Effect of Thermally Sprayed Ceramic Coating on Properties of Low Alloy Steel

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ABSTRACT

Thermal spraying technique was employed for coating low alloy steel specimens that have been used in a derrick oil well frames.

Two types of ceramic materials were used as a coating material and two groups of steel samples were prepared for coating process.

The first group was coated by zirconia while the second group was coated by alumina. Ni-Al composite powder was used forbonding the coating material on the substrate surface of the steel specimens.

The hardness, adhesion strength of the coating layers as well as wear rateswere studied for the two steel group samples and compared with as received steel.

The results showed an increase in the mechanical properties with a decrease in wear rate values for coated samples as compared to those of uncoated samples.

Keywords: thermal spraying, low alloy steel, zirconia, alumina, wear rate, hardness.

تأثير طلاء الرش الحراري السيراميكي على خواص الفولاذ منحفض السبائكيه

الخلاصه:

أستخدمت تقنية الرش الحراري لغرض طلاء نماذج من سبائك الفولاذ منحفض السبائكيه والتي تستخدم في برج حفر الابار النفطيه والغازيه . أستخدم نوعين من المواد السيراميكيه كماده طلاء لمجموعتين من نماذج الفولاذ منخفض السبائكيه . حيث كانت الاولى زركونيا والثانيه الالومينا كذلك أستخدم مسحوق متراكب من النيكل- الالمنيوم كماده رابطه. تم دراسه الصلاده ومتانه الالتصاق لطبقات الطلاء بالاضافه الى معدل البلى للمجموعتين ومقارنتها مع النماذج الغير مطليه. أظهرت النتائج زياده في الخواص الميكانيكيه ونقصان بقيم معدل البلى للنماذج المطليه مقارنة مع النماذج غيرالمطلية.

INTRODUCTION

Steel oil derricks are to be found today in all the important oil and gas fields of the world. It is necessary that a derrick should be able to be kept in use for a long period of time without frequent shutdowns for repairs; that is, their rate of deterioration must be slow. Because of the nature of the materials of which they are constructed, they do not rot in the humid, swampy districts in which they are frequently erected[1, 2].Steel alloy alone would corrode under such conditions, it should be protected by such coating materials [3].Coating is layer that is applied to the surface of material or component, usually referred to as substrate, which improve its surface properties such as wear resistance, corrosion resistance and friction coefficient etc. There are many coating technologies like plasma spraying, flame spraying, electric arc spraying and flame spraying with powders. Flame spraying with powder is the famous and easer due to its low cost and simple spraying parts [4]. To prevent the steel alloys from corrosion, ceramic coating materials are used such zirconia which is widely used as a thermal coating due to its strength, toughness, wear, density, high hardness and thermal properties. Also alumina is used as a good coating material [5,6].Polonsky et al.[7] showed that the coating thickness which is important in connection with residual stress has to be well optimized low thickness has no significant effect on fatigue properties whilst a too thick layer deteriorates them. Almdeny[8] confirmed that the spray distance is one of the most important factors that must be tuned to control the resulting porous coating, and found that the increased spray distance leads to an increase in the proportion of coatings.

Satapathy[9]found that the use of plasma spraying on the surface of (Al, Cu, mild steel, stainless steel) with a red mud, makes the coatings possess good adhesion strength, hardness with reasonable porosity, erosion wear .Sahab[10]showed that the high temperature of flame permit ceramic materials such as Al_2O_3 powder to be melted and sprayed toward substrate in producing a coating. Ammar et al.[11]studied the effect of flame spray parameters(distance, roughness, temperature of substrate, thickness) on wear rate and found that the best distance is (150-200)mm, substrate temperature (200-300)°C, and thickness(0.15-0.5)mm gavethe lower rate of wear and the highest adhesion. Liu et al.[12] showed that the adding appropriate amount of nano WC-12Co is believed to be the reason for more wear and erosion resistance. This confirmed that this addition can greatly improve the performance of WC-10Co-4Cr sprayed coatings. Michaela et al [13]found that adhesive-cohesive strength influences (melting and localized alloying of the contact surfaces between particles and between the substrate and adjoining particles, and the coating adhesive-cohesive behavior depends on two spray parameters: the flame temperature and particles kinetic energy by using high velocity oxy-fuel (HVOF) and Flame spray. Lampke et al. [14]found that thermally sprayed (flame spray, arc spraying, plasma-electrolytic) of alumina coatings are widely used in a range of industrial applications to improve wear and erosion resistance, corrosion protection and thermal insulation of metallic surfaces. They found that the created Al_2O_3 layers show outstanding hardness up to 1600 HV0.1, good bonding strength and excellent abrasion resistance as compared to atmospheric plasma-sprayed Al_2O_3-coatings. The results showed the superior performance of coatings and demonstrate their applicability for technical components in extreme operating conditions. Hot corrosion resistance of

