G Model
CIRP-1682; No. of Pages 4
ARTICLE IN PRESS
CIRP Annals - Manufacturing Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Direct electroplating of plastic for advanced electrical applications

Aminul Islam [a,b,*], Hans Nørgaard Hansen (1)[b], Peter Torben Tang [c]

[a] *Centre for Acoustic-Mechanical Micro Systems, Technical University of Denmark, Lyngby, Denmark*
[b] *Department of Mechanical Engineering, Technical University of Denmark, Lyngby, Denmark*
[c] *IPU, Lyngby, Denmark*

ARTICLE INFO

Keywords:
Composite
Surface analysis
Electroplating

ABSTRACT

Electrodeposition or electroplating is predominantly applied to metallic components. Electroplating of plastics is possible in some cases where an initial electroless plating layer of nickel or copper is made to provide a conductive surface on the plastic part. This paper proposes a method for direct electroplating of plastic eliminating the need for slow and expensive processes like electroless metal deposition, PVD coating, painting with conductive inks etc. The results obtained from the test demonstrate the potential of direct electroplating of plastic to enhance the electrical conductivity and the use of electroplated plastics for advanced applications like Moulded Interconnect Devices (MIDs).

1. Introduction and motivation

Electrically conductive plastics combine the properties of plastics with the properties of metals. They are easy to process, lightweight, corrosion resistant, can be shaped by moulding; moreover they provide the electrical conductivity needed for many applications. Some plastics can be naturally conductive, but plastics can also be artificially made conductive by doping or compounding techniques [1]. The focus of this paper is the plastics that are made artificially conductive — the so called conductive composites. Different techniques are used to make plastic conductive like the addition of fillers, such as carbon black, graphite, carbon nano-tubes, metallic fibers etc. [2]. These compounds are typically used in electrostatic discharge (ESD) control and electromagnetic interference (EMI) shielding [3]. In the near future, the modified electrically conductive plastics can be used in many other industrial applications like for the production of Moulded Interconnect Devices (MIDs), for antennas, solar cells, polymer electronics, touch sensors, transistors and many more. Particularly the MIDs show enormous potential in using electrically conductive polymers, due to the adaption of conductive patterns to the geometric form of the products [4]. But before the electrically conductive plastics can be used in such wide spread applications, there are some technical challenges to overcome. One of these is the achievable electrical conductivity of the composites [5]. It is possible to produce highly complex 3D conductive elements by injection moulding from conductive composites, but the offered conductivity is not as good as required for many applications. One example of such is demonstrated in Ref. [6] with an FM antenna for hearing aids. Currently available electrically conductive composites are unable to fulfil the future demands and when it comes to the point of thin-walled or miniaturized components, so far conductive plastics have nothing to offer as the conductivity of the material is drastically reduced due to smaller dimensions [5]. In this paper, a novel method for the direct electroplating of plastics is proposed. The proposed method can significantly improve the electrical conductivity of the plastic composite with limited conductivity.

2. Materials and methods

To select a mouldable and highly conductive plastic composite, an extensive search was made in material databases and also in literature. The final selection was Schulatec TinCo 50 from A. Schulman Inc., Akron, USA which showed the highest electrical conductivity among the available options and also good mechanical properties. This material consists of 56 vol.% (15 wt.%) Polyamide 6 (PA6), 25 vol.% (52 wt.%) of fine copper fibres (average length 0.65 mm, diameter 35 μm) and 19 vol.% (33 wt.%) of a low-melting Tin/Zinc alloy (199 °C) [5]. Fig. 1 shows the commercially available granulates of the selected material (picture A). The Tin/Zinc alloy in the material becomes liquid during the processing phase (e.g. moulding) and makes the connection among the long copper fibers, and that is how the material makes a conductive network of metallic components in the plastic matrix (schematically presented in picture B of Fig. 1).

