METABK METABK 56(3-4) 415-418 (2017)
UDC – UDK 666.31.0002.4:620.178.1:669.13.26:620.18:666.76=111

APPLICATION OF CERAMIC COATING TO IMPROVE ABRASIVE WEAR RESISTANCE OF DIE INSERTS USED TO PRESS-MOULD STAMPINGS OF REFRACTORIES

Received – Prispjelo: 2016-12-15
Accepted – Prihvaćeno: 2017-04-10
Preliminary Note – Prethodno priopćenje

The paper presents results of a study on abrasive wear resistance of die inserts for composite moulds used to press-mould stampings from refractory materials, determined based on susceptibility to scratching with a diamond indenter. For the study, two inserts of high-chromium cast iron were prepared, of which one was provided with a ceramic coating (60 % Al_2O_3 + 40 % TiO_2) with a metallic interlayer (NiAlCrSi). Both layers were deposited by means of the Atmospheric Plasma Spraying (APS) method. The obtained scratch test results indicate that with the use of the same load force (20 N), die inserts with ceramic coating are characterized with less indenter penetration depth which should translate to higher resistance to abrasive wear.

Key words: ceramic coating, abrasive wear resistance, high chromium cast iron, microstructure, refractories

INTRODUCTION

In many cases, resistance to abrasive wear is one of the most important criteria adopted when materials for machine parts and tools are selected both in the design process and operating conditions. Replaceable inserts for metal dies used to press-mould stampings from refractory materials are an example of such sensitive parts. The main factor causing degradation of the inserts and thus reduction of their service life, is the process of abrasive wear of the insert surface as a result of scratching it by grains of the raw mass of which the refractory half-products are press-moulded. The mass often contains very hard particles, such as e.g. fused alumina (1842 HV0.5).

In most cases, the inserts are made from cold-work tool steels, e.g. NC6, NC11. Despite application of additional thermal treatment processes methods (e.g. quenching and tempering up to hardness 60 - 61 HRC), the service life of such inserts remains unsatisfactory. This encourages to search of new technological processes which would ensure significant improvement of the material's resistance to abrasive wear.

Unconventional methods of improving resistance to abrasive wear include application of coatings with the use of plasma spraying methods. Among those most widely used, one may count ceramic coatings based on aluminum oxide with an addition of titanium oxide which, apart from high resistance to abrasive wear, are characterized with high resistance to thermal load and corrosion [1 - 3].

In a number of published studies, resistance of a ceramic coating to abrasive wear was assessed based on measurements of its hardness [4], indentation test results [5,6] or with a use of abrasive wear testing set-ups [3,7]. In this study, the susceptibility to scratching with a diamond indenter (scratch test result) was adopted as the measure of a die insert resistance to abrasive wear.

A.W. Orłowicz, M. Mróz, M. Tupaj, B. Kupiec, Department of Casting and Welding, Rzeszow University of Technology, Rzeszow, Poland. L. Kozak. T. Kij., Zakłady Magnezytowe "ROPCZYCE" S.A., Ropczyce, Poland

EXPERIMENTAL MATERIALS AND PROCEDURES

Die inserts used to press-mould stampings from refractory masses were made out of high-chromium cast iron, chemistry of which is presented in Table 1. The inserts were rectangular prisms with dimensions 363 × 99,5 × 15 mm.

Table 1 **Chemical composition of the developed high-chromium cast iron / wt.%**

C	Si	Mn	P	S	Cr
3,65	1,26	0,53	0,030	0,033	23,96
Mo	Ni	Cu	B	Fe	
0,44	0,30	0,031	0,02	t.b.	

One of the die inserts, before application of the interlayer and the ceramic coating, was subjected to a process of abrasive machining with abradant fed in the compressed air jet, to increase surface development and obtain better adhesion of the interlayer to the insert surface. The used abrasive was NT 55 (75 - 82 % Al_2O_3, 9 - 15 % SiO_2, 1,5 - 4 % Fe_2O_3, 4 - 5 % TiO_2), with grain size 150 - 250 µm. The abrasive blasting process was carried out at the nozzle inclination angle 45°.

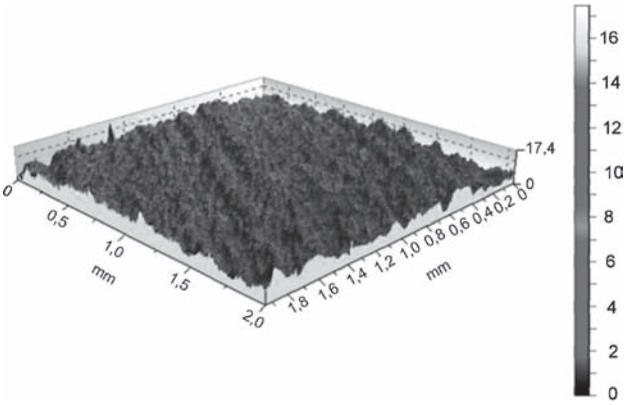


Figure 1 An example 3D surface map of a die insert after abrasive blasting

An example view of 3D surface after abrasive machining is shown in Figure 1.