stainless steel has been studied on the base of the degradation rate and corrosive layer thickness by Hibibi et al. [15]. They concluded that at 1050°C temperature abetter corrosion resistance was obtained.
Yaping Ye et al.[16]found that the ceramic top coat isdensified by the precipitated zirconia in the open pores. Therefore, the sealed YSZ coatings exhibit reduced porosity, higher hardness and a better adhesion onto the bond coat.
This work aims to evaluate the hardness, wear resistance and adhesion strength of zirconia and alumina coated low alloy steel.

Experimental part
Low alloy steel has been used as substrate material, its chemical composition is listed in table 1.

Table(1)Chemical composition of low alloy steel.

Element	C	Si	S	Mg	p	Fe
Wt%	0.24	0.55	0.03	1.6	0.03	balance

ZrO_2powder which has apartially stabilization by Y_2O_3 of 0.365 µm particle size and Al_2O_3 Alpha (α) powder of 43 µm particle size were used as coating materials. Aluminum-Nickel powder of 70 µm average particle size was used as a binding material with 93% Ni and 7% Al. Before coating process two groups of specimens were prepared by sand blasting using silicon carbide grits of 1.18 mm in sized, they were then cleaned by trichloroethylene. The specimens of the two groups were preheated to a temperature of 200°C by oxy-acetylene flame, then sprayed by Ni-Al bonding material. The first groupof the specimens were coated by Alumina at a temperature of 1000°C, while the second group were coated by Zirconia at 1300°C by using oxy-acetylene flame spraying system in Fig. 1. Fig. 2 shows the microstructure of Alumina and Zirconia.

Figure.(1) Spraying system.

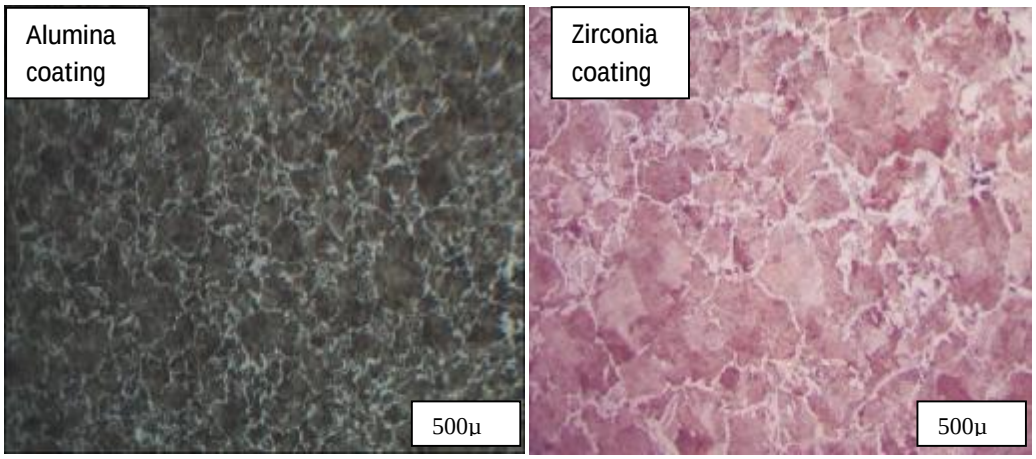

Figure.(2) Optical micrographs of coating samples.

The two groups of coated specimens were tested for hardness, adhesion strength of the coating layers as well as wear rates and compared with as received steel specimens. Wear tests were performed by sliding the specimens against a tool steel rotating disc of 38 Hvunder 3.5 Kg load and 1200 Cm/min sliding distance. The specimens were weight before and after each test and loss was recorded. Fig. 3 shows the wear machine.

Figure. (3) Wear machine.

Wear rates were calculated according the following equation:

$$\textbf{wear rate} = \frac{\Delta W}{S.D}(\text{gm/mm})$$

Where:

ΔW = weight loss

S.D= Sliding distance.

The adhesion strength of the coating layers on the specimen surfaces were tested by using tensile testing machine until the fracture

Inhardness tests, load applied is (9.8KN), during a test, the load is maintained constant for time (15 Sec).

Results and Discussion

1- Hardness Testing Results: Fig. 4 shows the hardness results of the as received steel samples and samples that have been coated by alumina and zirconia.The figure revealsa significant increase in the hardness of both steel samples that have been coated by alumina and zirconia as compared to as received samples.

