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METALLIZATION OF 3D PRINTED POLYMER PARTS AS THE METHOD OF IMPROVING ITS PROPERTIES – A MINI-REVIEW

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Abstract: *Metallization is used to improve the properties of FDM printed parts. It improves mechanical strength, reduces surface roughness and enables new functionalities such as electrical conductivity and chemical or corrosion resistance. Metallization requires special knowledge and skills in the chemistry and access to appropriate equipment. One must take into account the cost of metallization; it is necessary to carefully evaluate the benefits obtained after its application and solve the technological problems associated with the process. In this paper we discuss metallization methods, along with how metals can be applied to 3D printed polymers using the FDM method.*

Keywords: Metallization, Polymers, 3D Printing, FDM Method.

1. Introduction

There are several methods for improving the properties and durability of 3D printed parts. Among the most important are annealing, chemical surface dissolving, machining and metallization (Afshar and Mihut, Moetazedian et al., Głowacki et al., Pérez-Fonseca et al.). Metallization is the process of applying a thin layer of metal to the surface of various materials. This process is used in many technologies, including the electronics and automotive industries, where it is used to produce components with the required properties such as: mechanical, electrical, magnetic, etc. FDM (Fused Deposition Modeling) is technology that allows the production of three-dimensional models of the material. In recent times, metallization has become increasingly popular for coating 3D printed parts.

The effect of metallization on FDM-printed polymers depends on numerous factors, such as the type of metal, the thickness of the applied layer, the method of application and the type of printed polymer. The most important effects of metallization on FDM-printed parts are: the increase in mechanical strength and durability. Covering a printed component with a layer of metal increases its resistance to mechanical damage, corrosion and the effects of heat and moisture. As a result, FDM-printed components can be used in harsh work environments, and its lifetime will be prolonged.

Another advantage of metallizing FDM-printed components is that gives them new characteristics, such as electrical, magnetic or thermal conductivity. This allows the printed parts to be used in industries, where this was previously not possible, such as electronics or the automotive or marine industries.

Metallization also reduces the roughness of the surface, which in most cases increases the strength, especially to cyclic loads, and increases the life of the object. It also increases resistance to aggressive working environments and corrosion. An additional benefit is that metallized parts are often more visually attractive.

In the following sections, based on the available literature, the most commonly used methods of metallization were discussed, and selected examples of effects were presented.

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2. Methods of metallization

2.1. Application of metal layer by chemical methods

In this group of methods, different techniques are used. Probably the simplest method is to immerse the printed part in a chemical solution containing metal particles. After immersion, the print is then subjected to a hardening process. Another is the oxide deposition technique, which is also used to coat polymer parts with metal. Obuchowsky et al. in their study used the ALD (Atomic Layer Deposition) technique, which involves coating the object with alternating layers of metal and oxide. The authors evaluated how the type of polymer to which the metal is applied affects the efficiency of metal oxide coating. In their study, they used polyethylene with high crystallinity and polystyrene as a low-crystalline material. They showed that with higher crystallinity of the polymer, the diffusion of the metal deep into the matrix was less efficient. This resulted in uneven thickness of layers. At low crystallinity of the polymer, the deposition process and layer thickness are more uniform.

Romani et al. evaluated the limitations of the metallization method in relation to commonly used thermoplastic materials, such as ABS, PLA, PETG or PC. The metallization was performed using chemical techniques such as electroplating or vapor phase deposition. The authors demonstrated the positive effect of metallization on the mechanical and thermal properties of all materials tested. The use of electroplating resulted in better quality and durability of coatings. Vapor phase deposition provided better electrical and thermal conductivity.

Zenkiewicz et al. compared the results of vapor phase deposition, chemical deposition and electrolytic deposition of copper and nickel layers. The substrates were the following polymers: polycarbonate, polystyrene or polymethylmethacrylate. They were evaluated from the point of view of various parameters of the electrodeposition process such as temperature, pH, chemical concentration and the quality of the deposited metal layer. The results indicated that all three methods are effective for metallization, but have different advantages and disadvantages. The electrolysis method is characterized by low quality and thickness of the coating, chemical deposition obtains a very thin coating of high quality but the process is complicated and expensive. In the case of vapor phase deposition, the effects were similar to those of chemical deposition.

2.2. Spraying methods

There are papers in the literature describing various spraying techniques as methods of metallization. The main ones include plasma spraying, spraying through an electric arc and flame spraying. Gonzales et al. concluded that flame spraying requires relatively large object distances and can lead to an increase in the surface temperature of the polymer. Arc spraying is very precise, and produces a high-quality deposited metal layer. Unfortunately, it negatively affects polymer surface changes. Plasma arc spraying is the most expensive method, but it achieves the highest quality and thickness of the deposited metal layer.

