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Thermal Processes in HVOF Sprayed WC-Co Coating on a Copper Substrate

(Work in Progress)

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Mathematical modelling of the heat transfer between a WC-Co coating and a copper substrate during high-velocity oxygen-fuel (HVOF) spraying was undertaken. The modeling included the investigation of temperature variation, coating solidification, melting and solidification in the substrate interfacial region, and specific features of the substrate-coating thermal interaction.

1. Introduction

Development of coating structure and properties depends essentially on the substrate-coating heat transfer during coating deposition and solidification (Ref 1, 2). Particularly, it refers to the heat transfer in the substrate-coating interfacial region, which includes the first coating layer and the substrate interfacial zone, because in this region bonding of the coating to the substrate develops (Ref 3-5).

This article analyzes the heat-transfer processes during formation of high-velocity oxygen fuel (HVOF) sprayed WC-Co coatings on smooth and rough (grit-blasted) copper substrates. The results can be used to predict the substrate-coating adhesion and the development of the coating and substrate interfacial region structure.

2. Results and Discussion

The full solidification time of the first coating layer for the grit-blasted surface of the substrate varies nonuniformly with respect to the initial temperatures of the substrate and the layer. In the case of the smooth surface, the behavior of this solidification time with respect to the initial substrate temperature becomes more uniform. The layer solidification time increases with an increase in layer thickness.

The relative time of the liquidus isotherm movement during solidification of the first coating layer for the smooth surface of the substrate increases as the initial substrate temperature and the layer thickness increase, but this relative time decreases as the initial layer temperature increases. The relative time of the solidus isotherm movement for the smooth surface increases with an increase in the layer thickness and initial temperatures of the layer and the substrate.

For a grit-blasted substrate, the behavior of the relative time of the solidus isotherm movement during solidification of the first coating layer with respect to the layer thickness and the initial temperatures of the layer and the substrate is the same as with a smooth surface. However, the value of the relative time of the solidus isotherm movement decreases as the initial temperatures of the layer and the substrate increase and increases with the layer thickness.

During solidification of the first coating layer, the liquidus isotherm moves faster than the solidus isotherm. The difference between the relative times of movement of the isotherms of liquidus and solidus decreases with a decrease in the contact thermal resistance between the coating and the substrate, that is, with a decrease in the roughness of the substrate surface.

Liquid is present in the solidifying first layer for 70 to 80% of the complete solidification time for the smooth surface of the substrate and for 40 to 70% of the corresponding time for the grit-blasted surface of the substrate. The mushy state remains near the upper boundary of the layer for 85 to 97% of the solidification time. This result differs markedly from the situation when a WC-Co coating is developed on steel and aluminum alloy substrates.

The substrate interfacial region melts partially and is retained in the solid-liquid (mushy) state during heating from the coating layer. The depth of melting is ~0,1μm for the smooth surface of the substrate and is ~0,5μm for the grit-blasted surface.

For a smooth substrate the solidification time of the substrate interfacial region increases with an increase in the initial temperatures of the substrate and the layer and does not vary much as layer thickness increases. In the case of the grit-blasted surface, the solidification time of the substrate interfacial region also increases with an increase in the initial temperature of the substrate and the layer, and varies nonuniformly as the layer thickness increases.

The substrate interfacial region remains in the mushy state during a significant portion of solidification time, and this time in the mushy-zone region is greater for the grit-blasted surface than for the smooth substrate.

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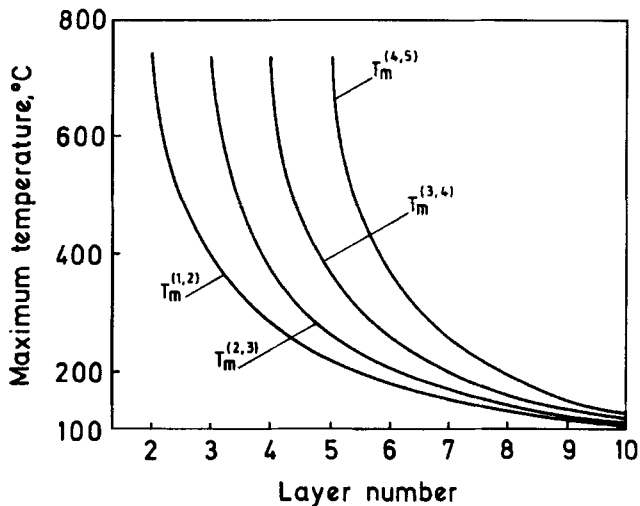
Fig. 1 Variation of maximum temperatures at interfaces between different layers with respect to layer number. Superscripts (e.g., 1 and 2) represent the temperature between layers 1 and 2.

The solidification time of the substrate interfacial region for the grit-blasted surface of the substrate is approximately twice that of the first layer of the coating. The corresponding time for the smooth substrate is approximately one order of magnitude greater than that of the first layer.

During cooling of the second layer of the coating, the temperature at the substrate-coating interface increases, but this increase is not sufficient to remelt the substrate interfacial region. The influence of cooling of the subsequent layers on the interface decreases with an increase in the layer number. The interface temperature depends weakly on the morphology of the substrate surface. The maximum temperatures at the interfaces between different coating layers decrease with increasing layer number and do not depend on the morphology of the substrate surface (Fig 1).

3. Summary

Kinetics of solidification of the coating and the substrate interfacial region are established for different substrate surface morphologies, taking into account the coating-layer thickness and the initial temperatures of the substrate and the layer. The results can be used for predicting the parameters of the coating crystalline structure, porosity, chemical inhomogeneity, and the coating-substrate adhesion (Ref 6).

References

1. C. Moreau, P. Cielo, and M. Lamontagne, Flattening and Solidification of Thermally Sprayed Particles, *J. Therm. Spray Technol.*, Vol 1 (No. 4), 1992, p 317-323
2. R.C. Dykhuizen, Review of Impact and Solidification of Molten Thermal Spray Droplets, *J. Therm. Spray Technol.*, Vol 3 (No. 4), 1994, p 351-561
3. V.V. Sobolev, J.M. Guilemany, and J.A. Calero, Substrate-Coating Thermal Interaction during High Velocity Oxy-Fuel (HVOF) Spraying. Part 1. Heat Transfer Processes, *Mater. Sci. Technol.*, Vol 11, (No. 8), 1995, p 810-819
4. V.V. Sobolev, J.M. Guilemany, and J.A. Calero, Substrate-Coating Thermal Interaction during High Velocity Oxy-Fuel (HVOF) Spraying—Part 2: Structure Formation, *Mater. Sci. Technol.*, Vol 11, (No. 10), 1995, p 1052-1059
5. D.T. Gawne, B.J. Griffiths, and G. Dong, Splat Morphology and Adhesion of Thermally Sprayed Coatings, *Thermal Spraying—Current Status and Future Trends*, A. Ohmori, Ed., High Temperature Society of Japan, 1995, p 779-784
6. V.V. Sobolev, J.M. Guilemany, J. Nutting, and J.R. Miquel, Development of Substrate-Coating Adhesion in Thermal Spraying, *Int. Mater. Rev.*, Vol 42, (No. 3), 1997, p 117-136