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Experimental analysis of metal/plastic composites made by a new hybrid method

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ABSTRACT

The purpose of this paper is to identify the key elements of a new hybrid process to produce high quality metal/plastic composites. The process is a combination of Fused Deposition Modelling (FDM), vacuum forming and CNC machining. The research aims to provide details of the proposed hybrid process, equipment used, and the experimental results of the composites produced. The research has been separated into three study areas. In the first, the hybrid process has been defined as a whole whereas the second area deals with the breakdown of steps to produce the metal/plastic composites. The third area explains the varied materials used for the production and testing of the composites. Composites have been made by joining copper (99.99% pure) mesh with ABS (acrylonitrile butadiene styrene). Strain measurement has been carried out on Cu/ABS sample to analyse the effect of metal mesh and to verify the effectiveness of the hybrid process. The resulting composites (Cu/ABS) have also been subjected to tensile loading with different layers of metal mesh, followed by microstructural analysis and comparative studies to serve as a proof of the methodology. The results show that the proposed hybrid process is very effective in producing metal/plastic composites with lower strain values compared to the parent plastic indicating a lower level of deformation due to interlocking of the metal and plastic layers. This effect has been reinforced by the tensile testing where the composites showed higher fracture load values compared to the parent plastic. Microstructural analysis shows the layer of metal mesh sandwiched between ABS layers indicating the existence of a bond holding the layers of metal and plastic together. These results demonstrate the capabilities and effectiveness of the proposed process that has shown promising results under tensile and static loading.

1. Introduction

Plastics are widely used in engineering applications due to the various advantages that they offer including low cost, high elastic modulus, low weight, designing freedom, thermal and electrical insulation [1]. These factors have steered technological research into their direction so that they can be combined with metals to get the benefits of both materials. Metals albeit capable of providing excellent mechanical properties (impact resistance, strength, stiffness etc.), are significantly heavier than plastics [2]. Therefore, the combination of plastics with metals provides a cost effective, high strength and lightweight alternative to the conventional products. Such metal/plastic composites are widely used in aerospace and automotive industries without compromising features such as performance, safety, weight and energy costs reduction [3]. Joining metals and plastics is not an easy endeavour and a considerable amount of research is still required to fully understand their integration due to their vastly different properties. From an engineering standpoint, it is imperative to have a material that can be made into complex geometries with ease and which also possess good mechanical properties to maximise its usage in engineering applications.

In view of these functionality gains, a few methods joining methods showed reliable results for a composite joint between metals and plastics. They include adhesive bonding, mechanical fastening and welding [4]. Adhesive bonding suffers from long processing times, surface pre-treatments, difficulty of disassembly, environmental degradation due to humidity, temperature and moisture, uncertainty regarding long term durability and unreliable non-destructive testing methodologies [5]. Mechanical fastening requires clamping and the use of screws and rivets for bonding which is acceptable for some joints but is not appropriate for product development. The method is simple and can join various plastics with metals, but the practices add weight, thickness and stress concentration on the structure which is a big problem [6]. Welding techniques, such as laser welding, ultrasonic welding and friction spot joining, have been exploited to create high quality joints between metals and plastics of various kinds. Laser welding can

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work with aluminium, steel and titanium. It has some advantages like fast welding times, small heat input and high adaptability but is limited by setting several welding parameters such as laser power, welding speed, pulse mode and beam quality that adversely affect the quality of the final joint [7]. Ultrasonic welding has shown high joint strengths while working with aluminium and carbon reinforced plastics but is limited to small components [8]. The benefits of friction spot joining include short welding times, operational simplicity, commercial equipment availability and good mechanical performance of the joints [9]. Its disadvantages are limited joint configurations, use of low melting point materials and inability to work with thicknesses greater than 2 mm [10].

All the aforementioned methods have their limitations and should be used based on their suitability to the joining materials. It is also clear from the literature that new joining techniques to produce high quality and reliable metal/plastic composites are required. Therefore, this paper presents a new hybrid process for the production of high quality composites that offer simplicity and ease of operation. It is based on the principles of Fused Deposition Modelling (FDM) for plastic part and vacuum forming for placing metal mesh to create a layered metal/plastic composite. ABS and PLA are two of the most commonly used material for 3D printing. ABS has been chosen for this research work because of its unique properties including high mechanical strength, rigidity, good long-term load carrying ability, dimensional stability, good chemical and heat resistance. The chosen metal mesh is of 99.99% pure copper. The next section explains the new hybrid process is detail.

