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Mechanical Properties Investigation of Thermally Sprayed Ceramic Coatings

A Thesis

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By

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CHAPTER ONE

INTRODUCTION

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1.1 Background

The coating may be defined as a near surface region with properties different from the bulk material that deposited on it. Thus , the material system (coating and substrate) form a composite where one set of properties is obtained from the bulk substrate and another from the coating itself. [1] .

Ceramic coatings have been extensively employed in the surface modification field during the last decades due to their excellent properties [2]. The coating of metal surfaces with a thin ceramic layer has always been a useful means to enhance the mechanical performance of metallic substrates [3]. Ceramic coatings are mainly used for the protection of base alloys against hot corrosion and oxidation. Another function of ceramic coatings is to reduce the base metal temperature in the case of thermal barrier coatings [4]**.** Ceramic coatings have already proved to be good candidates for resistance against wear and corrosion . Meanwhile there are several obstacles in the way of using ceramics in industry that may limit the usage of these engineering materials. Finding a solution for these problems cause a huge impact on application of ceramics. These problems are usually rooted in the mechanical properties of ceramics. In general, ceramics tend to be very hard and stable in combating wear and corrosion. But, they usually present very low toughness values and they are generally brittle. The brittleness of ceramics sometimes prevents them from being used as engineering materials in places where plastic or severe elastic deformation is present. Recently thermally sprayed ceramic composite coatings fabricated from nanostructured powder particles have shown improved mechanical properties compared to coatings fabricated from conventional powders . Their plastic deformation, crack propagation resistance and toughness are also shown to be superior in comparison to the other counterparts. Therefore, this new kind of ceramics could be more effective when used as coating materials on the parts exposed to severe wear conditions**)**[5].

Thermal spraying materials are being developed for engineering applications for their good mechanical properties at high temperature. The most important approach to this application involves deposition of thermal insulating ceramic onto a metallic substrate. The coating processes of metallic or non- metallic material onto a prepared substrate by thermal spraying should form a thickness greater than about 50μm [6].Thermally sprayed materials consist of a number of forms, such as powders, rods, wires, etc... . Thermal spraying method used in aerospace industry for applying thermal barriers and wear resistance coatings. It offers a solution for different engineering and maintenance tasks. Uses of thermal processes and materials are expanding to include hundreds of coatings that meet the strict performance standards of the automotive, biomedical, turbo machining and general industries.

The flame spray process exhibits density, hardness and bond strength coating characteristics that can significantly improve operating components. This is due to flame spray properties including operating at elevated temperature, corrosion resistance, wear and abrasion resistance [7]**.** The sprayed material is introduced in the powder feeder via a carrier gas and is heated and accelerated simultaneously onto the substrate surface by the high temperature and high speed flame spray plume. Accordingly, spray coating rates greatly depend on gun design, spray gases, powder injection schemes, and materials properties. Also, coating properties and characteristics depend on the coating materials ,spray equipment configuration, and spray parameters(distance, powder feed rate, particle size, temperature substrate, acetylene and oxygen pressure) [8].

In recent years, indentation/scratch technique has been widely used to study the fracture behavior of ceramic coatings. Indentation technique, historically employed as a testing method of hardness, has been employed in the study of the mechanical properties of brittle materials [9]. For example, indentation is used to evaluate fracture toughness through crack length measurement. The particular attraction of this technique lies in its unique simplicity as a nondestructive means for producing regions of high stress intensity in a specimen. Attempts have been made to determine the fracture toughness of coatings and the coating-substrate interface strength via indentation [10]. For example, coating fracture toughness, as an important parameter in cavitation erosion resistance of a thermally sprayed coating, was determined through Vickers indentation [11], the using of indentation technique depth as a measure of the actual resistance of the coating to deformation in determination of the coating fracture toughness was made [12]. A lateral force-sensing microindentation technique was developed for determination of the interface bonding strength of coatings[13].

Residual stresses are known to play an important role in coating durability; for example, tensile residual stresses typically increase the susceptibility to cracking and deboning. Many studies have been devoted to the measurement of residual stresses in coatings [14].

Residual stresses develop during cooling of a thermally sprayed coating due to the mismatch of thermal expansion coefficients of the coating and substrate. Depending on the relative magnitudes of the thermal expansion coefficients of the coating and substrate residual stress can be either tensile or compressive [15]**.** Parameters that strongly affect the magnitude of residual stresses in coating and substrate are temperature during spray deposition and properties of the coating such as thickness, roughness, and porosity. X-ray diffraction (XRD) technique was used to study the stress in coating layer. This technique is non-destructive, and therefore allows to monitor the evolution of the stress with thermal exposure time[16]**.** In this method, a phase-specific diffraction peak position, corresponding to a lattice plane spacing d, is determined as a function of Ψ tilt angle, defined relative to the surface normal to the sample. Shifts in d-spacing vs Ψ correlate with internal strains in the coating. Owing to the reflection geometry, the technique only probes the near surface of the coating to the penetration depth of the X-rays, which is typically in the several micrometers range [17].

