A NOVEL TEST ARTIFACT FOR PERFORMANCE EVALUATION OF ADDITIVE MANUFACTURING PROCESSES

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INTRODUCTION

In the last decade, additive manufacturing (AM) has been emerged as a viable technique for creating functional parts with complex geometries that are difficult or impossible to fabricate through subtractive manufacturing techniques [1, 2]. However, the full potential of the AM processes cannot be realized without completing comprehensive analyses of the output quality [3]. Hence, quality characteristics of the fabricated parts, such as geometric accuracy and repeatability, must be thoroughly assessed to demonstrate the capabilities and limitations of AM processes as well as to predict process outcomes.

A broadly accepted approach for qualifying AM processes is to fabricate a specifically designed test artifact (benchmark product) and measuring the geometric accuracy and repeatability of the created features on the artifact [3-5]. The existing artifacts presented in the literature are suitable to evaluate the performance of AM processes for fabricating macro-scale parts [3-5]. However, AM processes have been recently used as an effective technique for meso- and micro-manufacturing [1]. Therefore, it’s crucial to assess the geometric accuracy and repeatability of meso- and micro-scale features fabricated by AM processes. This paper presents a novel test artifact design that can be used to evaluate the quality of additive manufacturing processes, particularly for fabricating micro- and meso-scale features. A set of tests is then performed through the use of proposed test artifact to determine the geometric accuracy and repeatability of an inkjet printing based AM process.

ARTIFACT DESIGN

The proposed test artifact with its key features is shown in Fig. 1. The overall dimension of the test artifact product design is selected to be 46 mm x 50 mm x 3 mm to include all necessary features that will enable evaluation of the limitations and capabilities of AM processes. This artifact is significantly smaller than those presented in the literature. The top surface is considered as the reference surface of the part, which is the primary datum defining the z direction. The substrate thickness of 3 mm is determined as a result of several iterations to prevent any possible warping and to ensure that the reference surface is flat.

FIGURE 1: The proposed artifact design with its key features: (a) Top view of the proposed design and (b) Trimetric perspective view of the proposed design.
The test artifact design includes several basic features such as holes, boss features, walls, pillars, slots with identical geometries and varying aspect ratios to highlight the limitations and basic capabilities of the AM processes of creating these features within desired accuracy level in a reproducible manner. Many identical features including square pillars array and cylindrical pillars array are embedded in this design to assess repeatability of the process. Furthermore, these features are oriented along different directions to test the accuracy of the processes in each of the three axes. In addition to these basic features, free-form surfaces, based on sinusoidal curves, are added onto this part to highlight the feasibility of AM processes in fabricating complex features. In addition to relatively large features, fine features are included to test the accuracy of the process and to obtain the minimum attainable feature size. These micro-scale features have the dimension down to 40 μm in x and y directions, and the minimum feature size in z direction is 80 μm. These features can be used to highlight the limitations of AM processes in terms of fabricating micro-scale features. Some other features such as suspended bridge and T-shape are also included to test the physical properties and mechanical properties of the materials used for additive manufacturing processes.

**PERFORMANCE EVALUATION**

In this study, a high resolution (30 μm) Objet Connex 350 multi-material three-dimensional printing system is used to fabricate the proposed test artifact (see Fig.2). The physical mechanism in this system is photo-polymerization through UV-light curing, and ultra-thin layers (30 μm) are employed layer by layer onto a build tray (350 mm x 350 mm x 200 mm) by inkjet printing technology. A round robin test is then performed to determine the geometric accuracy and repeatability of the process using white light interferometer (WLI), coordinate measuring machine (CMM-see Fig.2), and environmental scanning electron microscope (ESEM) with Matlab Image Processing Toolbox. The obtained quantitative assessments are used to highlight the limitations and capabilities of the process.

As a part of tests, the height measurements for staircases are performed using both WLI and CMM. The obtained dimensions are then compared with the corresponding dimensions on the design. The height measurements of the staircases are listed in Table 1. The first and second value in actual row corresponds to WLI and CMM measurements; respectively. It is concluded that the accuracy of the process in z direction is a primary function of resolution (minimum layer) thickness and the features having the dimensions of integer multiples of resolution can be fabricated more accurately.

**TABLE 1: Height Accuracy Measurements**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Design (µm)</th>
<th>Actual (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400</td>
<td>391.72/392.64</td>
</tr>
<tr>
<td>2</td>
<td>560</td>
<td>571.24/572.12</td>
</tr>
<tr>
<td>3</td>
<td>800</td>
<td>809.24/809.66</td>
</tr>
<tr>
<td>4</td>
<td>1600</td>
<td>1589.24/1590.12</td>
</tr>
</tbody>
</table>

**REFERENCES**


