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A novel rapid prototyping process for the production of metal parts

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***Abstract*—Rapid Prototyping (RP) has made massive strides in the technological industries and is at the fore front of innovation. However, the majority of them use different types of plastic and other materials including resins, flour etc., for the production of prototypes. They can only be used as visual prototypes in most instances and do not provide sufficient information for direct material testing which is needed to understand the mechanical properties for large scale production. The current methods employing powder metals have their limitations and are very expensive. There is an emphasis on the production of metal parts because they provide real time results rather than approximations and usually give more insight into the design parameters. This paper presents a novel rapid prototyping method for the production of cheap and high quality metal parts that are suitable for direct testing. The process is a combination of Laminated Object Manufacturing (LOM) and soldering technologies. The process is referred to as Composite Metal Foil Manufacturing (CMFM) and this paper presents its principle both in theory and in practice. Tensile testing has been done to prove the effectiveness of the process that shows promising results.**

***Keywords*—rapid prototyping, laminated object manufacturing, soldering, composite metal foil manufacturing**

I. Introduction

Laminated Object Manufacturing (LOM) and soldering technologies have been around for decades but never integrated together. The process of Composite Metal Foil Manufacturing is achieving this goal to produce cheap and reliable metal parts. Laminated Object Manufacturing has been integrated with diffusion welding before [1] using metal foils for the production of metal parts but the setup is expensive and poses operating issues. It cannot work with thicknesses less than 0.5mm as anything less than that results in staircase effect. The process also requires the generation of contours that require a sufficient self-stiffness of the sheets and anything less than 0.5mm result in failure of the contour generation. The surface quality is not very good and the products require post processing such as milling, build-up welding or shot peening if necessary [2]. These problems are eradicated with the proposed process as it is capable of using foils as thick as 0.1mm with no problem of having a staircase effect.

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There is no need for any post-processing and the products made by the proposed process have good surface finish. The product is actually the metal itself and it keeps all the properties of the parent metal from which it is produced. In terms of mechanical properties, the parts produced by the proposed process have surpassed the parts produced by traditional methods because of the strong bonding among the layers.

II. Composite Metal Foil Manufacturing Process Design

A. *Process Details*

The proposed method starts with the three dimensional computer aided design model of the part being transferred, by the use of SLICE software, to a set of layer data according to the geometry of the part. The main components of the process are a feed mechanism that advances a metal sheet over a build platform, a laser to cut the outline of the part in each sheet layer, a dispenser that dispenses special solder paste on the metal sheets, a roller that smooth the paste into a uniform layer, a heated plate to apply pressure to bond the sheet to the layer below. Parts are produced by stacking, bonding, and cutting layers of solder paste-coated sheet material on top of the previous one [3].

A laser cuts the outline of the part into each layer. After each cut is completed, the build platform lowers by a depth equal to the thickness of the sheet. The dispenser then dispenses solder paste on the sheet and a roller rolls on the surface to make a uniform layer of the paste. Another sheet is advanced on top of the previously deposited layers. The platform then rises slightly and the heated plate applies pressure and heat to bond the new layer. The laser cuts the outline and the process is repeated until the part is completed. After a layer is cut, the extra material remains in place to support the part during build [4].

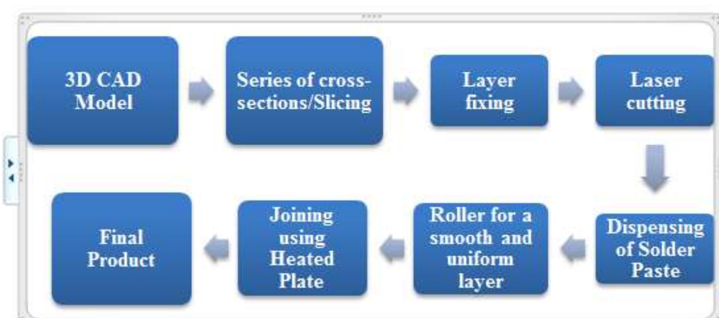

Figure 1: Composite metal foil manufacturing process

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

B. *Process Justification*

Since every step was performed independently, it was important to make sure that the process utilizes minimum resources as one of the objectives is to make this process as cheap as possible. The following gives the step by step description of the process:

