CERAMICS — Silikáty *34*, s. **241—245** (1990)

THE EFFECT OF PLASMA SPRAYING TECHNOLOGY ON THERMAL DIFFUSIVITY OF Al_2O_3 COATINGS

ALEXANDRA RUDAJEVOVÁ, KAREL NEUFUSS

Institute of Plasma Physics, Czechoslovak Academy of Sciences
Pod vodárenskou věží 4, 182 11 Prague 8

Received 2. 6. 1989

The results of measuring the thermal diffusivity of plasma-sprayed Al_2O_3 *coatings are given in terms of the parameters of their preparation. The coatings were applied by means of the PAL 160 apparatus. Corundum of two grain sizes was used in the experiments. With both types of coatings, the thermal diffusivity decreased with increasing distance of the burner face from the object being coated.*

INTRODUCTION

Al_2O_3 coatings have already been paid considerable attention, but in spite of this the physical properties of plasma-sprayed coatings specified in the literature cannot be taken for granted as is the case with compact materials. The properties of the coatings are given by the properties of the material being applied, i.e. its composition and grain size, as well as the actual plasma coating technology. Porosity of plasma-sprayed coatings is one of their most important characteristics, as it influences their adhesion, apparent density, thermal conductivity, etc. The porosity of the coatings is determined by the application technology, above all by the distance of the object from the burner face, and the output of the respective apparatus [1]. These two factors affect the temperature and velocity of the particles in the plasma stream during their impact onto the base.

The thermal conductivity λ of compact Al_2O_3 materials is about 30 W/mK, which corresponds to thermal diffusivity $a = \lambda/(\varrho c) \approx 0.10\ cm^2/s$, where ϱ is apparent density and c is specific heat. With plasma-sprayed coatings of Al_2O_3, the thermal conductivity falls down to one tenth of the value of the compact material. This decrease is due to the porosity of the coating as well as to its structure which differs from that of compact Al_2O_3. The thermal conductivity of plasma-sprayed Al_2O_3 coatings varies over a wide range of values according to the initial material and the application technology employed. It is therefore necessary to seek the optimum conditions for application separately for each type of spraying apparatus, and each material being sprayed.

The present study had the purpose to establish the dependence of thermal diffusivity of plasma-sprayed Al_2O_3 coatings on the distance between the front of the PAL 160 apparatus and the object being sprayed. The additional aim was to find the way the grain size of the initial material affects the thermal diffusivity of the coatings.

EXPERIMENTAL

The Al_2O_3 coatings were applied by the PAL 160 apparatus (manufactured by the Institute of Plasma Physics of the Czechoslovak Academy of Sciences) using water stabilization of the electric arc with an output of 160 kW at a current of

500—510 Amps and a voltage of 310—320 V. The powdered material was fed into the plasma stream by compressed air in amounts of 19—20 kg per hour. The plasma application was carried out under atmospheric air pressure. The actual burner of the plasma apparatus was fitted to the arm of the APR 40 robot. The burner was moved at a linear speed of 0.1 m per second. The distance between the plasma burner front and the specimens was varied from 200 to 350 mm. Artificial white corundum A99 —Ia No. 4 and 6 to ČSN 22 4040, manufactured by Karborundum Benátky, was used as the coating material. The specific grain size according to ČSN 22 4012 amounted to 40—50 μm for corundum No. 4 and 63—80 μm for corundum No. 6.

The thermal diffusivity of the plasma-sprayed coatings was measured at room temperature by the flash method, adjusted for two layers (2). From the side of the coating, the specimen was irradiated by an energy pulse from the Xe pulse discharge lamp. A chromel-alumel thermocouple welded to the rear side of the specimen was used to measure the time dependence of temperature following the heating of the specimen by the discharge lamp. The apparatus employed is described in (3). The specimens for thermal diffusivity measurements consisted of the base material and the coating, and were 16 mm in diameter. The base was prepared from steel to ČSN 17 346. The base was 2.5 mm in thickness, while that of the coatings was in the range of 0.45 to 0.70 mm.

