superalloys, which have been used for their construction, especially in the last 40 years. Due to increasing thermal efficiency there arose the requirement of higher temperatures in the combustion chamber [1]. This requirement was first solved by cooling the engine parts or by a better resistance of construction materials. At the beginning of the 60's the given problem began to be solved by the application of protective coatings.

A protective coating must meet a number of demands, which at present cannot be fully satisfied by the bearing material. It concerns especially protection against hot corrosion, mechanical erosion, thermal fatigue, etc. Some newly developed coatings can fulfil the function of lubricant and sealing (around the rotating parts).

For instance, ceramics, especially a mixture of ZrO_2—Y_2O_3, proved a good thermal barrier. Coatings of the MCrAl type (M means Fe, Co, or Ni) are most frequently used as protection against hor corrosion. An oxygen-active element is often added to these alloys, for example Y or Hf [2]. These coatings consist of 10—30 wt.% Cr, 5—15 wt.% Al and about 1 wt.% Y [3]. The coatings of the MCrAl type also serve as bond coatings between Ni-based superalloys and ceramic barriers. Their typical properties are a colourless metallic sheen, ferromagnetism, considerable hardness, but the increase of the al content leads to their brittleness. The coatings are very corrosion resistant and protect themselves by forming Al_2O_3 on their surfaces [4].

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II. DEPOSITION OF COATINGS

Due to the wide use of the MCrAl type coatings we carried out a research into their deposition. On the basis of our experimental possibilities a circular planar magnetron was chosen, which had been developed in ÚFP ČSAV, Prague. It was installed in the vacuum chamber of our plant B.55.3 (Hochwakuum, Dresden). The magnetron was equiped with a water cooled target CoCr (14 wt.%) Al (10 wt.%). The target was sputtered in Ar with a pressure of 1 Pa (measured with a digital Pirani gauge) onto turbine blades which had been made of a ŽS6K alloy (Motorlet, prague). The chamber was pumped in flowing regime by means of an oil diffusion pump.

The fastening of the blades resulted from reguirements of a uniform coating thickness. The thickness dependence on a substrate position had been measured before, for example for Cu on planar substrates [5], and results can be seen in figure 1. There were always two blades in one deposition cycle rotating around a common axis. This axis lay in the focus of two elliptical mirrors, equipped with comercial radiant heaters.

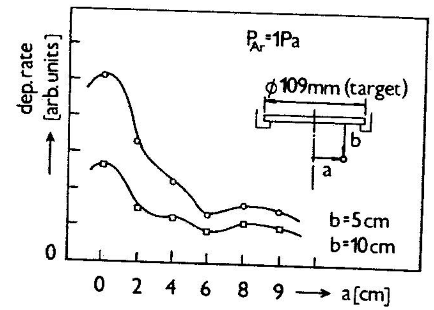

Fig. 1. Dependence of deposition rate of Cu on the distance from the magnetron target.

Before putting in the chamber the blades were chemically cleaned, and after closing the chamber they were cleaned by a d.c. glow discharge in Ar. Then they were heated up to a pre-dposition temperature, which was maximally 400 °C (it was measured with a thermocouple on immobile blades).

III. PROPERTIES OF THE COATINGS

The physical and the chemical properties of the coatings are determined mainly by the choice of a target material and the way of deposition. That is why the adhesion of the coatings was investigated first. The scratching trace caused by sharp metallic, glass and diamond tips was observed under an optical microscope. The adhesion was evaluated positively if bigger pieces of coatings did not break away.

The influence of chemical and plasma cleaning upon adhesion was investigated. Chemical cleaning was the most effective if chemical dissolvents (acetone), detergents and acid and alkaline (industrial Synalod) liquids were combined. Plasma cleaning is very advantagenous, even though it cleans a surface very unevenly in dependence on substrate geometry.

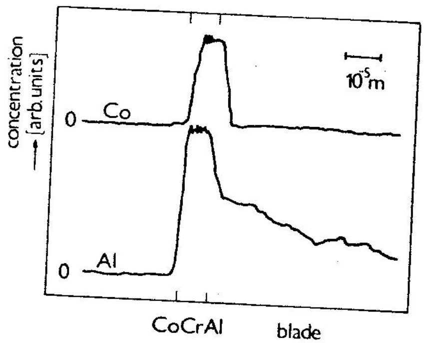

Fig. 2. Relative concentration of Co and Al in a not heated blade.