Fig. 2 presents the results from the morphological investigation (Particle and Pore Analysis) done on the parts moulded with Schulatec TinCo 50. The analysis was carried out with the help of an Alicona Infinite Focus microscope and a commercially available software package for processing and analysing microscopy images (Scanning Probe Image Processor version 6.6.1) [7]. Picture C of Fig. 2 was taken at the cross section of a moulded sample. The

* Corresponding author at: Department of Mechanical Engineering, Technical University of Denmark, Lyngby, Denmark.
E-mail address: mais@mek.dtu.dk (A. Islam).

http://dx.doi.org/10.1016/j.cirp.2017.04.124
0007-8506/© 2017 Published by Elsevier Ltd on behalf of CIRP.

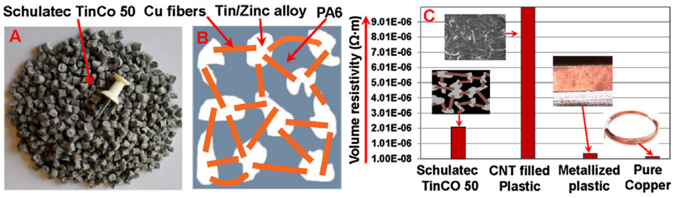

Fig. 1. Granulates of Schulatec TinCo 50 (A), schematic representation of conductive network inside moulded parts (B), comparative resistivity (approximate) of Schulatec TinCo 50 compared with other materials (C).

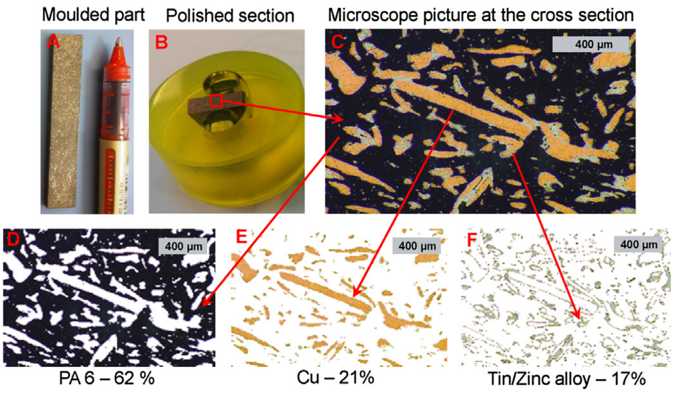

Fig. 2. Moulded specimen (A), sample prepared for microscopic investigation (B), optical microscope image at the part cross section (C), material analysis results for PA6 (D), Cu (E) and Tin/Zinc alloy (F).

copper fibers are clearly visible in the cross section which are connected by the Tin/Zinc alloy (grey colour substance) to some extent. In this way the copper fibers and the alloys are forming a conductive network of metallic materials inside the polymer matrix. Many disconnections among the neighbouring fibers are visible too. This proves that a theoretical continuous network of copper fibers (as presented in picture B of Fig. 1) is not possible. It is characterized by a combination of continuous and discontinuous fiber networks. The morphological analysis at the cross section revealed that about 21% area was covered with copper (yellow substance in picture E), about 17% area was covered by Tin/Zinc alloy (grey in picture F) and the remainder was the plastic material — PA6 (black in picture D).

Schulatec TinCo 50 is a non-homogeneous mixture (can also be seen in Fig. 2) that has no defined conductive direction. For the material, the manufacturer claims a conductivity of 5×10^5 S/m [8] (volume resistivity of 2.00×10^{-4} Ω-m). It is important to note that detailed studies about similar materials report that the conductivity values are susceptible to the injection moulding conditions such as: mould temperature, distance from the injection gate, flow direction, part geometry, dimension etc. [5,8,9]. Nevertheless, the electrical conductivity of Schulatec TinCo 50 is among the highest ranking conductive composites. The comparative volume resistivity of Schulatec TinCo 50 is presented in Fig. 1C. The resistivity is significantly lower than other commercially available conductive plastics like Plasticyl PA 1501 which is Polyamide (PA66) filled with 15 wt.% Carbon Nano Tubes (CNTs). But the resistivity of Schulatec TinCo 50 is still many times higher than pure copper or metallized plastics (with copper). This is the problem for many current and future applications as discussed before.