- The sheets were cut using cutters according to the geometry required.
- The solder paste was deposited manually to each and every layer. The deposited layer was made smooth by first pressing down the layers with a heavy metal bar and then by putting the specimen in stainless steel plates and tightening with nuts and bolts.
- The stainless steel plates served three purposes: (1) smooth out the solder paste layer, (2) keep the specimen properly aligned and (3) serve as heat plates when the entire assembly (solder coated foils and plates) are put in the furnace.
- The furnace heats up the air inside its door which will then heat the structure that is placed in it. The heat from the surroundings gradually sets in the plates and reaches the solder paste to melt it so that the layers can be soldered together.
- Depending on the specimen, the structure is kept inside the furnace and then taken out after a set time. The nuts are unscrewed and the specimen is allowed to be air cooled.
- There is no post process cleaning involved as the product is not affected in any way and is ready for testing after cooling.

III. Experimental Methodology

Lap-shear and tensile comparative analysis were carried out to assess the effectiveness of the proposed process. Specimens were produced using Copper foils (99.9% copper) with a thickness of 0.1mm and they were used as supplied with no surface treatment. Tests were carried out in accordance with British and International Standards where applicable.

A. *Lap-shear Test*

No current lap-shear standard exists for foils at 100 microns. The BS ISO 4587:2003 was followed where possible even though it relates to thicker foils of metal (1.6±0.1mm). The Hounsfield Tinius Olsen Tensile Testing machine was used for carrying out the lap-shear testing. The machine was operated at a speed of 1.667mm/s (100mm/min) with the 200mm long and 25mm wide specimens at an overlap length of 12.5mm. The foils of copper were coated with solder paste and then stacked on top of each other. The specimen once ready was pressed down by a heavy metal bar to remove any excess paste and to make the solder layer smooth between the foils. It was then sandwiched between two 3mm thick stainless steel plates with nuts and bolts along the edges. The nuts were tightened to make sure that sufficient pressure was applied at all times to the specimen [5]. The entire assembly was then put into an open chamber Carbolite CWF1200 furnace. The temperature on the display was set at 550 degree Celsius. The structure was kept in the furnace for a total of 120 seconds (2 minutes) and was then taken out. During that time, the door was not opened for any reason to make sure that the process of soldering could take place uninterrupted.

B. *Tensile Test for Dog-bone Specimens*

A dog-bone specimen was produced by following ISO 6892-1. The specimen (Composite Copper) produced by Composite Metal Foil Manufacturing was first tested and was then compared to the same shaped specimen machined out of a copper block. Both the specimens were 2.5mm thick, 87.5mm long, 12.5mm wide and had a gauge length of 50mm. The composite copper (specimen produced by the proposed process) was made up of 14 layers stacked on top of each other. The same procedure was applied as with lap-shear and peel test specimen preparation with the same display setting but an operating time of 180 seconds (3 minutes) as there are more layers to be soldered in this case.

IV. Results and Discussion

A. *Results from Lap-shear Test*

From the ten specimens tested, all broke within the base metal adjacent to the bonded area. Failure did not occur within the soldered region in any of the specimens. As in tensile testing, specimens failed at locations with minimum cross-sectional area (i.e. the base metal, instead of the lapped region which had twice the cross-sectional area). Fig. 2 shows the failure mode of one of the specimens.

Figure 2: Failure Modes of Lap-Shear Specimens

Fig. 3 shows the results of the lap-shear test and in all the specimens the failure was recorded according to BS EN ISO 10365:1995. The failure pattern was always substrate failure with the designation SF.

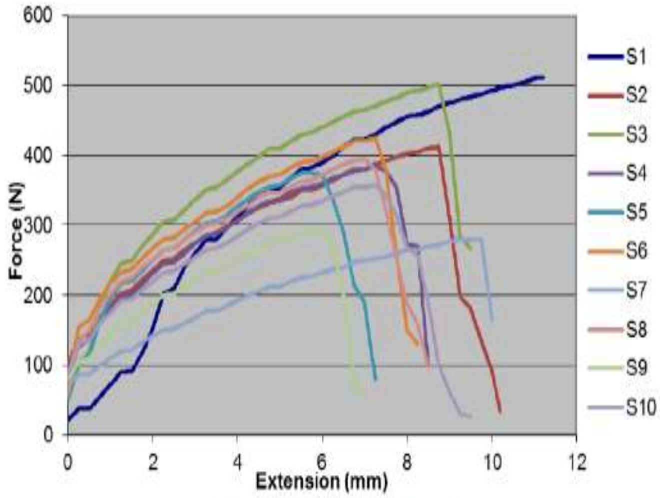

Figure 3: Lap-shear test results

B. *Tensile Test for Dog-bone Specimens*

The test was done to compare the tensile strength of a copper specimen machined using conventional methods against one produced by composite metal foil manufacturing.

