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Study of protective coatings for aluminum die casting molds

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ABSTRACT

In this paper, the development and characterization of some protective coatings on steel substrate are presented. The coatings are realized by plasma spray techniques. The substrate material used is a Cr–Mo–V based hot work tool steel, initially submitted to vacuum heat treatment to achieve homogeneous hardness. The main attention is focused on the study of wear and on the characterization of the interface between the substrate material and the coating layer, because of their key role in determining the resistance of the coating layer. Simulation of friction and wear processes is performed by pin-on-disk test and the tested samples are observed by scanning electron microscopy.

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1. Introduction

The use of hot-work tool steel is a common feature of many different industrial productions; these materials find applications in hot plastic deformation (e.g. forging and extrusion) and in foundry processes. Hot-work components are generally affected by failure mechanisms (Fig. 1) such as erosion, corrosion, wear, and thermal fatigue [1–4]: all these mechanisms directly involve the surface. The difficulties coming from the corrosion of the tool's surface during service create a serious problem in the manufacturing of castings [5,6]. Engineering studies are directed toward the modification of surfaces either by the application of protective hard coatings or diffusional treatments [7]. Thin ceramic coatings applied by vapour deposition techniques have been largely studied [8,9], low wetting to aluminum alloy reduces soldering damaging, while different thermal expansion properties bring in spallation and delamination damaging of the coatings. In this paper, three thermal sprayed coatings are proposed and their wear resistance have been characterized. High Velocity Oxygen Fuel (HVOF) technique was applied in depositing a nickel-based metallic coating, while atmospheric plasma spray technique was applied for two zirconia-based ceramic coatings [10]. Thick coatings were chosen because in addition to protecting the tool surface from corrosive and thermal damaging [11,12] they can be used when restoring simple shaped parts in die casting dies.

2. Materials and methods

2.1. Coated samples

AISI H11 was used as substrate for the deposition of the three coatings: these coatings were chosen due to their good properties in wear, corrosion and thermal resistance. Three steel disks each with 35 mm in diameter and 8 mm in thickness were coated with thick thermal sprayed coatings. Two ceramic coatings and a metallic coating were deposited using commercially available powders: a Nickel based alloy (Table 1) and two partially stabilized ZrO2 based powders (Table 2). The metallic Nickel based alloy was sprayed by HVOF while ceramic coatings were deposited through Atmospheric Plasma Spray technique (APS); a metallic Nickel–Chrome–Cobalt–Aluminum (NiCoCrAl) bond layer was deposited by APS between the steel and the ceramic layer (Table 1). This bond-layer made of NiCoCrAl alloy is typically used as a protective layer in high temperature working components to prevent oxidation and damaging [13]. In both ceramic powders the maximum monoclinic phase is reported to be around 10% (Table 2): this is a negative feature in the distinctive toughening behavior of partially stabilized zirconia because reduces the fraction of tetragonal zirconia able to transform thus dissipating energy and creating a compressive stress zone.

2.2. Tribological analysis

To perform a tribological comparison among the coated surfaces, pin-on-disk analysis was chosen (Fig. 2). The present study is

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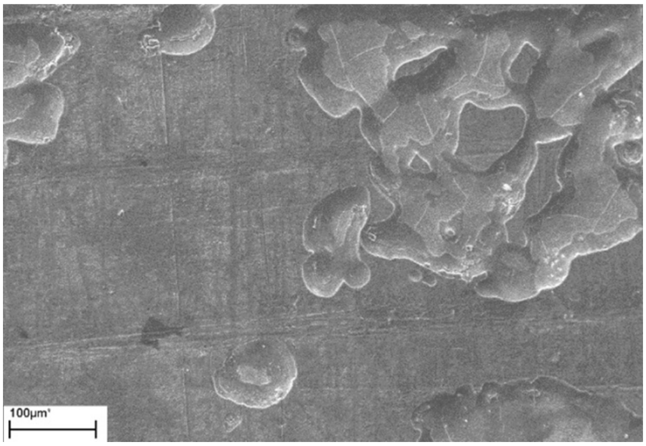

Fig. 1. SEM micrograph showing the corroded area on the surface of a hot-work tool steel (AISI H11) after 3500.

Table 1
Chemical composition of the used metallic powders.

Coating	Chemical composition (%wt.)						
	Ni	Cr	B	Si	C	Fe	Others
Ni-based alloy	Bal.	17	3.5	4	1	4	–
Bond-coat	26.25	25.21					35% Co 10% Al

Table 2
Chemical composition of the used ceramic powders.

