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The influence of hot isostatic pressing on plasma sprayed coatings properties

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Abstract

Die-casting moulds are subjected to severe conditions of cyclical thermal and mechanical loads, as well as chemical and mechanical wear. Dies mostly fail due to a combination of wear mechanisms. Heat checking, erosion, hot corrosion and soldering often lead to complete die failure. Ceramic plasma-sprayed coatings have a great potential for die protection, since they are chemically inert, and show high form stability at elevated temperatures. Furthermore, they show good resistance against thermal shock due to the porous state of the coated layer and low Young's modulus. In the present study, the influence of hot isostatic pressing on thermal fatigue resistance of plasma spraying coatings is investigated. Thermal and thermo-mechanical tests were applied to characterise their ability to protect dies. The coatings were evaluated by residual stress measurements, metallography, hardness test and X-ray diffraction.

Keywords: Thermal spray; HIP; Thermal cycling test; Residual stresses; Thixoforming

1. Introduction

Thixoforming is a method of forming technology, where a semi-solid-slug is formed to a near-net-shape part. Thixoforming can be subdivided into thixocasting and thixoforging. Thixocasting is done on slightly modified die casting machines. In this forming variant the inductively reheated and partly molten billet is set into the shot sleeve. The semi-solid material is pressed into the closed die by the shot ram.

Thixoforging is done on hydraulic forging presses. The reheated billet is taken into the opened forging die. While closing the die, the work piece is formed. thixoforging in closed dies can be realized using double action presses. The slurry is taken into the open die. After the die is closed, the work piece is formed by the press piston. On single action presses a closing tool is necessary to perform this forming variant [1–3].

In service, thixoforming dies are subjected alternately to heating and cooling. When hot metal strikes the surface of a die it expands and the cold die core is subjected to plastic compression. During cooling, the elongated surface will contract, which generates tensile stress in it. This gives rise to severe strains in the surface layer of the material, gradually leading to thermal fatigue cracks. Cracking occurs when the die surface is under tensile stress in the shot cycle, i.e. during the cooling phase at the low temperature end. Can result in a pattern of surface cracks and this often called "heat checking". This is a common cause of die failure.

Surfaces of the thixoforming dies are subjected to very severe conditions of cyclical thermal and mechanical load, and chemical and mechanical wear. It is conceivable that appropriate surface treatments and coatings have a favourable influence on the temperature performance of the surface of the die [4,5].

Plasma spraying of ceramic zirconia-based particles was studied for possible use as a die coating for light alloys such as aluminium. Zirconia-based plasma sprayed coatings showed high wear resistance and good heat transfer resistance and would, therefore, provide improved die coating [6]. The thermal fatigue resistance of the tool steel had an improvement of 33% using plasma spraying [7].

After deposition, residual stresses are present in the top coat owing to quenching and secondary cooling effects. When the coat is heat treated (isothermally or cyclically) the as-sprayed stress state can be completely altered. The alteration is due to relaxation at high temperature or stress during cooling (This

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cooling is result of either different thermal expansion between substrate and ceramic). It is often reported that the residual stress state after spraying is an important parameter for the life and adhesion of zirconia based thermal barrier coating (TBC) [8].

The failure mechanisms that cause coating spallation are bond coat oxidation, hot corrosion, thermal cycling and mechanical loading. There have been several attempts to solve these problems by sealing the zirconia based thermal barrier coating. Sealing of open porosity in TBC coating can be done by liquid metal impregnation (1), laser glazing (2), hot isostatic pressing (HIP) (3), sol–gel process or by thin chemical vapour deposition (CVD) coatings [9]. The heat treatment of small defects in the coatings by these treatment leads to an increase in the coating modulus and enhances the hardness and density [10].

Best fatigue characteristics were defined as compressive residual stresses in the coating [11]. Several new strategies have been developed for the introduction of compressive stresses at the surfaces of coatings. These include temperature control of the substrate during plasma-spray, which can result in different levels of compressive stresses in the outer coating.

The objective of this study was to study the influence of hot isostatic pressing on the thermal fatigue resistance of plasma spray coating system.

2. Experimental work

2.1. Coating production

Hot working steel H11 (1.2343) samples were first sandblasted using a grain size of 710–850 μm (F24) and then coated, using Atmospheric Plasma Spray gun (Plasma-Technik PT-F4 , Sulzer Metco AG).

Plasma spraying was carried out using commercial powders as indicated in Table 1.

2.2. Coating characterisation

Phase identification was performed at room temperature according to: ASTM E 1920-03 using a CuKα X-ray diffractometer (Seifert HT-X-ray Diffraction System).

The coatings' microstructure was examined at the cross-section of the samples after vacuum embedding in cold hardening resin. Samples were ground and polished for optical microscopic research.

2.3. Hot isostatic pressing (HIP)

HIP treatment was performed at 1100 °C at a pressure of 100 MPa for 6 h using argon gas, heating in 3 h and slow cooling to room temperature.

Table 1
Powders for plasma spraying

Coat type	Material	Powder reference	Size range (μm)
Bond coat	Ni5Mo5Al	Metco 447NS	−90+45
Top coat	ZrO_2+24 wt.% MgO	Metco 210NS-1-G	−75+11

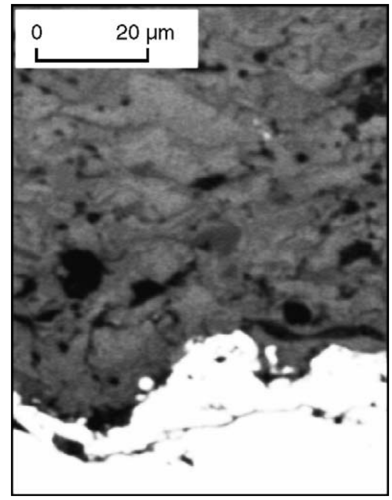

Fig. 1. Microstructure of plasma sprayed $Mg_2Zr_5O_{12}$ coating.

2.4. Thermal cycling test

To evaluate thermal shock resistance of the coatings, samples were exposed to thermal cycling. During the thermal shock cycle, the sample was heated to 1000 °C within 4 min in air. Cooling the samples with a compressed air jet (2 bar) for 30 s leads to a temperature of 200 °C. This routine was repeated until first signs of spallation occurred. For each sample 1000 thermal cycling tests were performed to evaluate the thermo-mechanical resistance of the coatings. During the thermo-mechanical cycle, the sample was heated up to 1200 °C in 5 s under pressure of 78 MPa followed by cooling in nitrogen atmosphere in 10 s.

2.5. Nanoindentation

The Nanoindenter XP instrument used in this study was manufactured by MTS Systems Corporation and is equipped with a Berkovich diamond indenter. The system acquires load and displacement data continuously during indentation, and the

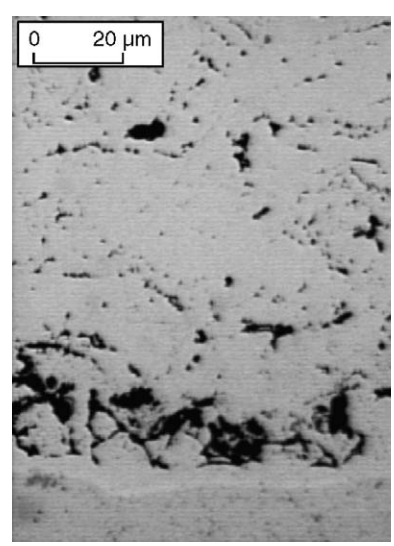

Fig. 2. Microstructure of HIP'ed plasma sprayed $Mg_2Zr_5O_{12}$ coating.