R. SAMUR, B. G. ÇETINER

ISSN 0543-5846
METABK 44 (1) 41-44 (2005)
UDC - UDK 621.793:669.018.95:620.187=111

QUANTITATIVE DETERMINATION OF MICROCRACKS ON CERAMIC COATINGS BY MEANS OF COMPUTER IMAGE ANALYSIS

Received - Primljeno: 2003-12-24
Accepted - Prihvaćeno: 2004-07-15
Preliminary Note - Prethodno priopćenje

In this study, composite and metallic powder is coated on steel, cast iron and aluminium surfaces using flame spray and plasma spray under atmospheric conditions. Surface morphologies have been investigated in detail using Scanning Electron Microscope (SEM). Studies using SEM have illustrated that micro-cracks occur in structures of composite and metallic coatings independently from coating and process parameters. Using segmentation through threshold techniques, amount of microcracks from the point of view quantitative analysis is computed on digital images of microcracks.

Key words: *quantitative analysis, microcracks, metallic and ceramic composites, powder coatings*

Kvantitativno određivanje mikropukotina na keramičkim premazima. U radu se prikazuju premazi kompozitnog i metalnog praha nanešenog plamenim sprejem ili sprejom plazme na površinu čeličnog predmeta, predmeta od ljevanog željeza, aluminija - pod atmosferskim uvjetima. Morfologiju površina je skenirano elektronskim mikroskopom (SEM) i detalno ispitana. Studije napravljene SEM-om pokazale su da se mikropukotine pojavljuju u strukturama kompozitnih i metalnih premaza. Količina mikropukotina s računa s točke gledišta kvantitativne analize na digitalnim slikama mikropukotina koristeći se segmentacijom pomoću tehnika praga.

Ključne riječi: *kvantitativna analiza, mikropukotine, metalni i keramički kompoziti, prah*

INTRODUCTION

The concept of placing a protective barrier between materials and their environment is so old that its origin is lost in the mist of history. As it can be expected, with a concept so old, its materials, methods and qualifications are numerous and diverse [1]. Advances in materials performance require the development of composite systems, of which coated materials are one form. Abrasion and corrosion resistance of components can be greatly increased by protective coatings and this is a growing industry of considerable economic importance [2]. In the processes of metallic composite and ceramic composite coating, the pre-coating materials, dependent upon their future use are oxides with varied stoichometry, carbide, nitride, boride and powder metal composite or mixtures of these in various proportions [3]. General coating methods are flame spray, plasma spray, and high velocity oxygen fuel (HVOF). The plasma spray technique is the most widely used coating method because it presents process flexibility and coating quality in combination [4]. The aim of usage of composite coating in engineering applications can mainly be grouped as preventive and reconstructive. However, composite coating applications are usually used for preventive purposes. The most common examples of composite coating types used for preventive purposes are those applications at which the surfaces are resistant to wear, high temperature, and corrosion [5,6]. The most important parameters of composite coatings, that determine their engineering properties and thus their preventive functions, are the quantitative amount of contained porosity and microcracks and the bond strength of the coating on the surface in question [7, 8].

Microcracks and porosity are undesired microstructural features because they increase permeability in an application requiring resistance to corrosion and because they increase friction coefficient and thus wear in an application entailing wear resistance [5, 9].

It is known that microcracks in bulk ceramic materials negatively affect the mechanical properties of the material. From this standpoint, the effects of microcracks on certain properties of the composite coatings are to be investigated. In this study, the quantitative amounts of

R. Samur, Marmara Umiversity, Faculty of Technical Education, Göztepe, Istanbul, Turkey, B. G. Çetiner, Istanbul Technical University, Maslak, Istanbul, Turkey

microcracks occurring in the composite coatings produced through the use of various composite powder mixtures with different methods have been investigated.

The methods of digital imaging and artificial intelligence are successfully employed in many applications. These applications cover many fields ranging from optical character identification to receiving images from satellites [8].