The maximum hardness observedfor steel coated by zirconia is 198 HB while the hardness value of steel coated by alumina is 180 HB. It is clear from the figure that the hardness of steel samples that have been coated by alumina is increased by 6% as compared with as received steel, while those samples coated by zirconia was increased by 16%.

The higher hardness value shown for steel coated by zirconia is due to the particle size of zirconia as well as the higher toughness of ZrO_2 ceramics. It can be explained due to ZrO_2 composition which consists of three polymorphism phases; tetragonal, monoclinic and cubic phase. At high temperature the tetragonal phase transforms to monoclinic, and that phase transformation is a compiled by a volume increase of about 6%. That increase in volume led to toughening the coated steel and prevents microcracksformation [17, 18].

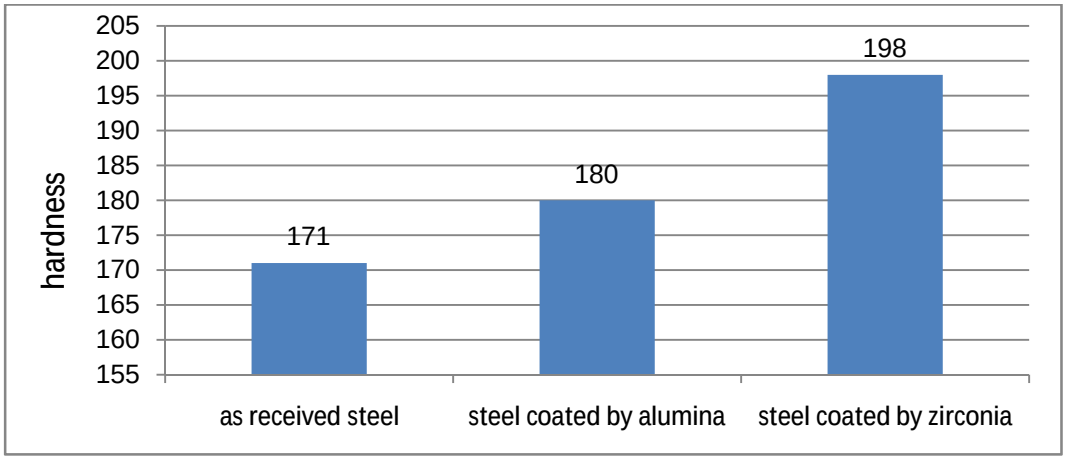

Figure.(4) hardness of as received steel and coating samples.

2- Wear Test Results:

Fig. 5 shows the wear rate of all samples including the as received steel. The comparative wear rate for the as received steel is higher than both steel samples that have been coated by alumina and zirconia, so the coatings improve the wear resistance

especially for zirconia coating which has the lowest wear rate and that may be due to the smallest particle size ofzirconia. In another way the ceramic materials always have a good wear resistance than the metals. The analysis of the factors that affect the wear behavior were complex, since the wear resistance is not a material property but it depends upon mechanical performance and operating parameters such asload , sliding velocity and temperature. The main relevant mechanical properties which affect the wear resistance are, fracture toughness, hardness and Young's modulus, because a fraction of the input energy is dissipated through frictional heating , properties like the specific heat and the thermal conductivity must be included in the analysis. The explanation may be that the sliding of abrasives on a solid surface results in volume removed, and wear mechanism depends on the hardness of the composite component which is a key parameter in governing the amount of material removal, so that the presence of the hard coating increases the effective hardness of the composite which act to reduce the amount of material removal which means to decreased the wear rate [19].