Coating	Chemical composition (%wt.)				
	ZrO_2	MgO	Y_2O_3	Other oxides	Monoclinic phase
ZrO_2–Y_2O_3	Bal.	–	8	<1.5	<10
ZrO_2–MgO	Bal.	15–30	–	<7	<10

application-oriented research and it was born starting from a real industrial need. For these reason, both wear testing and hot corrosion testing were made with surface roughness values as close as possible to the real application ones in order to achieve the results according to the applicative foundry casting requirements using the coated molds. A computer connected to the pin-on-disk apparatus records the variations in the ratio between tangential force (F_T) and normal force (F_N) and returns the friction coefficient (cof) μ as in the friction equation (Eq. (1)).

$$F_T = \mu F_N \tag{1}$$

The force F_N is applied by a weight screwed on top of the pin holder, a load cell detects force variations and returns a setting value which has to be discarded from the final cof values. Because of the samples dimensions, a custom specimen-holder was needed to perform the analysis. It was made of hard plastic and provided suitably firm hold of the samples. Load, speed and distance parameters were set as described in the Standard ASTM G99. Low load (15 N) and speed (0.15 m/s) were chosen in order to have low vibrations. The total distance was set to 3000 m, and experiments have been conducted at room temperature (25 °C) and with approx. 50% humidity. The pin used for the tests was a spherical ended 3 mm radius WC pin, while the wear track was at 12 mm from the center of the sample. Coated samples were not polished but were tested in the as-sprayed condition (Ra_Nickel-based coating = 4.0 μm, Ra_ZrO_2–MgO coating = 7.5 μm, Ra_ZrO_2–MgO coating = 7.5 μm). After each 500 m the samples were analyzed: friction and wear data were recorded. Geometric variations of the wear scars were measured with a stylus profilometer (Mahr mod. MarSurf XC 2). Track depth (d) and width (w) were measured. Arithmetic mean, standard deviation and variance were calculated in order to make a comparison with other data from literature [14]. The wear scar was approximated by a circular segment to obtain the volumetric wear data. Surface roughness was measured for the coatings with a Hommelwerke T1000 rugosimeter. After performing the pin-on-disk analysis, the coated disks were cut by abrasive disk, mounted on phenolic resin and ground first with 300 and 600 μm grit SiC papers, then polished with special diamond disks (75, 58, 18 μm). Coatings thickness, porosity and adhesion to the substrates have been assessed by SEM imaging (SEM, Leo 1450VP).

2.3. *Corrosion and thermal fatigue resistance*

Coated samples were tested to cyclic dipping in molten aluminum alloy to evaluate both the corrosion resistance and thermal fatigue resistance when in contact with molten aluminum alloy. Two of the three coatings were tested, the selection was made after their performances in wear testing. This study was performed through a specifically designed device; the thermal test was interrupted after a fixed number of cycles and the sample's surface was analyzed through SEM analysis. The shape of the samples used in this study is a hollow cylinder type with a cooling channel placed in the central cavity (Fig. 3); samples were bolt to a pneumatic-driven bar. The testing equipment consists of a special apparatus where the specimen is dipped alternatively into a molten aluminum alloy bath as hot stage, and a cooling bath made of water based silicone die-casting lubricant as cold stage. The test and the complete apparatus were conceived, built and developed in our laboratory at Politecnico di Torino-Alessandria campus. The aluminum alloy used for the test was A356 (Al–Si7–Mg 0.3–Fe <0.2) while the molten bath was set to 830 ± 10 °C measured by

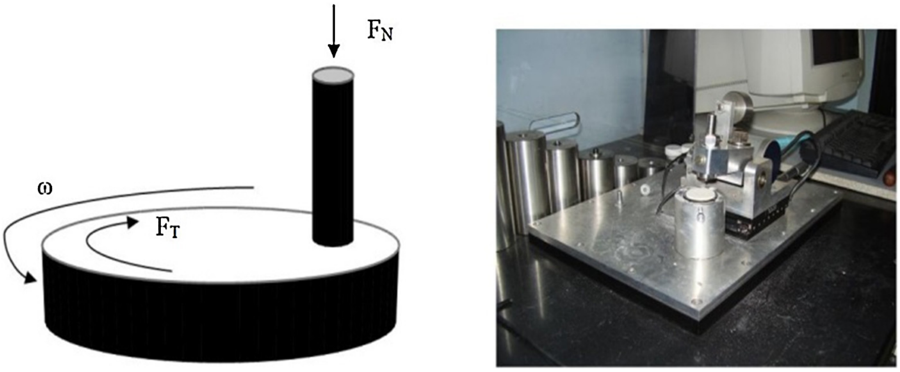

Fig. 2. On the left a schematic of the pin on disk test with the developed forces, on the right the pin on disk equipment.

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