An Investigation of Sloped Surface Roughness of Direct Poly-Jet 3D Printing

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***Abstract*—**This paper presents an experimental investigation of sloped surface roughness of the direct Poly Jet 3D printing process (DPJ-3DP). The parameter tested is the angle θ of the slopped surfaces in X and Y directions. The surface roughness parameter measured were the average mean surface roughness (Ra, μm), and the total height of the roughness profile (Rt, μm). The investigation shows that both Ra and Rt increased when the angle θ increased, in both X and Y directions. Additionally, the best value of surface parameters was achieved at angle θ equal to zero and the worst at θ equal to 90 degrees.

***Keywords*—**Surface roughness, direct poly-jet 3d printing, Sloped Surfaces

I. Introduction

The transition from the Rapid Prototyping (RP) and Rapid Tooling (RT) to the 3D Printing era has been taking place over the last years. The potentials brought about from such a technology aim to affect the way products are produced in a similar way that RP and RT transformed the traditional approaches for the design and development of a product. RP is an advanced manufacturing technology commercialized in the mid '80s. Currently, RP technology is widely utilized in manufacturing for conceptual and functional models. The application of RP has been shown to greatly shorten the design-manufacturing cycle, hence reducing the cost of product and increasing competitiveness. Further development of this technology is focusing on short and long term tooling which again has been proved in some cases to reduce costs and cycle times. Evolution of RP is the so called 3D printing processes. Recently developed technologies, such as Selective Laser Sintering (SLS), three-dimensional printing (3DP) and PolyJet enable to produce customized and complex parts in a short amount of time [1], compared to traditional RP technologies such as Stereolithography (SL). The Polyjet Direct 3D Printing (PJD-3DP) system builds detailed models with smooth surfaces by a process of addition photopolymer resin layers. This is enabled by a technology utilizing simultaneous jetting of modeling materials to create physical free form prototypes [2]. It is capable of creating parts of complex geometry with materials such as photo-curable resins that can be used in the areas of automotive, electronics, consumer goods, medical development, etc. In 3D printing, layers of a photopolymer resin are selectively jetted onto a build-tray via inkjet printing [3]. The printing head, composed by a number of micro jetting heads, injects a 16 μm thick layer of resin onto the built tray, corresponding to the built cross-sectional profile. The jetted photopolymer droplets are immediately cured with ultraviolet lamps that are mounted onto the print carriage. The repeated addition and solidification of resin layers produces an acrylic 3D model with a dimensional resolution of 16 microns. The PJD-3DP process has the ability to simultaneously jet multiple materials with different mechanical and optical properties. 3D printing could be considered a fully controllable process, since the majority of the process parameters can be altered on user's demand. Consequently the quality of the part does depend on a number of factors. Two basic quality indicators can be considered as major i.e. the model's surface roughness and model's dimensional accuracy. Both depend on the machine and the process variables [4]. Several attempts have been made to make a systematic analysis of errors and the quality of the prototypes.

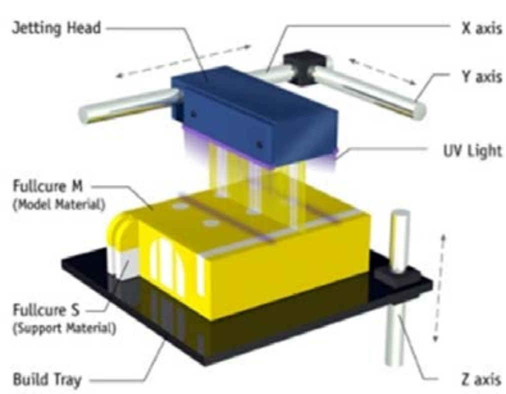

Fig. 1: The PolyJet Direct 3DP Process [2]

Experimental analysis of dimensions, surface roughness, and mechanical properties between PJD-3DP and ZCORP-3DP processes has been investigated in study [5]. Determination of surface texture parameters Ra and Rz for

