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Meeting-report

Additive Manufacturing of Highly Detailed Copper Shells by AMSME Process

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This paper presents the results of using additive manufacturing technology to fabricate copper shells with high detail reproduction. The copper shells can be used as wear tools for the die sinking EDM process. The AMSME process was selected to achieve complex geometries with microscopic details. The obtained results demonstrate high-quality copper depositions with excellent reproduction levels. Additionally, the process generates three-dimensional geometries that are impossible to achieve using conventional material removal manufacturing technologies. Throughout the experimental phase, special attention was given to controlling the electrical parameters of the electrochemical process, which are responsible for ensuring correct deposition during the geometry formation phase.

Technological advances are driving the need for smaller parts and components. This presents a significant challenge for manufacturing processes, which must adapt to the micrometer scale to achieve complex geometries and surface finishes with the same reliability as at the macro scale. Elements that contain micro-cavities are especially difficult to produce [1]. Conventional machining processes cannot achieve the high level of reproducibility and excellent finishes required for generating geometries with varying compositions, hardnesses, and surface finishes. Advanced manufacturing techniques such as additive manufacturing, laser techniques, or sinking EDM (SEDM) are necessary to achieve dimensional scales of the order of a micron. Surface texturing is a highly relevant application at these dimensional levels [2, 3]. The purpose of texturing is to modify the surface shape of a material in order to improve its properties [4]. Structured surfaces are obtained as a result of this modification when it is based on a properly defined pattern, structure or arrangement. The new surfaces acquire a new functional value to the extent that they are adapted to the needs of the intended improvements [5].

To produce micrometer-scale reproductions of intended details, the AMSME manufacturing process [6] was employed. This process combines two additive manufacturing techniques: electroforming and additive manufacturing using DLP (Digital Light Processing) technology.

The DLP process is used to create the functional model with the desired geometry, while the electroforming process deposits copper to form the final part.

The parts to be formed present a complex geometry based on protruding hemispherical cavities with details that present dimensions on a microscopic scale, unattainable for any other manufacturing process. These protruding geometries are designed based on hemispheres of 1mm in diameter with a matrix arrangement along the entire surface of the part. This typology poses great difficulties to obtain thickness uniformity during its manufacture by electroforming. For this reason, and in order to achieve good results, it has been necessary to use specialized equipment developed especially for this type of difficulty [7].

The electroforming process is an electrochemical additive manufacturing process. It involves the production or reproduction of articles by electrodeposition on a mandrel or mold that is subsequently separated from the deposit. The metal deposition on the surface of the functional model perfectly replicates its geometry, generating a shell that forms a part itself [8]. Deposition depends on several parameters, including deposition time, electrolytic bath conditions, and electrical process parameters. The longer the part remains in the electrolytic bath, the greater the thickness obtained, with values of up to 25 mm achievable under good reproduction conditions. The longer the part remains in the electrolytic bath, the greater the thickness obtained, with values of up to 25 mm achievable under good reproduction conditions.

The authors of the AMSME process emphasised the importance of establishing working phases with different current intensities to achieve complex geometries on a small scale. It is crucial to use a range of current intensities for achieving complex geometries in electroforming. Therefore, during the forming phase, small intensities are applied. This technique enables the control and limitation of disordered and undesired growth in areas where deposition is easier, directing it towards areas with more complex geometry or greater detail. This is particularly relevant for spherical or hemispherical geometries, where the final closing layers are critical. The growth phase allows for an increase in current intensities up to values close to 1A, resulting in increased deposited mass and decreased deposition time.

Electroforming has shown good results in accurately reproducing three-dimensional geometries at small scales, making it a viable option for microfabrication [9]. As a result, a specialized process called micro-electroforming has emerged [10].

Additive manufacturing is the process of creating three-dimensional objects by adding material layer by layer, based on a three-dimensional model designed using CAD tools [11].

One of the earliest techniques used is in-tank light-curing, which involves selectively curing a liquid photopolymer in a semi-liquid state in a tank using light [12]. Ultraviolet light is the most commonly used form of light for curing surfaces. The Digital Light Processing (DLP) system was used in this case, employing a liquid crystal display (LCD) that is illuminated layer by layer with the image of the geometry to be reproduced.

