

DEVELOPMENT OF A METAL/CERAMIC COATING APPLIED BY FLAME THERMAL SPRAYING PROCESS TO PROTECT MOLDS USED IN GLASS MANUFACTURING FROM THE EFFECTS OF TEMPERATURE.

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RESUMEN

Los moldes usados para la fabricación de vidrio son sometidos a continuos ciclos de calentamiento y enfriamiento, así como a contacto directo con material fundido, lo cual resulta en su falla por fatiga térmica. Por tales razones, se desea evaluar la utilidad y viabilidad técnica de recubrir dichos moldes a través de proyección térmica por llama oxiacetilénica, utilizando capas base de Ni, así como recubrimientos de WC, Al₂O₃-TiO₂, ZrO₂-Al₂O₃ y Al₂O₃, los cuales han sido probados previamente en la industria metalúrgica [1, 2]. Se elige dicha técnica porque no afecta significativamente al sustrato, permite obtener fuertes uniones metalúrgicas (>40MPa) [3], es económica, y puede ser utilizada en piezas de gran tamaño y geometrías complejas [4]. Los sustratos fueron proveídos por O-I y provienen de moldes originales. Las capas bases fueron proyectadas usando una llama neutra, y los recubrimientos fueron proyectados usando dos llamas: neutra y oxidante, esto con el fin de someter a diferentes condiciones térmicas las partículas. Los resultados obtenidos en choque térmico indican que la resistencia es mayor a 100 ciclos.

Palabras Claves: *Recubrimiento, Oxidante, Neutro, Fatiga Térmica*

ABSTRACT

Molds used in glass manufacturing are subjected to continuous heating and cooling cycles, as well as to contact with molten material, which result in their failure by thermal fatigue and abrasion. For these reasons, it is desired to evaluate the usefulness and technical feasibility to coat the molds with a bond coat of a nickel alloy and top coats of WC, Al₂O₃-TiO₂, ZrO₂-Al₂O₃ and Al₂O₃ deposited by oxy-fuel thermal spraying process, which have been previously tested successfully in the metallurgical industry [1, 2]. This technique is chosen because the substrate is not significantly affected, and it allows to obtain strong metallurgical bonds (>40 MPa) [3] between substrate and bond coat, it is economical and its use even in large pieces and complex geometries is easy [4]. Cast iron molds were supplied by O-I and used as substrate. Bond coatings were manufactured using a neutral flame while top coatings were deposited using both an oxidizing and a neutral oxy-acetylene flame, in order to supply different thermal conditions on the sprayed particles. The results of thermal shock tests realized to these coatings indicate that its resistance is higher than 100 thermal cycles.

Keywords: *Coating, Oxidizing, Neutral, Thermal Fatigue*

1 INTRODUCTION

Molds used in the glass manufacturing processes usually are made of compacted graphite iron, which provides better resistance to thermal fatigue and abrasion wear than those with flakes and nodules of graphite [1]. Furthermore, these molds are subjected to constant heating and cooling cycles, as well as abrasion by direct contact with molten glass, generating cracks by thermal fatigue [2]. For such reasons, some coatings have been tested in order to improve thermal fatigue and abrasion resistance. Specifically, coatings of $ZrO_2-Y_2O_3$, ZrO_2-MgO and $Ni-Al_2O_3$ have been deposited by thermal spraying process on compacted graphite iron [2,3]. Thermal shock resistance of thermal sprayed coatings deposited on nodular and compacted graphite iron was evaluated by other researchers, showing no significant thermal fatigue in bond coatings (NiCrAl, NiCrAlY and NiCrAlCoY), withstanding over 5000 cycles [2]. Meanwhile, top coatings have withstood between 5 and 600 cycles depending of spraying parameters and chemical composition of coatings evaluated [2]. A Fe_2O_3 layer is produced between the substrate and the bond coating during the thermal-spraying process, which produces cracking due to cyclic changes in temperature [2]. The highest resistance to thermal shock has been obtained in Al_2O_3 coatings fabricated by plasma-spraying [2,5]. Finally, this project aims to develop a coating that increases the molds useful life, withstanding the strong temperature conditions produced during glass manufacturing process.