MATERIALS AND METHOD

The substrates to be coated via thermal spraying methods firstly were cleaned off unwanted matters such as oil, dirt, and oxide. The substrates, then, were roughened through sandblasting technique to increase bond strength. The average roughness value was measured as $R_a = 4{,}50$ after sandblasting operation. Composition of metallic and ceramic composite materials, the kind of substrates and the thermal spraying methods used for coating material-substrate combinations are given in Table 1. The metallic composite powder material (WC12Co) NiCrBSiFeC was sprayed by flame spray method. On the other hand, ceramic composite material was sprayed by plasma spray method through the use of different electrical values with power parameters between 375A-500A. NiAl powder was used to form the bond-coat.

Table 1. **Kind of substrate, composite powder materials and spray methods used in the study**
Tablica 1. **Za potrebe studije rabljene su vrste supstrata, prah kompozitnih materijala i metode sprejanja**

Thermal Spray Methods	Composite Powder Material	Substrate Material
Flame spray (FS)	CuAl	Aluminium
Flame spray (FS)	(WC12Co) NiCrBSiFeC	Cast iron
Plasma spray	$Al_2O_3 + TiO_2$	Steel
Plasma spray	$Cr_2O_3 + SiO_2 + TiO_2$	Steel

Table 2. **Parameters of plasma spray**
Tablica 2. **Parametri spreja plazme**

Power (kW)	45
Pressure	Atmospheric
Plasma gas	(Ar/H_2) (88/12) Argon 70 l/min, Hidrogen 15 l/min
Carrier gas	Argon 5 l/min
Powder feed rate	800 g/h
Spraying distance	105 mm

Metallic composite powder was sprayed with Metco 5P spray gun onto cast iron substrates with spherical graphite. Vacuum furnace of 10^{-2} Torr parameters was used to sinter coatings by melting. Scanning Electron Microscope (SEM) was used for metalographic analyses. No etching reagent was needed to prepare the ceramic composite samples, (HNO_3 : HCl = 1 : 3) reagent was used to prepare the metallic composite samples.

Table 3. **Parameters of flame spray**
Tablica 3. **Parametri spreja plamena**

Gun type	Metco 5P
Preheating of surface before coating process / °C	150
Powder feed rate / (kg/h)	0,7 – 0,9
Spraying distance / mm	180
Acetylene flow rate / (1/min)	34
Oksigen flow rate / (1/min)	32
Air pressure / kPa	400

In this study, the amount of microcracks was determined by means of segmentation using thresholding. An optimal threshold value is found by means of histograms in which there are grey images of 0 - 255 shades. This threshold value is later used to put the image into two groups of object (microcrack) and background, which is called binarization. This application was developed by means of Delphi, a visual software-developing medium. In Figure 1., the picture of micro-crack of CuAl composite coating, its histogram and the crack in final form are illustrated.

RESULTS AND DISCUSSION

Typical structures of the sprayed metallic composite coatings are shown in Figure 2. (a, b). A large part of the spherical black sections in the nickel-based metallic composite coatings is of porous structure, which covers 15 % of the total volume. A typical matrix of a sprayed coating consists of flattened particles. It was observed that with nickel-based metallic powder coatings sprayed onto the cast iron and steel substrates after the heat treatment, microcracks entirely disappeared.

Typical structures of ceramic composite coating are shown in Figure 2. (c, d). Generally, surface morphology is composed of well-melted particles one on another. It is seen that the powder including Al_2O_3, when compared with the one including Cr_2O_3, is more suitable for melting and softening. In addition, the structure contains micro-cracks and porosities on its all sides. It is impossible to reduce or eliminate these microcracks by means of heat treatment, for ceramics and ceramic coatings melt at over 2000 °C.