The interlayer under the ceramic coating was deposited with the use of NiAlCrSi powder with grain size 50 - 180 μm (Figure 2a).

The ceramic coating was based on 60 % Al_2O_3 + 40 % TiO_2 powder (Sultzer Metco), with particle size ranging from 20 to 80 μm (Figure 2b).

Both the interlayer and the top ceramic coating were deposited by means of the Atmospheric Plasma Spraying (APS) method on with the use of spraying system by Sulzer Metco. A F4-MB-HBS burner was mounted on the arm of ABB model IRB 2400 robot. The device was equipped with two-hopper Twin-120-A/H powder feeder with volumetric control of powder feed rates.

Parameters characterizing the process of plasma spraying for NiAlCrSi interlayer and 60 % Al_2O_3 + 40 % TiO_2 ceramic coating are presented in Table 2.

a) b)

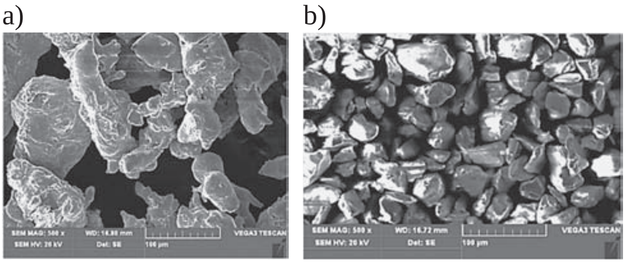


Figure 2 (a) A view of NiAlCrSi particles. (b) A view of 60 % Al_2O_3 + 40 % TiO_2 powder (Sultzer Metco) particles

Table 2 **Parameters of the plasma spraying process**

Parameter	NiAlCrSi interlayer	60 % Al_2O_3 + 40 % TiO_2 coat
Current intensity / A	550	550
Burner feed rate / mm/min	8	16
Argon output / l/min	55	55
Hydrogen output / l/min	15	15
Powder share / %	1	4
Powder carrier gas type and output / l/min	Argon, 2,0	Argon, 2,5
Powder stirrer speed / %	90	90
Burner distance / mm	100	100
Cooling gas type and pressure / bar	Air, 6	Air, 6
Number of runs	2	8

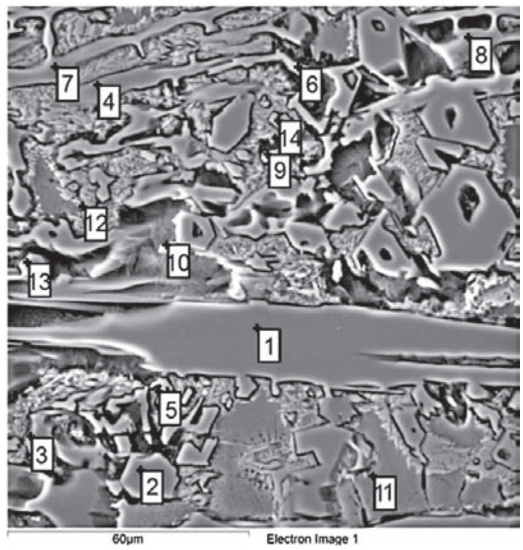
The analysis of microstructure and chemistry for the cast iron and the ceramic coating with interlayer was carried out with the use of Vega 3 electron microscope (Tescan) equipped with INCA x-Act electron back scattered diffraction system (Oxford Instruments).

Examination of resistance to scratching with a diamond indenter (the scratch test) was carried out with the use of Revetest RST macro scratch tester (CSM Instruments) at the following test parameters: Rockwell-type indenter C-281 with tip radius 200 μm; apex angle 120°; load force 20 N. The scratch length was 1 mm. In the scratch test, values of the following quantities were determined: the friction force F_t, the friction coefficient μ, the acoustic emission index *AE*, and the penetration depth P_d.

RESULTS AND DISCUSSION

An example microstructure and results of pinpoint X-ray microanalysis of the high-chromium cast iron is presented in Figure 3.