2 METHODOLOGY

A nickel alloy Eutectic Castolin CPM 1205TM was sprayed as bond coat onto cast iron substrates which were previously blasted using a corundum jet and sonicated in an ethanol bath. Additionally, three ceramic powders (Al_2O_3 Sulzer-Metco 105 SPFTM, Al_2O_3 - 40% wt. TiO_2 Saint Gobain SG-109TM, and ZrO_2 -40% wt. Al_2O_3 EutecticCastolin 25088TM) as well as a cermet Eutectic Castolin 10112TM were deposited onto the bond coat. The spraying parameters used to manufacture both: the bond and top coatings are shown in Table 1.

Table 1. Spraying parameters used to manufacture the bond and top coatings.

Variable	Ceramic Top Coatings		Cermet Top Coatings		Ni Bond Coatings
	Oxidizing	Neutral	Oxidizing	Neutral	Neutral
O ₂ Flow [L/min]	96.1	38.6	18.8	11.9	11.9
C ₂ H ₂ Flow [L/min]	22.5	22.5	7.3	7.3	7.3
O ₂ Pressure [psi]	50		50		50
C ₂ H ₂ Pressure [psi]	12		10		10
Powder Flow [g/min]	12 ± 1		60 ± 1		77 ± 1
Pre – Heating Cycles	3		3		6
Projection Cycles	10		13		9
Post – Heating Cycles	-----		9		16
Spray Distance [mm]	90		27		25
Rotojet	RPA3		-----		-----
Torch	Terodyn 2000 TM		Super-Jet Eutalloy TM		Super-Jet Eutalloy TM

The bond coating was manufactured using a Super-Jet Eutalloy™ torch, while top coatings were deposited with a Terodyn 2000™ torch using a neutral and an oxidizing flame to spraying each powder. The chemical composition and the distribution size particle of feedstock powders were characterized by Wave-Length X Ray Fluorescence (WD-XRF) and Laser Diffraction, respectively, while Scanning Electron Microscopy (SEM) was used to determine its morphology.

On the other hand, the microstructure of substrates supplied by O-I was characterized by optical microscopy. Thickness of bond and top coatings was controlled through the powder's flow (showed in table 1) and the torch's speed (maintained in 0.6 cm/s in front of substrates rotating to 114 rpm), achieving $300 \pm 20 \mu\text{m}$ and $250 \pm 10 \mu\text{m}$ for bond and top coatings respectively.

