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FAST TRACK COMMUNICATION

Re–Cr–Ni high-temperature resistant coatings on Cu substrates prepared by thermionic vacuum arc (TVA) method

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Abstract
Re–Cr–Ni composite metallic films were prepared using an original plasma deposition method developed at INFLPR, Bucharest, called thermionic vacuum arc (TVA). The method is based on the evaporation of a metal followed by ignition of a plasma in the vapours. These three-component films/alloy films were deposited using three simultaneous TVA plasma sources in the same vacuum chamber. Surface corrosion at temperatures up to 1000 °C was found not to take place in these Re–Cr–Ni alloy films as shown by thermogravimetric analysis. The current results demonstrate that the TVA method is a promising candidate tool for the synthesis of multiple compound films. Films of uniform and controlled composition can be simultaneously obtained using this method. Moreover, high melting point metals can be involved in these superalloy films, thus leading to applications in extremely hot conditions such as turbine blades and aircraft parts.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Efforts to increase the entry temperatures in gas turbines and in aircraft engines are of considerable importance for increasing the efficiencies and lifetime of such devices. Nickel-based superalloys are currently used in turbine blades and jet engines [1]. The inclusion of refractory metals in these superalloys is continuously researched due to their high melting temperature. For example, the addition of rhenium to inconel alloys increases its creep resistance [2]. Apart from bulk superalloys, thin films to be used as protective coatings in parts of gas turbines and aircraft engines are also being investigated [3]. Such films need to have good high-temperature resistance to corrosion and oxidation [4, 5], good long-term stability, good mechanical properties [6] and, moreover, need to have an industrially scalable production method. In this respect, refractory metals are important constituents of the coating. For example, rhenium addition decreases the oxidation rate of the superalloy coating and improves its mechanical properties [7].

This paper proposes an original plasma method for the deposition of quality high-temperature resistant coatings to be used in extremely hot environments. The deposition method has much potential for applications in this field, due to its unique capabilities which will be explained in the following.

The thermionic vacuum arc (TVA) plasma has definite advantages over the known plasma deposition techniques. Such important advantages relevant to the specific application of high-temperature resistant films include the following: no gas precursors or carrier gases needed—thus, no gas inclusions in the films, deposition of films of high melting temperature materials such as carbon, rhenium, nickel, tungsten and chromium [8–13] and the possibility of sustaining different TVA plasmas simultaneously in the same vacuum chamber and with no interference between them. The above materials are indeed difficult to process due to the fact that no crucible material can resist the high temperature necessary for their melting and evaporation: in this respect, the TVA is unique since a crucible is not needed to provide the vapours required

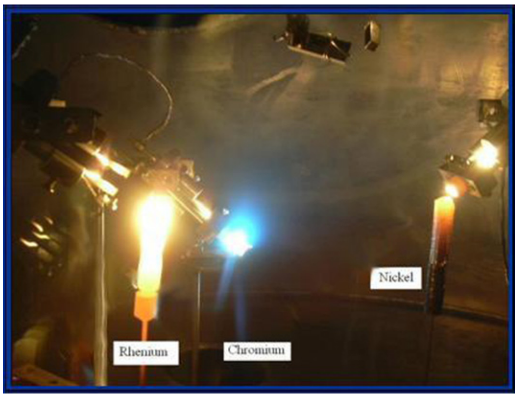

Figure 1. Photograph of a simultaneous ignition of the TVA plasma ingnited in Re, Ni and Cr vapours in the same vacuum chamber.

for igniting a corresponding plasma. This is due to the fact that the TVA is ignited locally, above the anode, in the vapours of the material, at vapour pressures of about 1 Torr. Such vapour pressures can be obtained just by heating the surface of the material/metal without melting the whole anode rod: an electron beam generated by a heated filament is utilized for this purpose. The metal vapours are then ionized by the same fast electrons accelerated by the anode. Under certain operating electrical parameters, the plasma becomes stable and can be maintained for as long as the anode material is present. Another important asset of the TVA plasma is the fact that the ion energy of the impinging ions is very high (many hundreds of eV), thus offering high compactness of the deposited films. Moreover, the ion energy is controllable and is directly proportional to the applied voltage on the anode. From the point of view of scalability, the TVA method is also powerful, as special configurations containing many TVA plasma sources can be developed for the deposition of large areas.

The novelty introduced by this work consists of the deposition of an alloy film comprising Re, Ni and Cr using three plasma sources in the same process chamber. Three simultaneous TVA plasmas were used for the deposition of such films.The composition of the alloy films is controllable and depends on the position of the substrate relative to the plasma sources and also on the deposition rate of each plasma source.

