Influence of Organic Composite Material for Coating Application: A Review

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Abstract. Composite materials have been used to coat products and substrates in different industries like Aerospace industry, Automobile industry; welding industry etc. The aim of this review is to describe the impacts and the effects of composite materials on coating applications in different industries. The first application mentioned was in the Aeronautic Industry, where powder (a composite material) is used to coat substrates. It has been studied and widely accepted as one of the most environmental friendly, economically beneficial and functional coating material. New types of powder coating are being developed to improve the aesthetic designs of Aeronautic and Automotive industries products. The second application was in the welding industry and its impacts on the electrode tool life was studied. The tool life is improved by 71% when TiC composite is used to coat the electrode.

Keywords: Composite Materials, Matrix Phase, Reinforcement’s Phase, Particulate, Fiber, Coating, Composite Coating, Nugget Diameter, Peel Force.

1. Introduction

When two or more materials are merged together to make a material that has better properties than the individual materials, the formed material is called a composite material [1]. The produced composite materials have more quality than the constituent materials in terms of its structural characteristics [2]. Composite materials are applied in sectors like Aerospace, Naval Constructions etc. [3]. They have been in use since 1984 according to Lukez Rudy in all some industries; for example, in the space industry [4]. Fiber composites are usually more efficient than other materials and has more beneficial to the environment thereby making it one of the most used material in the Aerospace industry[5]. According to corrosionpedia, composite coating is also the merging of different substances (2 or more) that provide protection against corrosion. The biggest merit of composite materials is their lightness and strength [6]. It is among the most used type of coating in the industry. Organic coating on its own was developed to reduce environmental disfigurement that occurs to industrial carriage vessels. In petrochemical industries, organic coatings were developed to shield equipment from disfigurement with the use of Epoxy, Chlorinated Rubber, and Polyvinyl Chloride etc. These protectants are used in the modern mechanized industry to prevent corrosion and to prevent the development of a cathodic reaction below the coating [7]. Generally, the advantages of composite materials include high stiffness, high strength and low density which result in lesser weight of the finished product. A matrix and a reinforcement are the two main constituents of a composite material [8].

The composite materials have different phases; the reinforcing and matrix phases. The reinforcing phase gives the composite material its stiffness and strength. The reinforcement is often in the form of a particulate or a fiber [8]. Particulate composites are usually less stiff and weaker in comparison to continuous fiber composite and also less expensive. Due to the brittleness of particulate composite, they tend to have lesser reinforcing phase. Continuous fibers usually have large aspect ratios while discontinuous fibers have short aspect ratios. The length per diameter ratio is referred to as Aspect Ratio. Due to their small diameter fibers, continuous fibers produce composites with higher strength. Generally,
the smaller the diameter of the fiber, the higher the strength of the composite as well as the flexibility and the cost. Examples of fibers composite include glass, carbon and aramid. The continuous phase is known as the matrix phase (Polymer, Ceramic, Metal). The functions of the matrix phase include; Spacing the fibers in their correct orientation, Maintaining the fibers in the correct orientation, Guarding fibers against abrasion. For example, in ceramic matrix composites, the aim is usually to improve the toughness of the ceramic instead of the stiffness [9].

Under this review, the different types of composite materials, differences between metals and composites, methods of composite coating, application of composite materials and impact of compost materials on will be discussed. The impact of tic composite coating on electrode degradation in micro resistance welding of nickel plated steel is also explained.

2. The Different Types of Composite Materials
Composite materials are of different types: Particulate composites and Continuous fiber composite. The particulate composites are the type of composite made from particles suspended in a matrix [10], while the continuous fiber composites are made from the combination of fiber reinforcements and polymer matrix [11]. By nature, the particulate composites are not very stiff but weak unlike the continuous fiber composite. The particulate composite is usually cheaper compared to the continuous fiber composite. They also have reduced reinforcing phase, the major factor responsible for the brittleness of particulate composite whereas, continuous fibers are stronger because they have large aspect ratios compared to discontinuous fibers that have short aspect ratios (Fig 2). The processes involved in the development of different composites are as shown in fig 3.
2.1. Differences Between Metals and Composites

| Alloy                                      | Composite                                      |
|--------------------------------------------|------------------------------------------------|
| An alloy is a mixture of one or more metals with other elements. | A composite is a mixture of non-metallic components |
| A metal alloy can either be a homogenous or heterogeneous mixture. | A composite is always a heterogeneous mixture. |
| Alloys are lustrous due to the presence of metals in their composition. | Composites are not lustrous as they do not contain metals in their composition. |
| Most alloys can conduct electricity.       | Composites do not conduct electricity except for polymeric composites. |
Alloys always contain a metal. Composites do not contain metals.