The experimental process and results presented in Section 3 will show one way to enhance the conductivity of the plastic composite based on electroplating. For the experimental demonstration, parts moulded with Schulatec TinCo 50 were used. The most widely applied plating process for plastics is the electroless plating (metallization) which is a slow and chemical-intensive process involving many different steps [10]. Moreover, the electroless process is toxic especially the etching solution that consists of a hot balanced mixture of chromic acid, sulfuric acid, and water [11]. The introduction of these chemicals to a production chain raises huge environmental and safety concerns. The direct electroplating of plastics can overcome most of these problems. Electroplating is primarily used to change the surface properties of an object (e.g. abrasion and wear resistance, corrosion protection, aesthetic qualities, etc. [11]). But this can be beneficial also for the global conductivity of the material as it can create a highly conductive surface layer. The presences of some degree of conductivity in Schulatec TinCo 50, suggests that direct plating of the material can be a possibility. This attempt has never been reported before according to the material supplier [8]. When electroplating is attempted for plastics, usually a thin initial layer of metal is deposited on the surface by processes like electroless metal deposition, conductive painting or PVD coating etc. But the use of the electrically conductive plastic as in the current case can potentially eliminate the need of any secondary processes to make the preliminary conductive surface.

3. Electroplating experiments and results

For the electroplating experiment, the injection moulded test specimen (shown in Fig. 2-picture A) made with Schulatec TinCo 50 was connected to the cathode terminal of the plating bath and the anode was pure copper (Cu) electrode. The plating bath was an acidic copper bath based on sulphuric acid and copper sulphate. During the first trial of the plating, the used current supply was 3 A/dm^2 and the plating time set was 6 min. The result of the initial trial of the electroplating is shown in Fig. 3 (pictures A–C). Some plating of Cu on some selective places of the part surface was visible but most of the surface was uncovered. As the current and plating time were the main parameters for the electroplating, several trial and error steps were carried out to find some optimized plating conditions by changing time and current. A current density of 8 A/dm^2 and a plating time of 11 min were found as the most optimized conditions for the electroplating. But even with these plating conditions, the metallic coverage was not good. About 12% area of test parts was covered with metal and the remaining area was uncovered.

To find the reason for the poor coverage of the surface after electroplating, the moulded part was subjected to microscopic investigation. Fig. 4 (picture A) shows a magnified view of a part

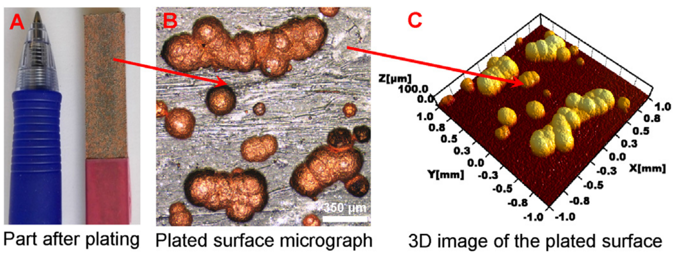

Fig. 3. Part after plating (A), optical microscope picture of the electroplated surface (B) and 3D profile image of the surface (C).

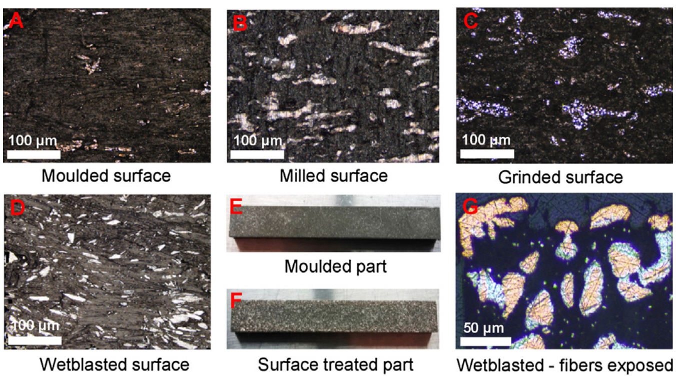

Fig. 4. Surfaces of the moulded Schulatec TinCo 50 parts modified by different surface treatment techniques.

Please cite this article in press as: Islam A, et al. Direct electroplating of plastic for advanced electrical applications. CIRP Annals - Manufacturing Technology (2017), http://dx.doi.org/10.1016/j.cirp.2017.04.124