Microstructure of high-chromium cast iron reveals both large and small carbide precipitates rich in iron and



Pkt	Element content / wt. %					
	Si	Cr	Mn	Fe	Ni	Mo
1	-	55,97	0,44	32,65	-	-
2	-	54,86	0,40	34,32	-	0,34
3	-	52,96	0,43	35,92	-	-
4	-	46,11	0,44	41,27	-	1,19
5	-	45,36	0,45	40,05	-	-
6	-	49,47	0,39	38,98	-	0,70
7	-	47,03	0,48	41,61	-	1,13
8	-	55,07	0,47	37,83	-	-
9	-	45,91	0,47	40,10	-	0,74
10	-	42,47	0,33	38,81	-	2,31
11	1,42	12,24	0,49	77,00	0,42	0,35
12	1,47	12,02	0,47	78,79	0,34	0,40
13	-	54,33	33,79	33,79	-	0,36
14	-	46,77	41,35	41,35	-	0,76

Figure 3 Microstructure and results of chemistry analysis for the high-chromium cast iron

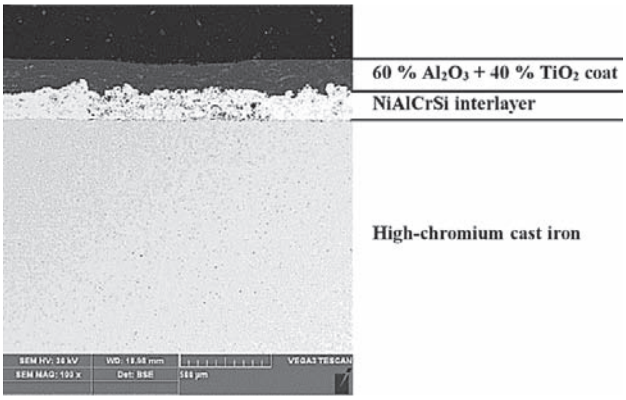


Figure 4 Microstructure of the ceramic coating with an interlayer

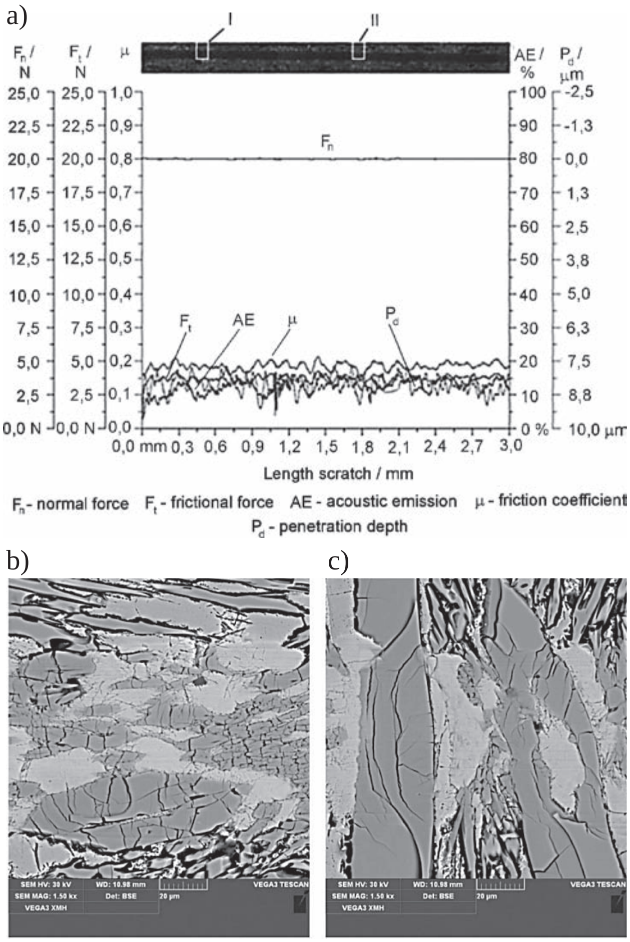


Figure 5 (a) Results of the scratch test and a view of scratch mark on high-chromium cast iron in (b) area I and (c) area II

chromium, containing also manganese and molybdenum.

An example microstructure of a ceramic coating with an interlayer is shown in Figure 4.

Results of examination of susceptibility of the high-chromium cast iron to scratching are presented in Figure 5.

Results of the scratching susceptibility test for the 60 % Al_2O_3 + 40 % TiO_2 ceramic coating deposited on the interlayer are presented in Figure 6.

The obtained results of the study indicate that in the case of ceramic coating, the depth of penetration of diamond indenter is almost two times less than the indenter penetration depth in case of scratching surface of high-chromium cast iron.