RESULTS

In the thermal diffusivity measurements by the method described above, each specimen was irradiated 5—7times at a given position of the thermocouple. Then the thermocouple was welded to another position at the specimen centre and the measurement was repeated. The results given above are means of values obtained by all these measurements. The thermal diffusivity values obtained at various positions of the thermocouples showed the maximum dispersion of 7 %. Fig. 1 gives a graphic plot of the measurements. For both types of coatings (i.e. those prepared from corundum No. 4 and 6), the thermal diffusivity decreased with increasing distance of the burner from the specimen (further on called spraying distance). Both curves intersect at a spraying distance of about 250 mm.

DISCUSSION

The cooling rate of particles passing out of the plasma stream depends on their velocity and size. The distance of the burner from the object being sprayed determines the state in which the particle will hit the object. If the particle is well fused throughout, the coatings will be more compact than those produced by particles already having a solidified surface on impact. These partially solidified particles produce coatings with a higher porosity compared to the case of completely molten particles.

Fig. 1 shows the dependence of thermal diffusitivity on the spraying distance for coatings produced from corundum No. 4 and No. 6. The thermal diffusivity of coatings prepared from both types of corundum decreases with increasing spraying distance. The curves for corundum No. 4 and No. 6 intersect at a spraying distance $L \approx 250$ mm. At shorter distances, coatings prepared from corundum No. 6 (larger specific grain size) show a higher thermal diffusivity. In this case the coatings are more compact than those prepared from finer corundum (No. 4), as the rate of particle solidification is indirectly proportional to its size. Beyond the optimum distance mentioned above, the coatings from both particles sizes are obviously formed from grains already solidified on their surface. In that case, the coatings made from material with a larger grain size show larger porosity than those formed from powder with a finer grain size. The greater the porosity, the lower the thermal diffusivity.

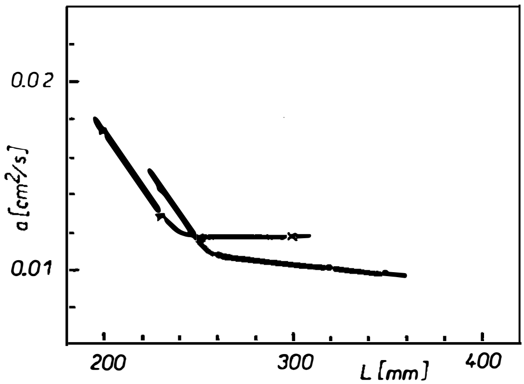

Fig. 1. Thermal diffusivity a vs. spraying distance L for coatings prepared from corundum No. 4, (×) and No. 6 (○).

It has already been mentioned that plasma-sprayed Al_2O_3 coatings have a thermal conductivity lower by a factor of upto 10 than compact Al_2O_3 materials. This great difference cannot been explained by a higher porosity alone. According to Eucken's equation (4) one finds that the increase in porosity by 10 % is responsible for an increase of thermal conductivity by about 20 %. The considerable decrease of thermal conductivity of plasma-sprayed corundum coatings compared to compact corundum is also due to the difference between the phase compositions of the two corundum materials. Whereas compact corundum is composed of α phase alone, the plasma-sprayed coatings are mixtures of α, δ and γ phases. The relative shares of the individual phases in plasma-sprayed coatings depend on the application technology. Both thermal conductivity and diffusivity of the α phase are higher than those of a mixture of the γ and δ phases. This also follows from theoretical considerations. For thermal conductivity it holds generally that

$$\lambda = \frac{1}{3} cv', \tag{1}$$

where λ is thermal conductivity, c is the specific heat per unit volume, v is the mean oscilllation velocity of the lattice and l is the mean free path of the phonons. According to (5) the mean free path of phonons is longest with phase α. With the γ and δ metastable phases, the mean free path is reduced, with proportionally decreasing thermal conductivity. For corundum No. 4 the phase composition of coatings was as follows: for $L = 200$ mm the coating contained 11% of phase α, the rest being a mixture of phases γ and δ, for L = 250 mm there were 3.4% of phase α, and for L = 300 mm the α phase amounted to only 2.1%, while a mixture of phases γ and δ always consituted the remaining content. The results are in good agreement with literary data. For example, according to [6], the coatings composed mostly of phases γ and δ showed a thermal diffusivity of 0.012 cm^2/s.

