Study the Properties of Two Pieces Welded After Ceramic Coating By Air Spray Coating Method

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Abstract: Surface coatings offer a wide range of purposes to get good properties of the components. There are more applications of surface coatings in different industries to improve the properties of substrate such as sports technology, automotive industries, chemical and petroleum, physical and electronic, decorative coating and thermal barrier coatings meter. Recently, surface coatings have been developed progressively in some specialized parts to enhance wear resistance and reduce diffusion and friction. In this study three samples were prepared by covering two welded pieces of low carbon steel with the ceramic material (mullite powder (3Al_{2}O_{3}.2SiO_{2}) for the ratio of (0\% as a control, 5\%, 10\%) and by adding varnish and thinner that were used as a binder material for reinforcement low carbon steel in welding region. Then study different properties of coating layer such as the thickness of the coating layer, contact angle, and roughness, finally examine the hardness test, wear test and Atomic Force Microscopy.

Keywords: Ceramic Material, Mullite, Air Spray method, Coating, Low Carbon Steel.

1. Introduction
The Ceramic coatings on metallic materials have been enhanced since 1970. Metals and metallic alloys need high performance in different environments. Technology improvement to employ the ceramic coatings in various applications such as adiabatic engines, gas turbine wings, cylinder lining, valve, piston crown surface were used for ceramic coatings. Ceramic coatings used in the surface modification field due to their excellent properties, the coating of metal surfaces with a thin ceramic layer that has always been a useful method to develop the mechanical performance of the metal substrate. Moreover, ceramic coatings play a good role in the safeguard of base alloys against hot corrosion and oxidation besides minimization of wear damage [1]. Another more important function of ceramic coatings such as decreasing the temperature of the base metal in the case of thermal barrier coatings. Above all these properties, ceramic materials have many advanced properties such as heat resistance, electrical, thermal and sound insulation[2]. Mullite coatings are used to protect Si-based substrate of gas turbine engines that are considered as the main protective layers of environmental barrier coatings (EBCs). In this research, examine the powder
morphology (SEM), (XRD), and mechanical properties (hardness and elastic modulus) of mullite coatings. By conventional air plasma spray (APS) three types of mullite powders, fused and crushed, spray dried and spray-dried flame-spheroid zed were deposited. Temperature and velocity for all these systems were measured. According to powder morphology coating crystallinity, microstructures and mechanical properties can be changed [3]. Mullite coating was used to cover steel substrates by plasma sprayed. In this study investigation the dry sliding as well as water and hydrochloric acid solution to determine the microstructure of multi coating and its tribological properties coupled with Si3N4 ball. The results show that mullite coating exhibits a high porosity and keeps an amorphous phase. The mullite coating-Si3N4 decrease coefficient of friction under HCl solution. At last the mullite coating has the maximum specific wear rate under water environment [4].

The aim of present research is to protection welded low carbon steel specimens by ceramic coatings with the air spray coating method.

2. Experimental Work

2.1. Material

2.1.1. Metal Substrate

The substrate (low carbon steel) used for applying the protective coating by air spray method. The chemical composition of the substrate material is presented in the Table 1 which examination in general company of the automotive industry.

| C%  | Si%  | Mn%  | Cr%  | MO%  | Ni%  |
|-----|------|------|------|------|------|
| 0.2 | 0.17 | 0.53 | 0.04 | 0.03 | 0.03 |

A microscopy test was conducted to determine the nature of the steel surface in welding region using an optical microscope type (BULB TYPE-Fuse 250V 3AF). Equipped with a digital camera connected to the computer through which to take pictures of the surface and strongly enlarge (200X) and after viewing them on the computer screen.

The process of sample preparation was carried out by smoothing process silicon carbide soften paper to its softness (220, 320, 400, 800, 1000, 2000), as well as the process of polishing using the paste of the diamond and after end of each stage of smoothing and polishing, wash the sample and dry with hot air. The Figure 1 shown the microstructure of low carbon steel in welding region.

![Figure 1. Microstructure of Low Carbon Steel in Welding Region](image)
2.1.2. Mullite

Mullite powder (3Al₂O₃·2SiO₂) was used with particles size about (65µ) and with purity (99.9%). Also the particle shape is dendritic as reinforcing material in protection coating by air-spray method. The Figure 2 shown particle shape of mulitte powder.