2. Metal/plastic hybrid process design

2.1. Process details

The main components of the process are two filaments of thermoplastic material (one for support material and the other for build material), an extrusion head for deposition of the material, a feed mechanism that advances a sheet of metal mesh over a build platform, a vacuum pump to remove the air from under the metal mesh and sucking it in order to have a layer of mesh on top of the part being built, a CNC machine to cut the outline of the part in each layer of the metal mesh and a chemical bath for the removal of the support material. Fig. 1 shows the conceptual model of the machine based on the principle of metal/plastic hybrid process. The process is a prime example of a hybrid method where the part is being built by adding layers of plastic and metal mesh followed by removal/subtraction of the additional mesh from the sides of the part to get the final product.

The proposed process starts with the 3D CAD model of the part being transferred, using the Slic3r software, to a set of layer data according to the geometry of the part. There are several open-access slicing software options available which have the capability to be modified according to customized applications. Slic3r has been chosen because it is free to use and enable easy bespoke additions to the firmware which are required for this process. The 3D CAD file has been set up with pauses where the metal mesh needs to be added to the part being built. Once the machine receives the layer data then it controls the building process. The extruder starts to heat up to initiate the building operation. In the meantime, the base plate is levelled on the build platform so that an accurate part can be printed. After the appropriate temperature has been achieved (depending on the material), the printing process starts with a base of support material to allow for easy removal after the build. The layers of metal mesh have been programmed after set intervals so that the part being built would get the advantages of thermoplastic as well as the metal. When it is time to add a layer of metal mesh, the extruder head depositing the thermoplastic material moves to a side and the vacuum pump gets activated. It creates a partial vacuum that pumps out all the air beneath the metal mesh sheet. Atmospheric pressure above the mesh sheet pushes it down on the part being built. The mesh wraps around the part according to its profile and then the vacuum pump is switched off. The CNC machine can either be used at this stage or at the end of the build to remove the mesh on the sides of the part as it is not required. This process is very similar to vacuum forming but the difference lies in the fact that instead of using a plastic sheet and heating it, the current method employs metal mesh and does not require any heat treatment. The metal mesh gets added to the plastic part by virtue of the amorphous plastic being deposited by the extrusion head. The plastic adheres to the mesh layer and runs through the holes of the mesh to create a strong bond between the plastic and metal. The process does not require any additional bonding mechanism other than the principles of FDM which saves cost on expensive adhesives. The process is repeated until the part has been built according to the layer data. The part is then removed from the base plate and placed in a chemical bath to remove the support material (if any). The process is simple and does not require high degree maintenance of the components. The flow chart of operation is shown in Fig. 2.

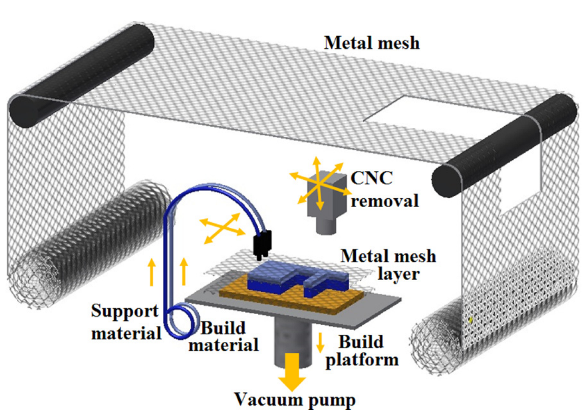

Fig. 1. Metal/plastic hybrid process.

The above explanation describes the process as a whole but the research was carried out by breaking down the process into independent steps that were performed to produce the testing samples. The next section explains that breakdown and the practices utilized to prove the process.

3. Materials and manufacturing process

The process is complex and needed to be broken down into simple steps for practicality, thus an experimental setup was created to demonstrate the capability of the process. It was important to ensure that the process utilizes minimum resources as one of the objectives is to make this process as cost effective as possible.

ABS and copper mesh sheets (99.99% pure) of varying thicknesses (30 microns, 60 microns and 150 microns) were used to build samples for tensile testing. The testing samples were built and tested according to British and International standards. A standard desktop 3D printer from RS Components was used with a working envelope of 150 mm x 150 mm × 140 mm as shown in Fig. 3. The 3D CAD Fig. 4 model of the part to be built was sent to the 3D printer which began the build operation by laying down the support material base for the part. The part was built at a speed of 30 mm/s with a layer thickness of 0.2 mm (Fig. 4a) with the set temperature being 220 °C. The metal mesh was added manually to the part as it was being built by pausing the build operation and then resuming it (Fig. 4b). The support material in this case was easily snapped off as the testing sample was a rectangular piece with no need for any additional support other than the base. The mesh was used without any surface treatment and was added carefully after set intervals to obtain good bonding with the plastic. After the build operation, the support material was snapped off and the part was ready to be tested.