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horizontal surfaces of parts produced by PJD-3DP have been performed in [6]. The results indicate that for mate surfaces Ra equals approximately 1.04μm while Rz about 5.6μm. For glossy surfaces Ra is approximately 0.84μm and Rz 3.8μm. Mechanical properties of parts produced by PJD-3DP, have been investigated in [7]. The study concluded that the part orientation has an effect on mechanical properties due to the heterogeneity of light energy by the photopolymer material during jetting process. The variability in the mechanical properties of parts manufactured via PJD-3DP has also been examined in [3]. It has been concluded that part orientation affects tensile strength and tensile modules with highest tensile modulus occurring in the XZ orientation. An investigation of the process parameters effects, concerning the dimensional accuracy of parts produced by the Polyjet Direct 3D Printing Process, was presented in [8]. The results indicate that the dimensional accuracy of external dimensions are affected in principle by the blade movement and the Layer Thickness, while the internal, primary by the Layer Thickness and the Scale factor. Additionally, an investigation of the process parameters effects, concerning the vertical and planar surface roughness of parts produced by Polyjet Direct 3D Printing Process was presented in [9]. The results indicate that the 16 microns layer thickness, and glossy style provide the optimum surface roughness results while scale factor could not be considered as a dominant factor.

In the current work, the slopped surface roughness is investigated in direction X and in direction Y as indicated in Figures 5 and 6. The results were compared with the analytical model (eq. 1) which is extracted in the [10]

$$\mathrm{Ra} = \frac{L_t \sin(\theta)}{4\tan(\theta)} \qquad (1)$$

where Lt is the layer thickness-height and θ is the sloped surface angle.

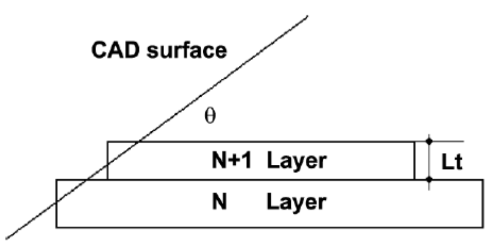

Fig. 2. Platform setup-Side view (Y-Z plane)

II. EXPERIMENTAL SETUP

A part has been designed with two details on the top surface (see Fig. 3) and then is placed seven times, on the same platform, as shown in Figures 4-6. Slopped surfaces on both X and Y directions are 0, 15, 30, 45, 60, 75 and 90 degrees from build platform. The selected part geometry has been prepared in STL format.

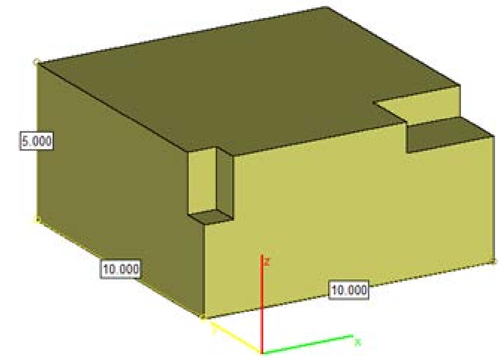

Fig. 3: CAD file of the test part

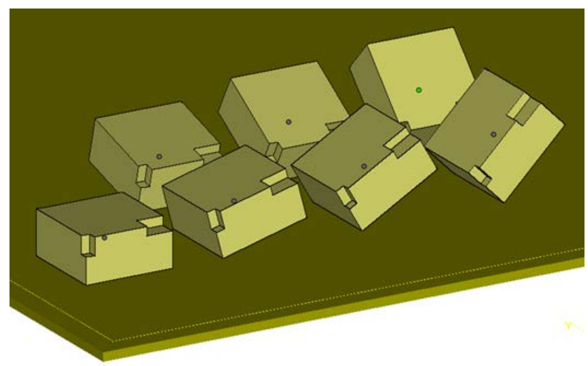

Fig. 4. Platform setup-ISO view

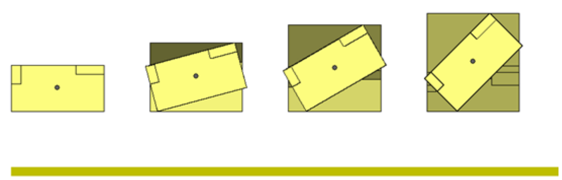

Fig. 5. Platform setup-Side view (X-Z plane)

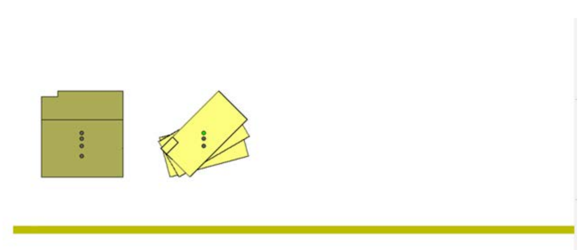

Fig. 6. Platform setup-Side view (Y-Z plane)