![Figure 2. Particle Shape of Mullite Powder](image)

X-Ray diffraction was used to characterize mullite by (XRD) type (Shimadzo, XRD6000, diffract meter, was conducted in Babylon University / College of Materials Engineering / Department of Ceramics Engineering and Building Materials Laboratories, Japan: X-Ray are generated using copper (Cu-K) radiation at 30KV, 40 mA and wave length λ=1.5406Å), radiation generating pattern of diffractions from a powder sample at room temperature in 2θ ranges of 20° to 80°. Figure 3 shown X-Ray diffraction of mullite powder.

![Figure 3. X-Ray Diffraction of Mullite Powder](image)

2.1.3. Binder Materials

Varnish was used with the solvent thinner and paint in the protective coating by air-spray method, so as to binder the particles of materials which used in reinforcement low carbon steel in welding region.
3. Welding Process
Welding was done on (Butt Joints) from low carbon steel with thickness (6mm). The distance between joints (3mm). Welding was done from both sides for the penetration of the welding material by Arc-welding.

4. Coating

4.1. Solution Coating Preparation
To prepare the coating solution used in the protection of low carbon steel in the welding region by using an air-spray gun method, it was using paint, varnish and thinner that were used as a binder material. And then adding reinforcement material by mixing all for the purpose of homogeneity. Table 2 shown the ratio of solution coating preparation.

| Mullite % | Thinner % | Paint % | Verinsh % |
|-----------|-----------|---------|-----------|
| 0         | 10        | 45      | 45        |
| 5         | 10        | 40      | 45        |
| 10        | 10        | 35      | 45        |

The substance of the paint is also known as the liquid substance, thick textures. It work to increase the spread process of mullit particles when mixing and prevents its deposition at the bottom. The varnish and thinner are materials that help to stick the mixture to the surface of the metal before starting for spraying process, the surface of the sample was cleaned to remove impurities which can work the difficulty of sticking the mixture on the surface then coating low carbon steel in welding region.

5. Testing

5.1. Contact Angle Measurement
After the coating process has been done in the welding region by using an air-spray method. This test was to know the effect of contact angle and wettability for the coating sample according to proven ratios that done in Materials engineering college, ceramic and building materials department laboratories. The device that used in this test is Optical Contact Angle Meter / Interfacial Tensiometer, model SL200KS. Has been done contact angle measurement to know the effect of contact angle and wettability for the coating sample according to proven ratios.

5.2. Atomic Force Microscopy (AFM) Test
Atomic force microscopy has been done to know the roughness of the surface for coating sample according to proven ratios, it was conducted by using the device (AA 3000 Scanning Probe Microscope, Contact Mode, Angstrom Advanced Inc.)

5.3. Hardness Testing
Hardness test was conducted by using a Vickers hardness method, Vickers devicetype (HVS-1000 China) that was carried at Babylon University- Collage of materials engineering / department of ceramic and building materials department laboratories. The load was used (100g) and time (15sec). The reading diameter rate was taken for each sample. The following law was adopted to calculate the Vickers hardness [5].

\[HV = 1.8544 \times \frac{P}{D_{average}^2}\] (1)
Where:
HV: Vickers hardness.
P: applied force (Kg/mm).
D: average diameter (µm)

5.4. Wear Test

A wear test for low carbon steel in the welding region was conducted by using a wear test device type (Spanish, mode (28021) that was conducted by the Department of Metallurgical Engineering Laboratories / College of materials Engineering / Babylon University. And the preparation of samples with the required dimension and applied loads of (5N) at time (5 min) to study the loss of weight. The weight method was used to calculate the weight of the sample after coating by air-spray method with a sensitive balance type (Germany-Acculab-Sartorius group, ATL-224-I).

6. Result and Discussions

6.1. Coating Thickness Measurement

Coating thickness measurement for low carbon steel in the welding region after protection coating by air spray method was conducted by using coating thickness measurement device to know the thickness of the coating layer that the Table3 shows values of coating thickness with different ratios of mullite.