In this paper, the deposition of composite ReNiCr films of uniform composition with very good thermal behaviour is presented.

2. Experimental setup

Figure 1 shows a photograph of the three simultaneous TVA plasmas sustained in the same vacuum chamber. As observed in this figure, the plasmas are localized and do not interfere with each other.

The relative concentrations of Re, Cr and Ni in the prepared films can be controlled by the plasma operating parameters (electrical and geometrical parameters).

Copper substrates positioned at different distances from the evaporation sources were used. They were placed away from the core of the TVA plasma, at a 10–30 cm distance. After deposition, they were cooled down slowly in vacuum for 24 h.

X-ray photoelectron spectroscopy (XPS) and thermogravimetric analysis (TGA) were undertaken to study the film composition and temperature stability of the composite films deposited by TVA.

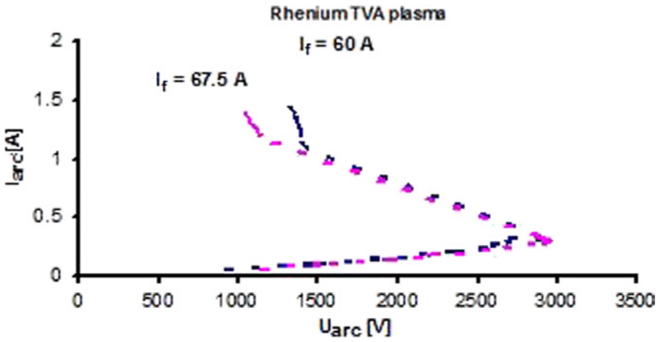

Figure 2. Current–voltage characteristics of the TVA plasma in Re for two filament currents (stable plasma regime: full line).

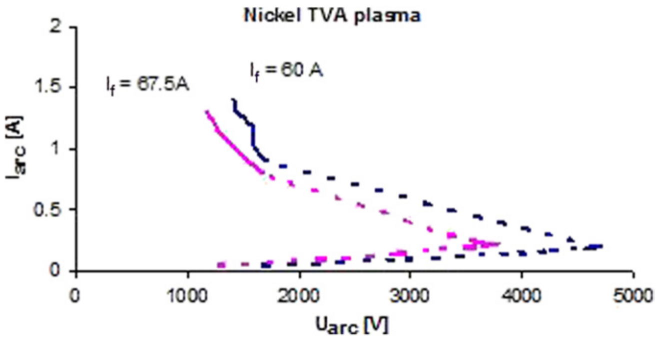

Figure 3. Current–voltage characteristics of the TVA plasma in Ni for two filament currents (stable plasma regime: full line).

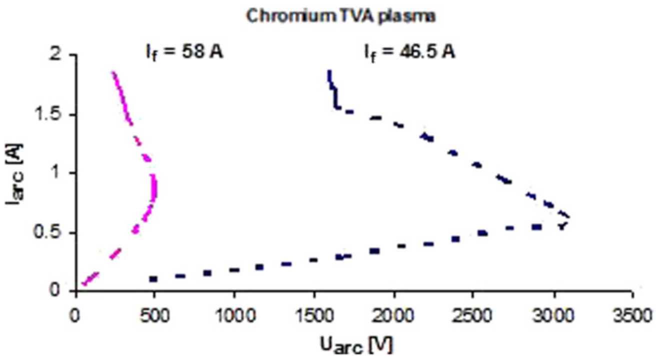

Figure 4. Current–voltage characteristics of the TVA plasma in Cr for two filament currents (stable plasma regime: full line).

3. Results and conclusions

Figures 2, 3 and 4 show the current–voltage characteristics of individual discharges Re, Ni and Cr for two values of the filament current I_f. The stable TVA regime is obtained at a high(er) arc current and a low(er) arc voltage. This regime is plotted with a full line in the figures. A higher deposition

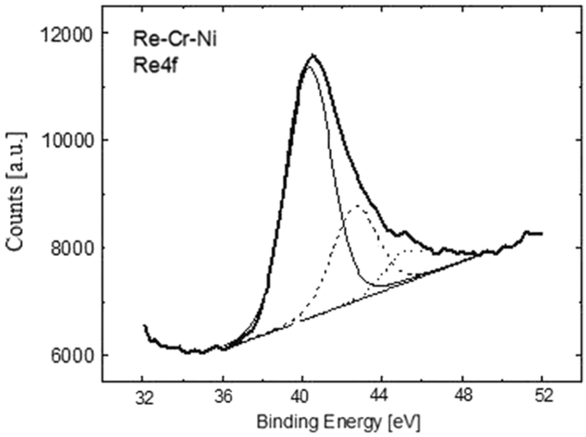

Figure 5. XPS spectrum showing the Re window.