CONCLUSION

1. The thermal diffusivity of plasma-sprayed Al_2O_3 coatings decreases with increasing distance of the burner from the specimen in the course of application.

2. With the PAL 160 spraying apparatus, the quality of corundum coatings produced from initial powders No. 4 and 6 is significantly affected by the spraying distance, which should be about 250 mm. Shorter spraying distances yield coatings with a higher thermal diffusivity from initial material with larger grain sizes. The opposite holds for longer spraying distances. The temperature conductivity is a sensitive index of porosity and phase composition of plasma-sprayed coatings.

References

[1] Pekshev P. Yu., Safiullin V. A.: Izvestija Sibirskogo otdelenija Akademii nauk SSSR *18*, 99 (1988).
[2] Larsen K. B., Koyama K.: Journal of Applied Physics *39*, 4408 (1968).
[3] Rudajevová A.: Silikáty *32*, 343 (1988).
[4] Kingery W. D., Bowen H. K., Uhlmann D. R.: *Introduction to Ceramics*, 2nd ed., Wiley-Interscience, New York 1976.
[5] Hurley G. F., Frank D. G.: American Ceramic Society Bulletin *58*, 5 (1979).
[6] Fiedler H. C.: Materials Research Society Symposia Proceedings *30*, 173 (1984).

VLIV TECHNOLOGIE PLAZMOVÉHO NANÁŠENÍ NA TEPLOTNÍ VODIVOST POVLAKŮ Al_2O_3

Alexandra Rudajevová, Karel Neufuss

Ústav fyziky plazmatu ČSAV, 182 11 Praha 8

Práce předkládá výsledky měření teplotní vodivosti v závislosti na technologii nanášení povlaku Al_2O_3. Povlaky Al_2O_3 byly připraveny z materiálu č. 4 a č. 6, které se lišily měrným rozměrem zrna. Povlaky byly nanášeny plazmovým agregátem PAL 160, přičemž vzdálenost čela hořáku od vzorku se měnila pro materiál č. 4 z 200 do 300 mm, pro materiál č. 6 z 230 do 350 mm. V obou případech teplotní vodivost s rostoucí stříkací vzdáleností klesala. Pro stříkací vzdálenost menší než 250 mm byla teplotní vodivost větší pro povlaky připravené z korundu s větším rozměrem zrna, než pro povlaky, kde výchozí materiál měl měrný rozměr zrna menší. Pro stříkací vzdálenosti větší než 250 mm tomu bylo naopak.

Obr. 1. Závislost teplotní vodivosti a na stříkací vzdálenosti L. pro povlaky připravené z korundu č. 4 (×) a č. 6 (○).

ВЛИЯНИЕ ТЕХНОЛОГИИ ПЛАЗМЕННОГО НАПЫЛЕНИЯ НА ТЕМПЕРАТУРОПРОВОДНОСТЬ ПОКРЫТИЙ Al_2O_3

Александра Рудаевова, Карел Нойфусс

Институт физики плазмы ЧСАН, 182 11 Прага 8

В предлагаемой работе приводятся результаты измерения температуропроводности в зависимости от технологии нанесения покрытия Al_2O_3. Покрытия Al_2O_3 были получены из материалов № 4 и 6, отличающихся удельным размером зерна. Покрытия наносились плазменным агрегатом PAL 160, причем расстояние между лобовой частью горелки и образцом изменялось: в случае материала № 4 с 200 до 300 мм, материала № 6 с 230 до 350 мм. В обоих случаях температуропроводность с растущим расстоянием нанесения понижалась. В случае расстояния нанесения меньше, чем 250 мм температуропроводность оказывалась более высокой при покрытиях, полученных из корунда с большим размером зерна по сравнению с покрытиями, где удельный размер зерна исходного материала был меньше. В случае расстояния нанесения больше, чем 250 мм этому было наоборот.

Рис. 1. Зависимость температуропроводности a от расстояния нанесения L у покрытий, полученных из корунда № 4 (×) и № 6 (○).