The sample reinforcement with (5%mullite) showed best coating thickness compare to the other samples, because of the main interconnection between coating layer and the substrate. It has been shown that good adhesion between coating layer and substrate give good mechanical properties with good cohesion particals, while the less cohesion between particles, decrease mechanical properties. An abnormal increase in thickness makes an interconnection weakens, so must be controlled on the coating thickness. The Figure 4 shows the thickness of coating for reinforced samples.

| No. | Ratio of Mullite % | Coating Thickness (µm) |
|-----|-------------------|------------------------|
| 1.  | 0                 | 146                    |
| 2.  | 5                 | 119                    |
| 3.  | 10                | 127                    |
6.2. Contact Angle Measurement

One of the application of contact angle measurement is to characterize the wetting properties of surfaces. Wetting is a property which describes how much a liquid spreads across the surface and the contact angle decrease, wetting increase.

The contact angle of samples coated reinforcement with (0, 5\% mullite, 10\% mullite) are (80.89°, 111.82°, 100.71°) respectively. The contact angle decreased due to the increasing of roughness of coating materials on the substrate and the increasing of the adhesion strength [6] as shown in Figure 5 and Figure 6.

![Figure 5. Contact Angle of Air Spray Coating](image)

(A)  (B)  (C)

**Figure 6.** Photograph Contact Angle of Air Spray Coating  
A: 0, B: 10\% Mullite, C: 5\% Mullite
6.3. Atomic Force Microscopy

The roughness average of the coated sample reinforced with (5% Mullite) lower than the roughness average of the sample coated with (10% Mullite, 0mullite) respectively. The surface roughness test results are shown Table 4 and Figure 7 which that indicate coated samples have significantly lower surface roughness than coated sample (0). The adding particle filler which tends to occupy the voids in thin film coating and serve as the bridges interconnected the matrix[6].

**Table 4.** Roughness Average of Air Spray Coating

| No. | Ratio of Mullite % | Roughness Average(nm) |
|-----|--------------------|------------------------|
| 1.  | 0                  | 10.4                   |
| 2.  | 5                  | 2.17                   |
| 3.  | 10                 | 4.75                   |
6.4. Hardness Test

The hardness test was done to show the effect of coating on the hardness values for welding low carbon steel and the Table 5 shows the results of the hardness test for reinforced samples with coating materials by air spray coating.

The sample coated reinforcement with (10% mullite) showed an increase in hardness because the materials hardness affected clearly by the size of the particles, where the coating with fine particles is distinguished with value of hardness is higher compared with the rough particles also the coated sample with reinforced with (5% mullite) has increase in hardness compared with coated sample (0) also the homogeneity is important because the aggregation of particles lead to the decrease of hardness. Figure 8 shows the results of hardness test.

Table 5. Hardness Test of Air Spray Coating

| No. | Ratio of Mullite % | Hardness Test (Kg/mm²) |
|-----|--------------------|------------------------|
| 1   | 0                  | 1.9                    |
| 2   | 5                  | 2.5                    |
| 3   | 10                 | 3.2                    |
6.5. Wear Test

Welded low carbon steel has a little resistance to wear with exposure time to friction surface so we go to different ways to improve its wear resistance, where we notice an improvement to resist the wear of reinforced welded steel and the Table 6 shows the results of loss weight for reinforced samples with coating materials.

The obvious improvement is to resist wear for the reinforced sample with (10% mullite) because the material mullite is resistant to wear also due to good adhesion to the coating layer with substrate and also due to the small size of the particles, when exposed to the friction surface separate small parts of coating layer with exposure time to friction. Figure 9 shows results of loss weight for samples.

| Table 6. Loss Weight of Air Spray Coating of Reinforced Samples |
|---------------------------------------------------------------|
| **Air spray coating** | **Ratio of mullite %** | **Loss weight (gm)** |
|----------------------|-------------------------|---------------------|
| 1                    | 0                       | 0.0184              |
| 2                    | 5                       | 0.0095              |
| 3                    | 10                      | 0.0019              |

Figure 8. Hardness Test of Air Spray Coating

Figure 9. Loss Weight for Reinforced Samples
7. Conclusion
More properties have been investigated such as coating thickness, contact angle, roughness, hardness and wear:

1. The sample reinforcement with (5% mullite) showed best thickness coating than other samples.
2. Also, the same sample that reinforcement with (5% mullite) has good contact angle compared to others.
3. The roughness average of coated sample reinforced with (5% mullite) is about half a value lower than other samples.
4. Other properties such as hardness and wear have been investigated. The sample coated reinforcement with (10% mullite) showed an increase in hardness compared with other samples.
5. The obvious improvement is to resist wear for the reinforced sample with (10% mullite) compared to other samples.

8. References
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