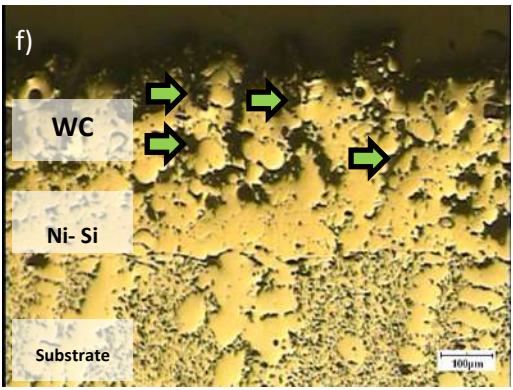
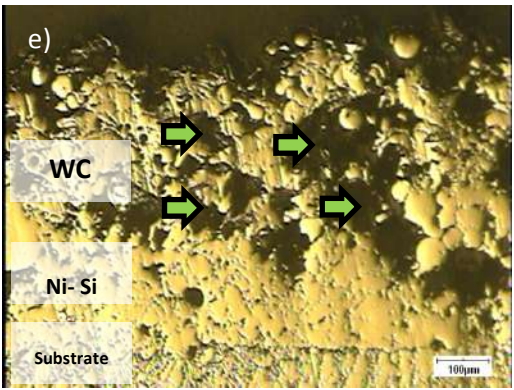
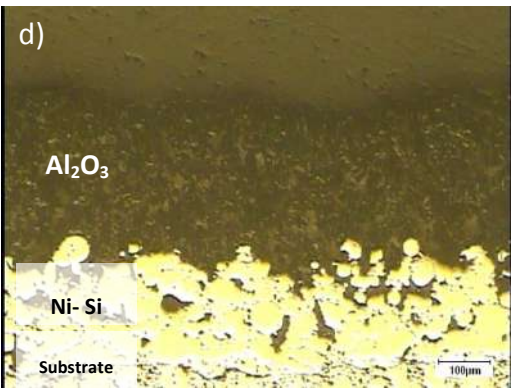
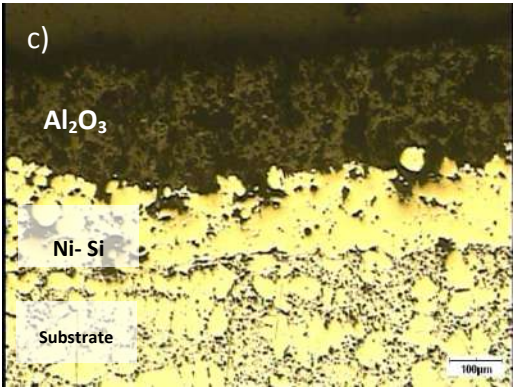
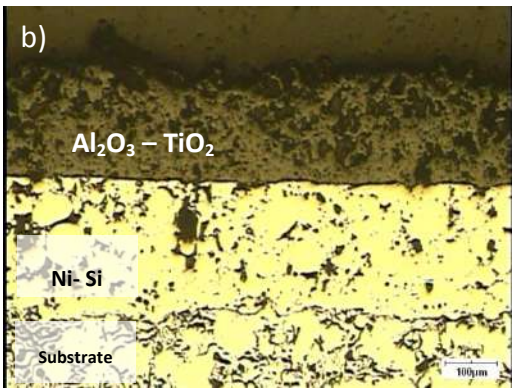
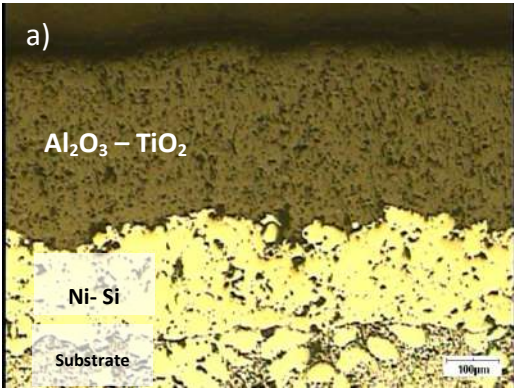
Finally, micro-structural characterization of coatings was made on its cross section by Optical Microscopy supported by Image analysis according to ASTM E1920 and ASTM E2109 standards [6]. Additionally, the thermal shock resistance of coatings was evaluated heating them at $650 \text{ }^\circ\text{C}$ during 10 minutes in an electrical furnace and then, the samples were fast cooled in water at room temperature. After each cycle the surface of coatings was evaluated in order to determine cracks or others failures produced during the test. This test was previously carried out by Wang [7].