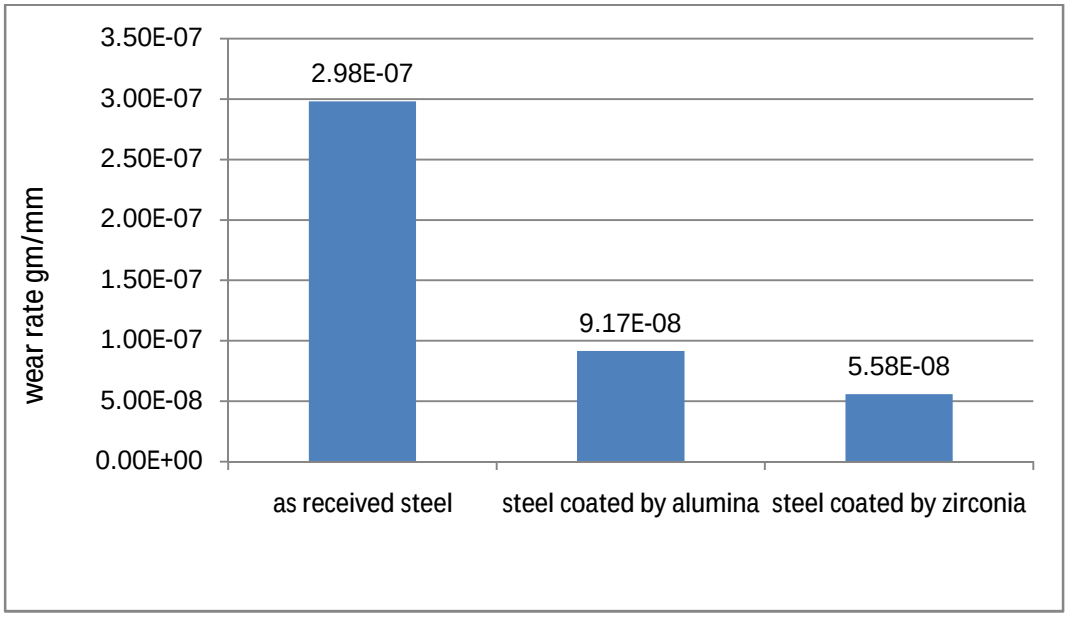

Figure.(5) Wear rates of as received steeland coating samples.

Adhesion Test Results:

Fig. 6 shows the adhesion strength for the coated sample.The tension load was applied on the adhesive sample using rate of (1mm/min) until the failure of the specimen. Actually the values shown in fig.7are not the true values of removing the ceramic coating from the substrate, but they are for strength of peeling the epoxy only. So the strength of peeling is much higher than these numbers and that may be due to good adhesion between the coating layer and substrate while has a good roughness before coating. Also

the heating of the substrate to about 200°C before coating increased coating interlocking with surface.

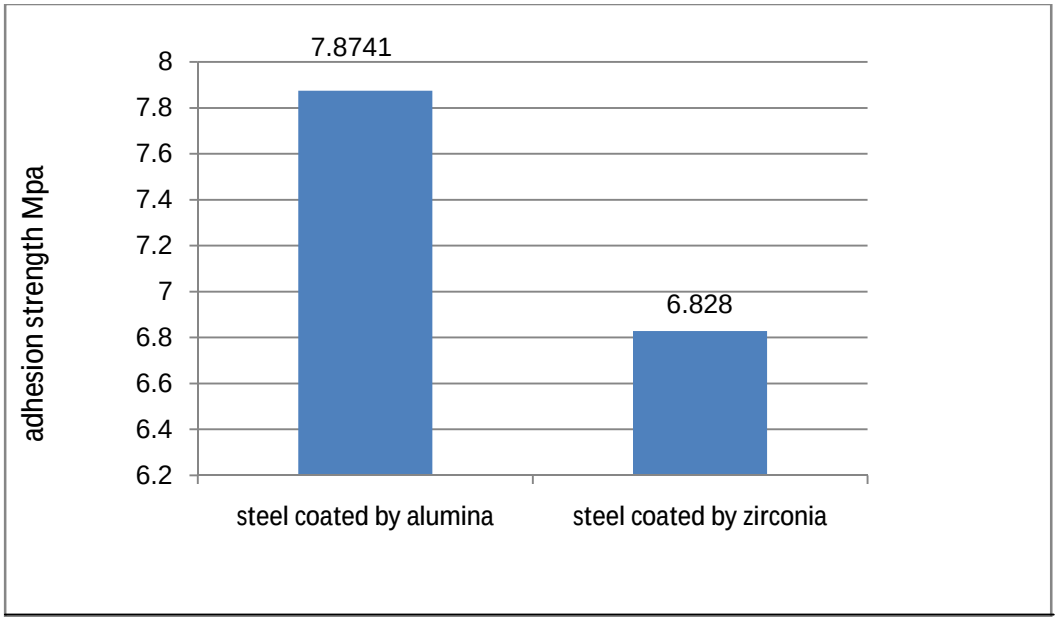

Figure. (6) Adhesion strength for both steel samples coated by alumina and zirconia.

CONCLUSIONS

For the results above the following remarks can be concluded:

1- The ceramic coating for both alumina and zirconia produced by thermal spraying technique has influence on the properties of derrick material.

2- Agood adhesion between ceramic coating and substrate was due to using Ni-Al binder in this technique of spraying.

3- Hardness of both ceramic coatingsalumina and zirconia sampleswas improved as compared to as received steel samples.

4- The comparative wear rate of the as received steel sample is higher than the steel coated samples; this means that coating improves the wear resistance.

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