It showed that the strength of the composite copper is higher than the parent copper. Both the specimens follow the same curve pattern but the composite copper fails at a higher value. Fig. 4 shows the comparison between the two specimens.

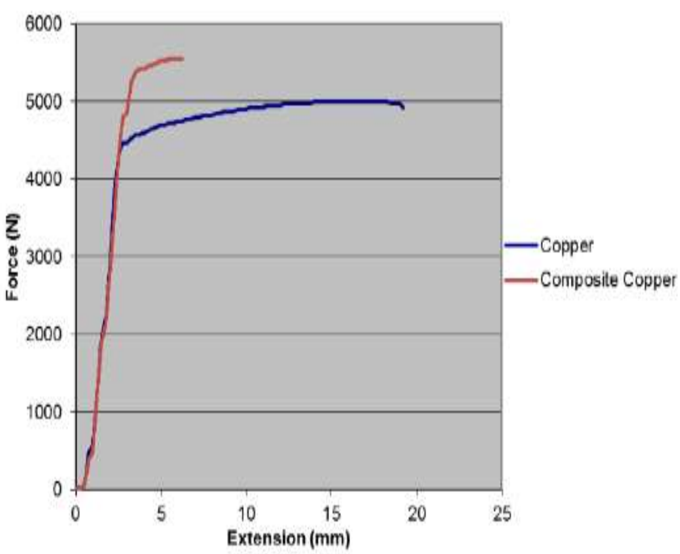

Figure 3: Comparative tensile test results

The maximum force for failure is 5550N for the composite whereas it is 5000N for the parent copper. There was no failure of individual layers but a complete failure of the specimen proving that the 14 layers that were bonded together were actually functioning as a single unit rather than individual layers and that added to the strength of the specimen.

V. Potential of Application

Once this technique is mastered, there is a potential to build a machine that works on this principle. This method could very well follow the same upward trend that three dimensional (3D) printers have gone through over the past few years. These printers have become a craze owing to the simplicity and flexibility that they offer to their end users. They are capable of producing customized plastic parts and the proposed process has the ability to do the same but with metal parts. There is an ever growing market for metal parts and if a technology can deliver the same high quality at a cheaper cost then it would become the next big thing in the field of rapid prototyping.

The process can easily solder tough metals like aluminum that has a very tenacious oxide layer but with the use of a special solder paste that can penetrate the oxide layer allowing wetting to take place. This has also been achieved and that also with an aluminium foil of 70 microns thickness. This goes to show the flexibility of the process dealing with varying thicknesses that could be used to produce products. It also has the capability to manufacture multiple material parts that could offer alternatives to the conventional metal products.

This process can have a massive impact as it has reduced the limitations related to the production of metal parts. It can use any metal, has the capability to produce multiple material parts, can easily attract the general public, does not require any post processing to improve mechanical properties, has a shorter production time compared to its rival technologies etc. The applications can range from small bespoke parts to large scale functional products that can be used without any post processing.

VI. Conclusions

Composite Metal Foil Manufacturing combines two of the oldest processes to produce high quality and cheap metal parts. The tests were performed to assess the integrity of the process and whether or not it has the capability to challenge the existing metal prototyping technologies. All the results showed that the proposed process has the potential to be a strong candidate in the field of metal prototyping.

The lap-shear tests proved that the bond between the layers is stronger than the material itself. It was always the parent metal that fractured and never the bonded area. It shows the presence of a bond that is stronger than the material which is a testament to the integrity of the process. The best example that could solidify Composite Metal Foil Manufacturing as a strong candidate is the comparative tensile dog-bone test where the composite copper specimen showed more strength than the parent copper. This shows that the process has the capability to produce stronger parts as compared to traditional machining methods.

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Composite Metal Foil Manufacturing has the potential to change the manufacturing industry and be at the forefront of technological innovation.