3 RESULTS AND DISCUSSION

The result of micro-structural characterization realized to substrate indicates that this is constituted by graphite flakes type D randomly dispersed inside a dendritic matrix. Regarding chemical and physical characterization of powders used as top coatings; the results indicate that Sulzer-Metco 105 SPF™ powder is constituted by Al_2O_3 (99.71wt.%) and SiO_2 (0.174 wt.%), with a distribution size particle between $d_{10}=6.0 \mu\text{m}$ and $d_{90}=25.5 \mu\text{m}$, and its morphology is irregular. The powder Saint Gobin SG-109™ is a mixture of Al_2O_3 (55.19 wt.%) and TiO_2 (43.14 wt.%), with a distribution size particle between $d_{10}=8.8 \mu\text{m}$ and $d_{90}=22.3 \mu\text{m}$, and its morphology is irregular. A mixture of ZrO_2 (59.72 wt.%) and Al_2O_3 (35.70 wt.%) was identified in Eutectic Castolin 25088™ powder, its shape is spherical and it is constituted by nanometric particle. On the other hand the Eutectic Castolin 10112™ powder is an cermet constituted by WC (60 wt.%) and a Ni-Cr-B-Si-Fe alloy (40 wt.%), whose morphology is a mixture of rounded particles of Ni, and irregular shape particles for WC. The Eutectic Castolin CPM 1205™ used as bond coating consists mainly of Ni (97.62 wt.%) and Si (1.79 wt.%), and its morphology is rounded. Structural analysis on cross section of samples showed continuous bond coatings (Figure 1) with low porosity produced by fused particles from "Self Fluxing Ni-Si Alloy" which allows to melt sprayed particles through a subsequent heating, getting structures with high density, few voids and pores, and high adhesion [8, 9, 10]. On the other hand, the rounded morphology of this powder allows better particle packing, and hence it allows improving the coating density. Additionally, top coatings structure shown typical voids and pores. However, it is important to mention that this kind of "defects" can improve the thermal shock resistance of coatings because they allow the rearrangement of material during abrupt changes of temperature [11]. Finally, a most compact structure was observed in top coatings manufactured using oxidizing flames due to the higher length of the most heat zone in this flame and then the higher time of particles in this zone increasing its melt. The structure of coating is showed in Figure 1.

Development of a metal/ceramic coating applied by flame thermal spraying process to protect molds used in glass manufacturing from the effects of temperature

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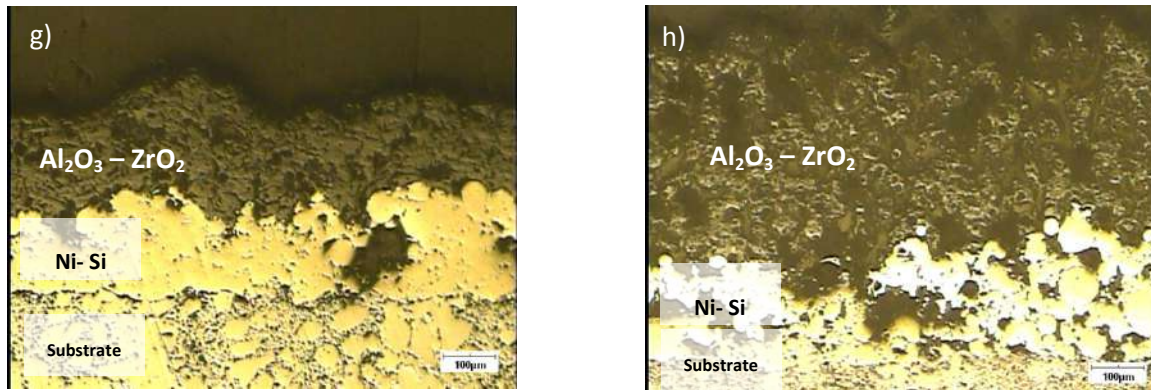


Figure 1. Structure on Cross-Sections of Coatings. a) Oxidizing flame. b) Neutral flame. c) Oxidizing flame. d) Neutral flame. e) Neutral flame. f) Oxidizing flame. g) Oxidizing flame. h) Neutral flame.