The quantitative identification of microcracks is of great importance in terms of determining mechanical properties of the coating, the amount of corrosion and thermal conductivity, and dielectric coefficient. Following an interdisciplinary approach in application, this study has used image-processing techniques on computer. Image histograms

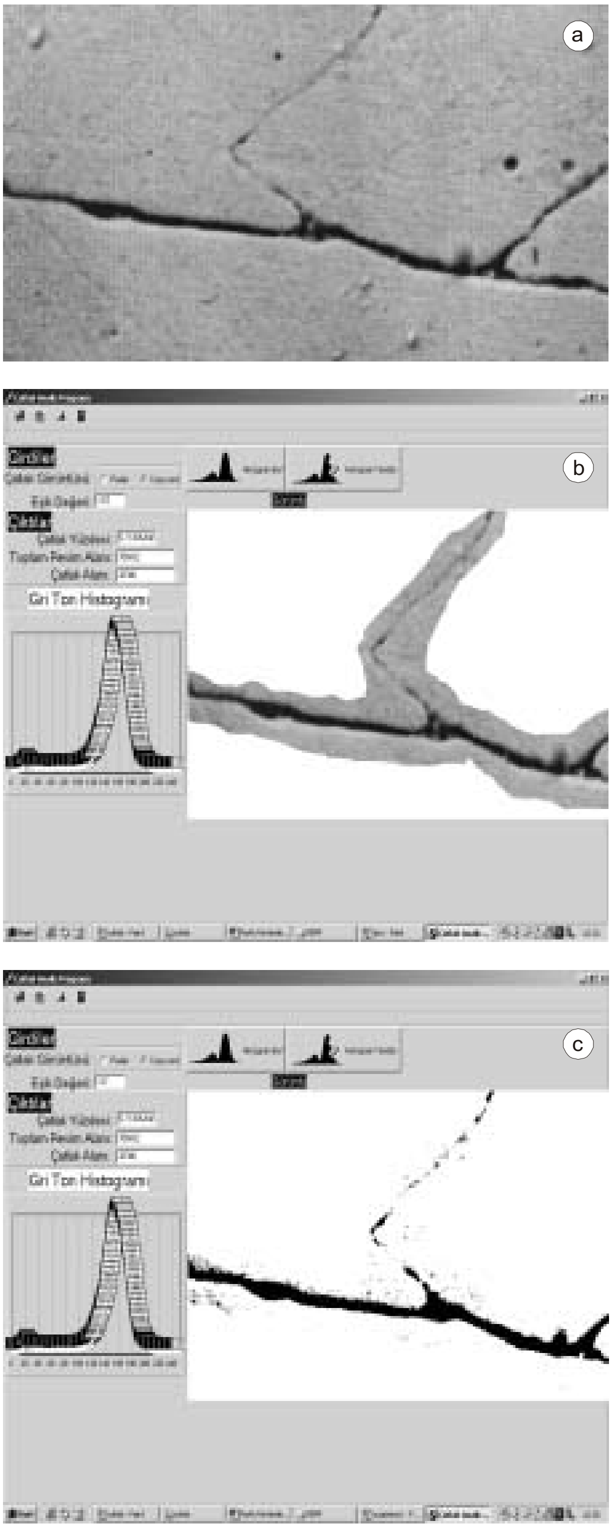

Figure 1. **Quantitative analysis of microcracks of CuAl Coating.: a) View of the CuAl coating containing microcracks, b) Quantitative analysis of microcrack, c) Total percent of microcracks**

Slika 1. **Kvantitativna anliza mikropukotina s CuAl premazom: a) izgled premaza CuAl s pukotinama, b) kvantitativna anliza mikropukotine, c) ukupni postotak pukotina**

are calculated with the selection of the images containing microcracks as a whole or selecting only those areas where microcracks exist. The information concerning whether the microcrack is dark or sometimes bright is entered into the application so that microcrack analysis for both cases can be possible. The percentage of microcrack is calculated through entering the threshold value separating the microcrack and the background on the estimated histogram. It is, however, necessary to manually eliminate such objects as porosity and shade, which are not microcracks, so that the analysis could include only the microcracks.