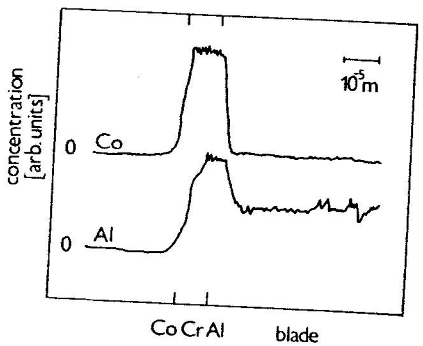

Fig. 3. Relative concentration of Co and Al in a temperature cycled blade.

The influence of the rise of pre-deposition temperature upon adhesion was positive in all temperature intervals. The increase of the magnetron power improved the quality of the coatings. Some of the blades were subjected to a temperature cycling in air in the temperature range 20—1000 °C. This cycling (maximally 20 times) did not cause a conspicuous change in adhesion.

Besides, the coated blades ware examined under a scanning electron microscope, type JEOL JCXA 25A. For this purpose a usual metallographic cut was done. It can be seen in the secondary electrons image that the coatings have a columnar structure, slightly damaged by temperature cycling. Fractures of coatings observed on some cuts, confirmed conclusions from optical microscopy (adhesion).

The thickness of the coatings was observed on the backscattered electrons image. In the plane perpendicular to the axis of rotation during deposition it had an unevenness of less than 10%. In the direction of the rotating axis results will be evidently similar to those in figure 1. The deposition rate was counted from the thickness and is about 0.15×10^{-6} m/min. for each kW of the magnetron power with chosen geometry. Practically, there were formed coatings with a thickness of up to 10^{-5} m.

From characteristic X-ray spectrum the relative concentration of Co and Al of the surface of the cut was determined. Results from a not heated blade can be seen in figure 2. Original concentration of al in the alloy ŽS6K is 5—6 wt% and of Co 4—5.5 wt%. Figure 3 shows the concentration in a blade, which went through the temperature cycling. By means of this method the presence of 0 was not found in any of the examined coatings.

A crystallographic analysis was made by means of X-ray diffraction. It was found the body of a blade is formed mainly by a solution of Co, resp. other metals in Ni. The crystallic lattice is cubic with the lattice constant enlarged to 0.35925 nm if compared with that of pure Ni (0.35238 nm). The measuring of the CoCrAl coating before temperature cycling showed the presence of crystallic phases of separate elements, Co was in the alpha-phase (hexagonal-hcp). After temperature cycling all the Co was in the beta-phase (cubic-fcc), the lattice constant 0.35693 nm, in which it was stabilized by dissolution of Al. Besides the coatings contained Cr with addition of about 20 wt% Co, which crystallized in a cubic lattice with constant 0.28652 nm (pure Cr 0.2884 nm).

DISCUSSION AND CONCLUSION

The way of blades cleaning, mentioned above, does not seem to be efficient enough, but the method of electropolishing seems to be promising. As far as pre-deposition heating is concerned, the deposition could be interesting with a temperature higher than that of the phase change of Co (about 450 °C).

The uniformity of coating thickness is sufficient. We can observe in Al concentration curves that the content of Al in the coataings decreases and the uniformity of its concentration in the blade improves after temperature cycling. With the given ratio of the contents of Co/Cr a decrease of the Al content is evidently needed.

Crystallographic analysis confirmed the possibility of a good adhesion of coatings with respect to the similarity of the lattice constants in coatings and blades. However, different coefficients of thermal expansivity play an important role, too.

The coatings are harder than the blade material and prove a higher corrosion resistivity, which has not been quantified yet.

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НАПЫЛЕНИЕ ЗАЩИТНЫХ ПОКРЫТИЙ CoCrAl НА ЛОПАТКИ ГАЗОВЫХ ТУРБИН

В работе исследовано нанесение металлических покрытий при помощи плоского магнетрона, питаемого постоянным током. Полученные тонкие пленки данного сплава анализировались при помощи растрового электронного микроскопа и рентгеновской дифракции. Испытания адгезии проводились методом периодического изменения температуры.