Thermal shock resistance for all samples has withstood more 100 cycles, equating the same results achieved for other authors. Specifically, several authors following the Wang's method at 650°C to evaluate coatings of Al₂O₃-TiO₂ and Al₂O₃ applied by flame thermal spraying, have reported 80 cycles and 120 cycles respectively. This behavior in thermal shock resistance is explainable and understandable due to the existence of voids and pores in the structure of coating, which helps to withstand the temperature changes aforementioned. In Figure 2, it is possible to observe the conditions of samples after 100 cycles of thermal shocks. There is evidence of failure (microcracks) in samples of Al₂O₃- 40% wt. TiO₂ (Saint Gobin SG-109TM). The rest of the samples just show coloration due to oxidation from samples' holder.

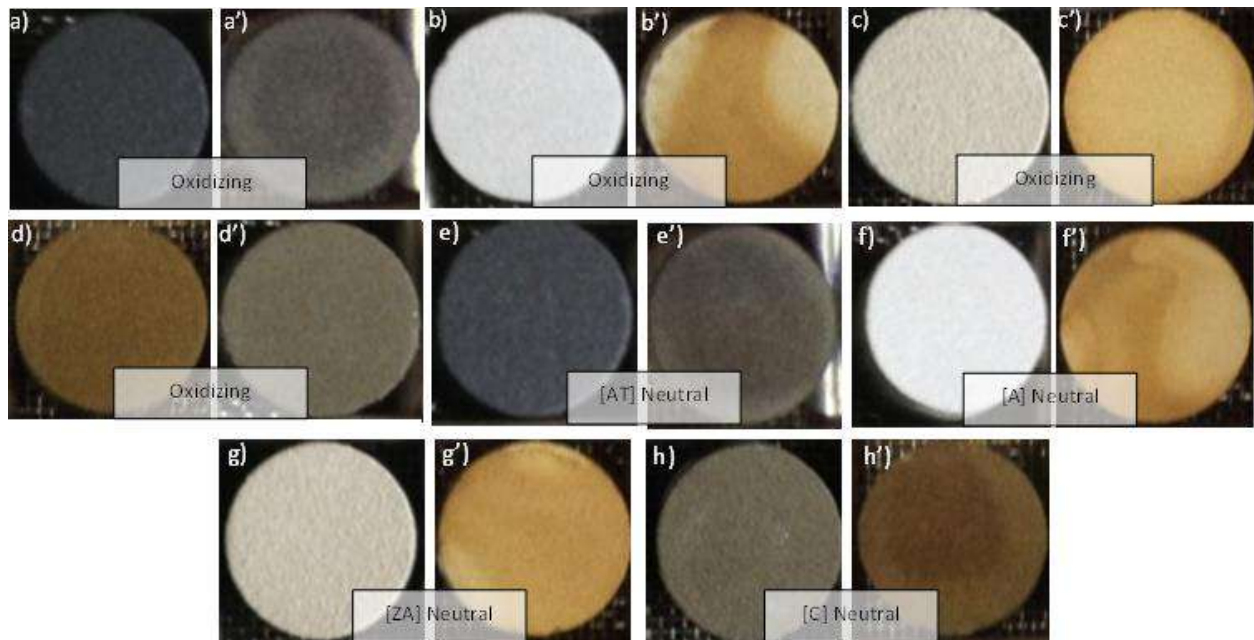


Figure 2. Surface of coatings tested under thermal shocks conditions. a) Cycle: 0. a') Cycle: 100. b) Cycle: 0. b') Cycle: 100. c) Cycle: 0. c') Cycle: 100. d) Cycle: 0. d') Cycle: 100. e) Cycle: 0. e') Cycle: 100. f) Cycle: 0. f') Cycle: 100. g) Cycle: 0. g') Cycle: 100. h) Cycle 0. h') Cycle: 100.

4 CONCLUSION

Based on the structural analysis, it is possible to conclude that the spraying parameters used to coat cast iron substrates let to get continuous bond and top coatings with a thickness and structure that confers a thermal shock resistance upper than 100 cycles of heating at 650 °C during 10 minutes and fast cooling at room temperature.

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