Table 2: Comparisons between metals and composites

| Condition                        | Comparative behavior relative to metals |
|----------------------------------|----------------------------------------|
| Load Strain relationship         | More Linear strain to failure          |
| Notch Sensitivity Static         | Greater Sensitivity                    |
| Fatigue                          | Less Sensitivity                       |
| Transverse Properties            | Weaker                                 |
| Mechanical Properties variability| Higher                                 |
| Fatigue Strength                 | Higher                                 |
| Sensitivity to hydrothermal environment | Greater               |
| Sensitivity to corrosion         | Much less                              |
| Damage growth mechanisms         | In plane delamination instead of through thickness cracks |

2.2. Methods of Composite Coating

Most engineering tools are vulnerable to stress that leads to the wearing out of the tools. One of such tools is the drill bits that wears out every time it is used for oil drilling. The surface properties that would decrease failure/wear rate can be improved via coating. The methods of coating these tools’ surfaces with composite materials include the following:

- **Composite Coating by Laser Cladding**
  Laser cladding method is remindful of the archaic welding. The method has been formed for its ability to add hard particles like Tungsten Carbide (WC), TiC, Cr₃C₂, SiC as reinforcements with high hardness and wear resistance. A Cr₃C₂-Ni/(Ni+Cr) composite coating can be developed by Laser Cladding. The hardness property is enhanced by adding Cr₃C₂ into the Ni or Ni-B, due to the total dissolving of the Cr₃C₂ particles in the matrix alloy. As more Cr₃C₂ is added into the solution/coating, the wear resistance and hardness is increased. Partial dissolution is observed in cases such as;
  - WCp/Ni-Cr-B-Si-C composite. Metastable phases could be formed on the WC particles interface. Mechanical properties may deteriorate due to these phases.
  - TiC/Ni-Cr-B-Si-C composite on steel.

- **Composite Coating by Laser Melt Injection**
  Composite coating is also prepared by Laser Melt Injection technology. In this method, the substrate’s surface would be melted using laser beam then the solid particles are transferred into the pool by inert gas. Demerits of Laser Melt Injection include;
  - Solid particles are not sufficiently wetted/damped by the alloys that are melted. Perfect dampness is necessary for autonomous immersion.
  - Another disadvantage of preparing composite coating by Laser Melt Injection are the wide differences in the density between reinforcing particles and the melted metal as well as chemical reaction that takes place at the surface of the metal.
  - The sample can also be deformed due to mechanical stresses [13]; [14].

- **Composite Coating by Brazing**
  In order to avoid mechanical stresses in the particles, researchers’ interest in composite coating by brazing is increasing. High vacuum atmosphere is used in the process of brazing and the sample is then heated up; with this method, mechanical stresses are reduced. WC or diamond
particles (high wear resistance and hardness) are used as reinforcing materials during coating. The following reinforcing pairs can be used for coating:

- WC/NiCrBSi(Co)
- WCTiC-Co/CuZnNi
- Diamond/Ni-Cr
- Diamond/Cu

[13]

✓ Composite Coating from aqueous solutions by electrochemical and electroless methods.

Wear resistance of cutting tools can be improved by Ni or Co coatings. A method of producing composite coating is via electrochemistry using aqueous solution (Table 2). Examples include the following:

- Ni/TiO2
- Ni/SiC
- Ni-W/SiC
- Ni-Co/SiC
- Ni-B/CoO2

Another method of producing composite coating is via electroless means. Examples of this coating include:

- Ni/SiC
- Co/SiC
- Ni – W – P/Al2O3
- Ni-P/Si3N4

Both electrochemical and electroless methods are methods applicable in preparation of composite coatings on tools with complicated surfaces [13]; [15].

| Types of Coating | Microhardness (VHN0.05g) |
|------------------|--------------------------|
|                  | As plated | 200°C | 400°C | 500°C | 600°C |
| Ni-W-P coating   | 578±29    | 612±16 | 1052±23 | 992±10 | 797±14 |
| Ni-W-P/Al2O3     | 581±18    | 836±47 | 1178±48 | 1227±72 | 939±42 |

[13].

✓ Protective Coating Deposition on Carbon-Carbon Composite Materials

Composite coatings can be produced as well by using chemical vapor deposition method with the aid of electrophoresis solution deposition and blend powder [16].

3. Composite Materials Application

3.1. Powder coating application in automotive and aeronautic industry

Due to regulations by Registration, Evaluation, Authorisation and Restriction of Chemicals (R.E.A.C.H), Automotive and Aeronautic Industries has to coat substrates with environmental friendly materials. A lot of experiments were made to test for the best coating materials that would be protective, functional with an excellent aesthetic design. Powder coat was tested and approved for use. This is due to the fact that, unlike other coating materials like Volatile Organic Compound (VOC), it is completely solvent free and it doesn’t affect the high performance level of the airplane and other products. It is also economically beneficial as it is one of the cheapest organic composite material.
Moreover, manufacturers are developing other kinds of powder coating that gives an overall excellent aesthetic design of the products as well as high functional performance.