Cold spraying, described Parmara et al., is a method that produces very high-velocity metal particles that strike the polymer surface, causing the particles to adhere to the material surface. Studies have shown no negative effect on properties of polymer materials. This method allows covering large areas of polymer with irregular shapes. Its disadvantage is the difficulty of maintaining control over the thickness of the deposited layer during the process.

2.3. Application of metal in the form of film

The method involves applying a special metal film to the polymer surface using high temperature and pressure. Panchuk et al. described, a method of depositing thin metal coatings of gold and aluminum on PET film. In Fig. 1A it is visible after the deposition of aluminum that the interfacial layer is continuous, and while in the case of gold coatings, easily-visible interfacial layers are formed between the polymer and the metal.

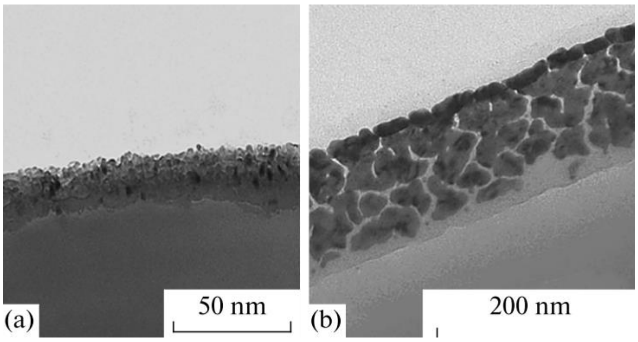

Fig. 1: Transmission Electron Microscopy images of ultra thin sections of PET films with aluminum and gold coatings – Image A and B respectively (Panchuk et al.).

2.4. Metallization under vacuum

Another technique used is to apply a thin layer of metal to the polymer surface in a vacuum. The authors Jun et al. and Brun et al. conducted an experiment in which a copper layer was applied to the surface of polycarbonate using the PVD (Physical Vapor Deposition) process in a vacuum. This method makes it possible to obtain a very high-quality metal layer with increased hardness and scratch resistance.

2.5. Self-coating method

This method use chemical properties of polymer, which reacts with metal ions forming a metallic layer on the surface of polymers. Kareem presented the process of preparing the surface of polyimide PI for metallization, followed by the process of self-sputtering silver onto the polymer. Resulting surfaces were characterized with high electrical conductivity, and its adhesion to the polymer was also satisfactory. Fig. 2 shows the thickness of the silver layer (Kareem A. A.).

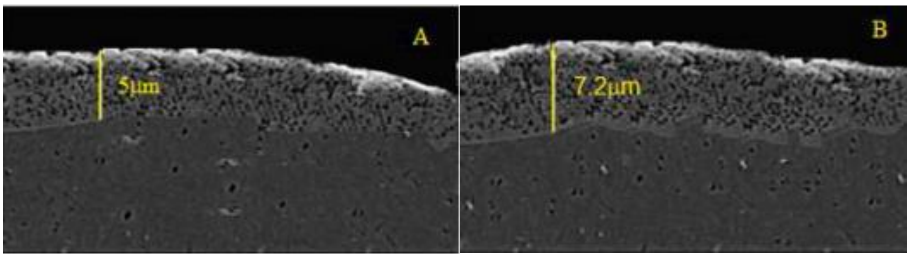

Fig. 2: Thickness of silver layer on PI material for deposition time 5 and 10 minutes - image A and B respectively (Kareem A.A.).

3. Conclusions

Based on the techniques described, several conclusions can be drawn about the use of metallization to improve the properties of FDM-printed parts.

1. Metallization can significantly improve the mechanical strength of FDM-printed parts. Metallization uses various metals such as nickel, copper and even gold to increase the bending, tensile and abrasion strength of polymer printed parts.
2. Metallization can improve the quality of surface of FDM-printed parts, including improving surface roughness, increasing abrasion resistance and resisting harsh work environments.
3. Metallization can be used to improve or impart new properties of material as well, for example electrical, magnetic and other properties of components made from polymers.

However, special knowledge and skills in the chemical field are required to perform the metallization process properly, as well as access to appropriate laboratory equipment.

Metallization can also increase manufacturing costs, as well as affect the dimensional tolerances of parts. For this reason, further research into the use of metallization to improve the properties of FDM-printed parts is needed to understand its full potential and application in practice.

Sometimes metallization can affect the properties of materials in negative ways if the wrong technique is chosen or the process is not carried out correctly. Metallization can change the dimensions of the printed part, its texture or affect mechanical properties in an undesirable way. Therefore, it is important to carefully study what effects in the printed material can appear after metallization.

In conclusion, metallization is a promising method for improving the properties of FDM printed parts. However, before applying metallization in manufacturing, the costs and benefits should be thoroughly checked, and the technological problems associated with the process should be solved.

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