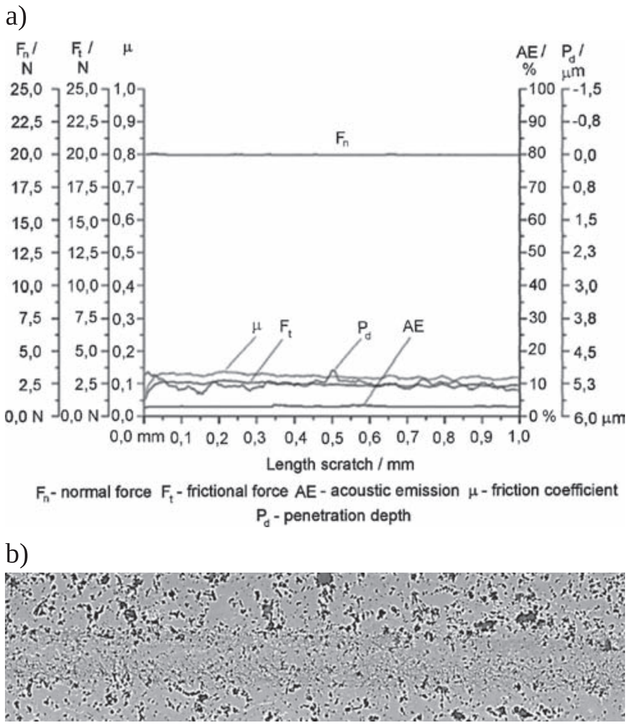


Figure 6 Results of the scratch test (a) in graphical form and (b) views of the scratch mark on ceramic coating

Results of examination of the scratch mark in combination with measured values of the friction force, the acoustic emission, and the penetration depth indicate that passage of the indenter over the cast-iron die insert results in cracking of carbide precipitates.

Values of the friction coefficient are on the similar level to those observed with the coating applied. The risk of cracking involves mainly large carbide precipitates, regardless of their orientation with respect to the indenter motion direction. A jump in the acoustic emission value corresponds to an instant of carbide cracking. Small carbide precipitates show less susceptibility to cracking.

In case of scratching the ceramic coating, no indications of cracking were found which is an evidence of high resistance of the coat to abrasion.

CONCLUSIONS

Results of examination of susceptibility to scratching with a diamond indenter (the scratch test) show that application of a ceramic coating with an interlayer on disposable die inserts used to press-mould stampings from raw refractory materials should be a guarantee of much higher resistance to abrasive wear and extended service life of the product.

Acknowledgements

The study presented in this paper was carried out in the framework of project entitled INNOVATIVE TECH-

NOLOGICAL PROCESS OF MANUFACTURING MOULDS FOR PRODUCTION OF REFRACTORY MATERIALS co-funded from Operational Programme Innovative Economy, Measure 1.4 Support for goal-oriented projects and support for implementation of results of R&D works. Project was carried out in Zakłady Magnezytowe „ROPCZYCE" S.A.

REFERENCES

[1] Tsuyoshi Irisawa, Hiroshi Matsumoto, Thermal shock resistance and adhesion strength of plasma-sprayed alumina coating on cast iron, Thin Solid Films 509 (2006), 141-144.

[2] P. Bansal, N.P. Padture, A. Vasiliev, Improved interfacial properties of Al_2O_3-13wt% TiO2 plasma sprayed coatings derived from nanocrytalline powders, Acta Materialia 51 (2003), 2959-2970.

[3] Xinhua Lin, Yi Zeng, Chuanxian Ding, Pingyu Zhang, Effects of temperature on tribological properties of nanostructured and conventional Al2O3–3 wt.% TiO2 coatings, Wear 256 (2004), 1018-1025.

[4] O. Culha, C. Tekmen, M. Toparli, Y. Tsunekawa, Mechanical properties of in situ Al_2O_3 formed Al–Si composite coating via atmospheric plasma spraying, Materials and Design 31 (2010), 533-544.

[5] A. Rico, J. Rodriguez, E. Otero, P. Zeng, W.M. Rainforth, Indentation properties of plasma sprayed. Al2O3–13% TiO2 nanocoatings, Acta Materialia 57 (2009), 3148-3156.

[6] J. Nohava, R. Mušálek, J. Matějiček, M. Vilémová, A contribution to understanding the results of instrumented indentation on thermal spray coatings - Case study on Al_2O_3 and stainless steel, Surface and Coating Technology 240 (2014), 243-249.

[7] V. Bolleddu, V. Racherla, P.P. Bandyopadhyay, Microstructural and tribological characteriza-tion of air plasma sprayed nanostructured alumina – titania coatings deposited with nitrogen and argon as primary plasma gases, Materials and Design 59 (2014), 252-263.

Note: Jan Snakowski is responsible for English language, Rzeszów, Poland