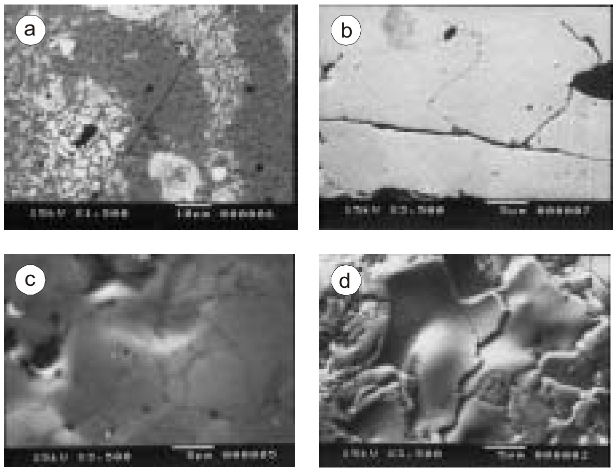

Figure 2. **Microcracks in metallic and ceramic coatings:**
a) (WC12Co) NiCrBSiFeC metallic composite powder coating,
b) CuAl metallic composite powder coating,
c) Al_2O_3-TiO_2 ceramic composite powder coating,
d) $Cr_2O_3SiO_2TiO_2$ ceramic composite powder coating

Slika 2. **Mikropukotine s keramičkim i metalnim premazima:**
a) premaz metalnog kompozita (WC12Co) NiCrBSiFeC u prahu,
b) premaz metalnog kompozita CuAl u prahu,
c) premaz keramičkog kompozita Al_2O_3-TiO_2 u prahu,
d) premaz keramičkog kompozita $Cr_2O_3SiO_2TiO_2$

CONCLUSIONS

1. The thermal extension, of the microcracks in the coatings formed during the process with ceramic composite powders is due to the fact that they are not elastically housed in the structure. Changing process parameters does not stop the formation of the micro-cracks. Further, it is impossible to eliminate by heat treatment the microcracks occurring in ceramic composite coatings, as opposed to those in metallic composite coatings, for ceramics and ceramic coatings are generally coated onto metallic materials and the values of melting points of the ceramics are over 2000 °C.
2. Positive results were obtained, concerning the quantitative analysis of the micro-cracks through the image processing techniques on computer used in this study.

3. Such studies are of great significance considering the fact that realizing the quantitative analysis of microcracks will provide significant information on the various coating parameters mentioned above.
4. This study manifests itself as an illuminating initial stage for future studies that could handle the qualitative and quantitative analysis of the microstructures of the coatings by making use of computer imaging and artificial intelligence techniques.

REFERENCES

[1] M. F. Stroosnijder, R. Mevrel, M. J. Bennet, Material at High Temperature, 12 (1994), 53 - 66.
[2] V. H. Hidalgo, F. J. B. Varela, E. F. Rico, Trib. Int, 30 (1997), 641 - 649.
[3] D. Matejka, Plazma Spraying of Metallic and Ceramic Materials, Bratislava, 1989, 12 - 38.
[4] I. A. Buckow, Proceedings, Int. Conf. on Thermal Spraying., London, UK, 4 - 9 June, 1989.
[5] D. Matejka, M. Krumpl, B, Benko, Proceedings of Int Conf. EUROCOR. Budapest, 1982.
[6] J. C. Wurst, J. A. Cherry, D. A. Gederman, The Evaluation of Materials Systems for High Temperature Aerospace Application, Wrigt Patterson, US,1966, 41 - 57.
[7] A. R. Nicall, Surface and Coatings Technology, 30 (1987), 223.
[8] T. Kohonen, K. Makisara, O. Simula, J. Kangas, Proceedings of the 1991 Int. Conf. On Artificial Neural Networks, Espoo, Finland, 24-28 June, 1991.
[9] M. K. Kulekci, Kovove Materialy, 41 (2003) 2, 97 - 105.