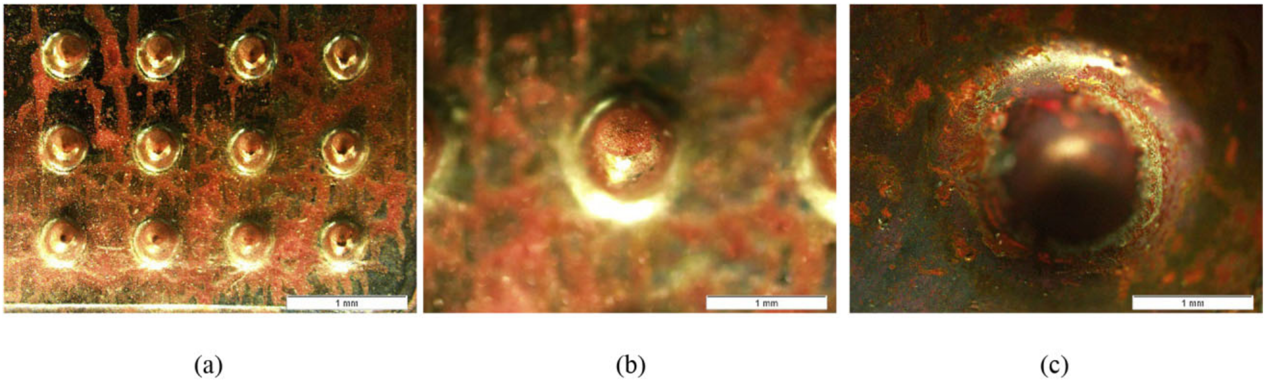
The aim of this work is to validate the reproduction quality of copper parts manufactured by the AMSME process. This paper presents the results obtained for the deposition of a copper shell on a functional model consisting of 100 protruding hemispheres arranged in a 10x10 matrix with a diameter of 1mm and a separation of 2mm between axes.

To assess the quality of the deposition, we conducted a comprehensive surface analysis to identify any cracks, deposition failures, incomplete geometries, rejects, or defects in the reproduction of details. For this purpose, we used an Olympus BX51 electron microscope with 20x magnification. Figure 1 displays the surface finish in various areas of the part. Microscopic details corresponding to the rings of the resin layers deposited during the formation of the functional model have been successfully reproduced. Figure 1b displays a microscope image of the upper part of the hemisphere, which is the most complex area to complete using this process. The deposition is complete, as shown in the image. Figure 1c shows a microscope image of the base of the hemisphere. It is evident that the transition to the flat surface has been completed smoothly, despite it being a delicate area.

Fig. 2 presents a side view of the part, clearly demonstrating the successful reproduction of the hemispherical protruding geometries.

The following conclusions can be drawn from the conducted research:

- The AMSME process is a validated procedure for forming surfaces with complex geometries. It has been successful in generating copper shells with high levels of detail, with some dimensions in the order of microns.
- The process has also successfully created incoming or protruding geometries on the material's surface, which are not feasible with other manufacturing processes at these scales.
- The use of additive manufacturing in the initial fabrication of models allows for the production of high-quality functional models with precise details. This overcomes the limitations of material removal manufacturing processes.



(a) (b) (c)

Fig. 1. Finished Shell. **(a)** View of the finished shell with a completed matrix pattern. **(b)** The top edge of the hemisphere has been completed without any defects. (c) The surface at the base of the hemisphere can be observed.

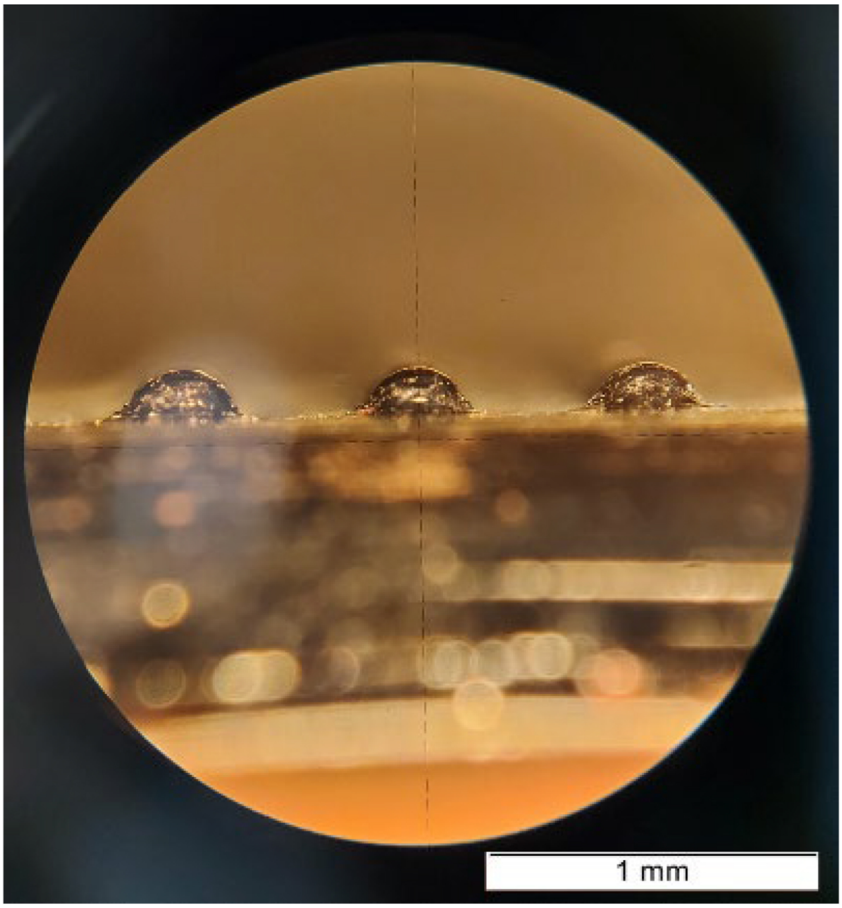


Fig. 2. View of the protruding hemispheres

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