1.2 Thesis Outline

The present study consists of six chapters as described below:

Chapter 1: This chapter includes a general introduction about the mechanical properties (hardness, fracture toughness and residual stresses) of composite ceramic coatings, research objective, and thesis outline.

Chapter 2: This chapter introduces an overview of previous studies about the mechanical properties (hardness, fracture toughness and residual stresses) of composite ceramic coatings.

Chapter 3: This chapter describes coatings, and thermal spraying coating techniques.

Chapter 4: This chapter describes experimental work and equipment that have been used.

Chapter 5: This chapter deals with the results obtained as well as results discussion in a highly.

Chapter 6: This chapter addresses the most important conclusions, recommendations .

1.3 Aims of the Study

The main aims of this study are:

1-Synthesis of composite hybrid ceramic coatings.

2-Determine the best of fracture toughness of composite ceramic coatings using indentation Vickers hardness technique.

3-Determine the type and quantity of residual stresses of composite ceramic coating using X-Ray diffraction technique .

4-Determine the best of Young's Modulus by using ultrasonic wave technique .

ABSTRACT

Flame Spraying (FS) technique has been widely adopted in many industries such as aerospace industries, automobile industries, aircraft industries,…etc., due to its flexibility, and cost effectiveness in producing superior quality of coatings. Also this technique utilized to apply coatings on the components to protect them against wear, heat and corrosion. The present work aims to evaluating of the mechanical properties (hardness, fracture toughness, residual stresses and young modulus) of hybrid ceramic coatings (ZrO_2 , (ZrO_2+ 15,20 wt%MgO) (ZrO_2 + 40, 80 wt% Al_2O_3), (Al_2O_3+13,40 wt%TiO_2), (Al_2O_3, +25 wt%SiC), SiC, (Al_2O_3, +18 wt%ZrO_2 + 10 wt% SiC)) synthesized by flame spraying coating technique on plain carbon steel (1015) substrate. The hardness are determined by Vickers hardness as an experimentally method, the higher value of the Vickers hardness is 1773 HV of the SiC ceramic coating compared with other ceramic coating. Fracture toughness measurement by Vickers indentation method, the fracture toughness increases from 0.829Mpa√m of (Al_2O_3+20%wt ZrO_2) to a maximum value 1.99MPa√m of (Al_2O_3+40wt% TiO_2) .while the residual stresses are determined by X-Ray diffraction technique, ,the higher value of the compressive residual stresses is -420.974Mpa in the (Al_2O_3, +20% ZrO2) ceramic composite coating. The young modulus is evaluated by Ultrasonic wave technique, the best value is 262Gpa of the (80% ZrO_2 +20 wt%MgO) at stressed coating state while unstressed state best value is 270Gpa of the (ZrO_{2+} 40 wt%Al_2O_3).Optical microscope , scanning electron microscope (SEM) and Energy dispersive spectroscopy (EDS) were used to investigate microstructure , surface characteristic and chemical elements. The phase structure of the composite ceramic coating layers is conducted using X-Ray

diffraction technique (XRD) . The X-Ray results showed m-ZrO_2 and c-ZrO_2 as the prominent phase in pure ZrO_2 ceramic coating , so in pure SiC ceramic coating is α-SiC, while in composite ceramic coating (Al_2O_3, - 25 wt% SiC) α-Al_2O_3 , Ɵ- Al_2O & α-SiC, and cubic for magnesia, tetragonal and monoclinic zirconia for (ZrO_2 + 15,20 wt%MgO) also (Al_2O_3,+13,40 wt% TiO2) α -Al_2O_3, & t-TiO2,while α -Al_2O_3, m-ZrO_2 & α-SiC for (Al_2O_3+18 ZrO_2 +10 wt% SiC)and α Al_2O_3,&m-ZrO_2 for (ZrO_2+40wt%Al_2O_3), and α-Al_2O_3,& m-ZrO_2 for (Al_2O_3+20 wt% ZrO_2).The thickness of the sprayed composite coating were from 200 μm to 260 μm for bond coat and 400 μm to 667 μm for top coat coating layer respectively. The best surface characteristics were for ZrO_2 ceramic composite coating layers less surface roughness 5.654µm while low porosity percentage is 6.107% for advanced composite ceramic coating (ZrO_2 + 20 wt%MgO).