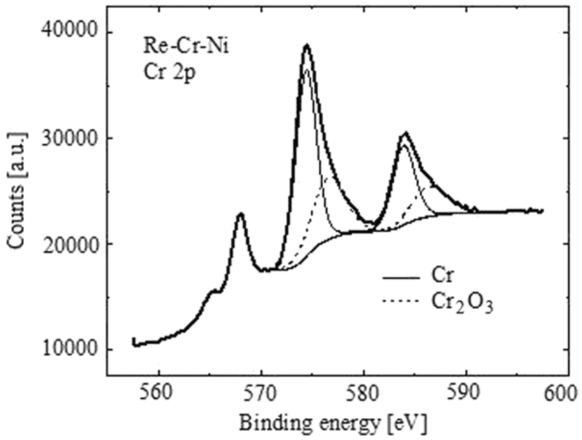

Figure 6. XPS spectrum showing the Cr window.

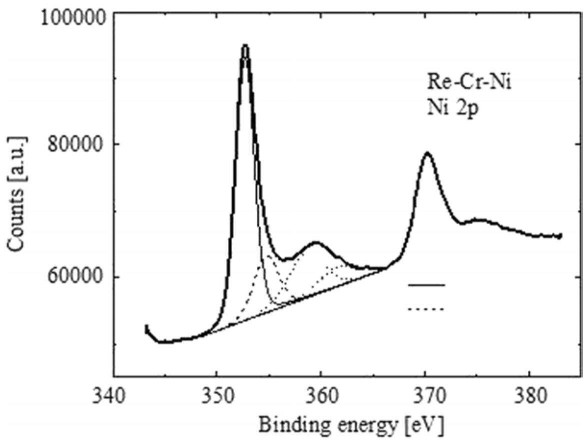

Figure 7. XPS spectrum showing the Ni window.

rate was obtained at a higher power input, e.g. at a higher arc current.

XPS analysis confirmed that the films obtained are very pure. Figures 5, 6 and 7 show the specific peaks of Re, Ni and Cr, respectively. The thin surface oxide was formed after deposition, by exposure to ambient air. To estimate the corrosion kinetics under high-temperature oxidation of the Re–Cr–Ni composite films, TGA tests were used. Thus,

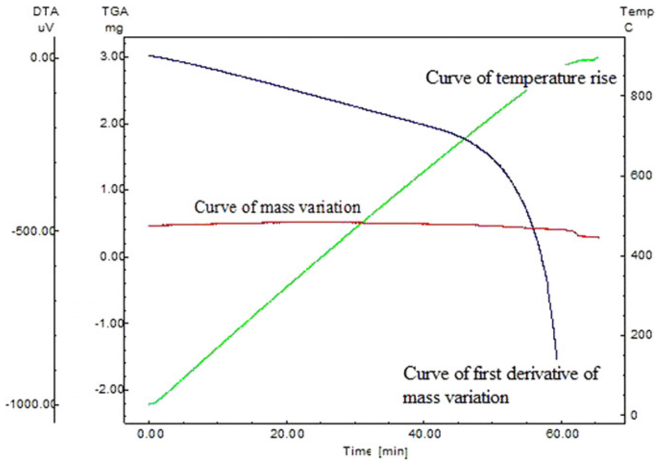

Figure 8. Typical TGA analysis of the ReNiCr composite film.

changes in weight in relation to changes in temperature were determined. The tests were conducted with a temperature rise of 10 °C min^{-1} in air from ambient to 1000 °C (accuracy: 0.001 mg; maximum static time at 1000 °C: 1 min). A typical result of the TGA tests is given in figure 8. It can be observed from this figure that the complex Re–Ni–Cr film had almost no mass loss at the end of the test, thus indicating the high thermal corrosion resistance of this material. This is also confirmed by the first derivative of the mass variation with a temperature curve which is smooth, with no peaks.

4. Conclusions

The TVA method is a powerful technique for the deposition of pure, dense alloy films composed of high-temperature materials.

The simultaneous deposition of Re, Ni and Cr on copper substrates provided high quality heat corrosion resistant films. The results suggest a great potential of the TVA deposition method to be at the forefront of new technologies for improving in the lifetime of turbo engines.

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