### 3.2. Challenges of Powder Coating in the Industry and Alternatives to Powder Coating

Some technological limitations however, impacts the application of powder paint. These limitations include; heat sensitivity and electrical insulating substrates. Naturally, powder paints can’t be air-dried, they require high temperature curable system before the paint gets dried and achieve full film characteristics. These high cure temperatures of about 120°C affect the types of substrates that can be coated.

The nature of the substrates also affects the adhesion of process of the powder paint. Powder paints are only applied on antistatic, semi conductive, electrically conductive substrates. Since powder paints can't be naturally used to coat electrically insulating substrates, processes like plasma treatment and flame spraying, to activate the surface has to be carried out before the powder coating can be applied to improve the adhesion process. Polymer based substrates on the other hand, when powder paint is applied to coat have the following limitations; low adhesion strength and high curing temperature. It is therefore, advisable to find alternate methods of coating polymer based substrates.

The requirements for the alternatives to powder coat on electrically insulating substrates are however strict, thereby making the limitations more challenging. The aim is to develop a powder coat that would be suitable for application on electrically insulating substrates and heat sensitive substrates without the need of surface activation process with a relatively low curing temperature. [17]; [18].

| Metal Alloys | Composites |
|-------------|------------|
| Mass        | 33.5 kg    |
| Number of Parts | 31         |
| Number of Fasteners | 3400    |

|          | 25.2 kg |
|----------|---------|
| Number of Parts | 1       |
| Number of Fasteners | 0       |

[19]

### 3.3. Impact of TiC Composite Coating On Electrode Degradation in Microresistance Welding of Nickel Plated Steel.

Processes that could damage electrodes and cause deterioration during resistance spot welding of Zinc coated steels include;

- Alloying
- Pitting
- Cavitation
- Recrystallization
- Plastic Deformation
- Fatigue

Coating of the electrodes being suggested as another method of improving the tool life of the electrode. A TiC composite coated electrode could increase the tool life in Industrial scale resistance welding.

An experiment was carried out by [20] on the impacts of the coating on the electrode, the extent of its impact on the tool life of the electrode and its effectiveness on precipitation. Two electrodes were used for the experiment, Copper Alloy C18200 composed of Cu – 0.84 weight percent, Cr – 0.05 weight percent and Zr (Cu – Cr – Zr) and C15760 composed of Cu - 1.1 weight percent, Al2O3 (Cu – Al2O3). Coating of the electrode material with TiC composite was carried out using arc coating process. Electrode tip life experiments were tested on Coupons (Nickel – Plated Steel Strips 4 mm wide and 50mm long; Nickel Plated Steel; Nickel Strip 9 mm wide and 30 mm long). Welding was stopped regularly after 100
welds in order to measure the peel force using a tester named Quad Romulus IV Universal Mechanical tester. The results of the experiment on the impacts of the Composite Coating on Electrode Life as shown in figures 4 and 5 below indicates the button diameter (nugget diameter) and peel force (joint strength) against the number of welds of the electrodes. The results show that reduction in the nugget diameter and the peel force was slower for coated electrodes in comparison to uncoated electrodes. This implies that the electrode life is longer when coated with composite coating rather than when uncoated (Table 5).

Fig 4.Impacts of the Composite Coating on Electrode Life[20].
Fig 5. Impacts of the Composite Coating on Electrode Life [20].
Table 5. Electrode Tip Life in the Number of Welds for an arbitrarily minimum nugget diameter of 0.1mm

| Electrodes                      | Cu-Cr-Zr (T3) | Cu-Al₂O₃ (T4) |
|--------------------------------|---------------|---------------|
| Uncoated with Composite        | 700           | 800           |
| Coated with TiC Composite      | 1200          | 1500          |
| \((T_2 - T_1)/T_1\)            | 71%           | 88%           |

NB. The table above indicates that usage of composite coating improves the electrode tip life by 71%, 71%, 88%, 63% [20].

4. Conclusion
From the review we can infer the following; organic composite materials are better coating materials than Volatile Organic Compound (VOC) when coating substrates in aeronautic, automobile, aerospace industries etc. and it has high functional performance. Also, TiC composite coating increases the tool life of Cu – Cr – Zr and Cu – Al₂O₃ electrodes by 70%. This is due to the fact that the TiC particles in the layer coated would reduce cohesion between the surface of the sheet or metal and the electrode’s tip, thereby reducing and decreasing material loss [20].

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