The surface texture parameters measured during this study were the following (Fig.7):

- Ra (μm): the arithmetic mean surface roughness (arithmetical mean of the sums of all profile values). Ra is by far the most commonly used parameter in surface finish measurement and for general quality control. Despite its inherent limitations, it is easy to measure and offers a good overall description of the height characteristics of a surface profile [3].

and

- Rt or Rmax (μm): total height of the roughness profile, i.e., the vertical distance between the highest peal and the lowest valley along the assessment length of the profile. From Fig.1, Rt= Zp + Zv. This parameter is very sensitive to the high peaks or deep scratches.

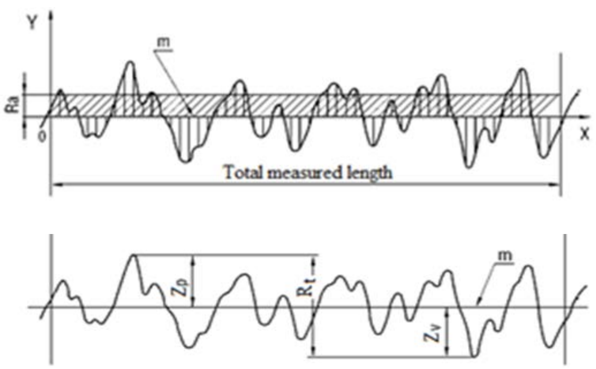

Fig. 7: Surface texture parameters

The seven prototypes have been built on an Objet Eden 250 using the Objet Fullcure 720 RGD material (Fig.8). The layer height was 16 microns, and the parts were built in mate mode.

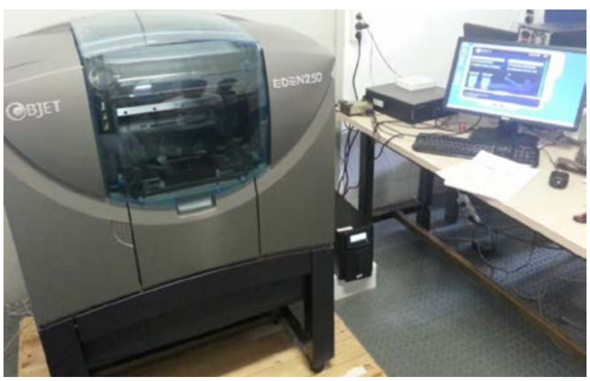

Fig. 8. Eden250™ 3D Printing System

III. I. EXPERIMENTAL RESULTS AND CONCLUTIONS

The seven parts were oriented and set on platform as shown in Figures 4-6. The layer thickness was set at 16 microns and the build style was set on mate mode. After the manufacturing the seven parts were cleaned using a waterjet machine and then sloped surfaces were measured using the Mitutoyo Surftest RJ-210 tester. The measurements of the sloped surfaces surface roughness were shown at Tables 1 and 2 in both X and Y directions. At Figures 9 and 10 the comparison between experimental and analytical (eq. 1) measurements are presented. The results shows that analytical model is not appropriate for surface roughness (Ra) prediction. Additionally, experimental results shows that the surface roughness increased when the angle degrees increased.

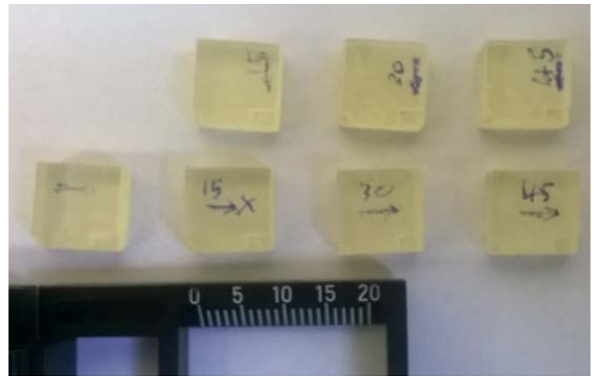

Fig. 9. Parts with sloped surfaces in X and Y directions

degrees	Ra (μm)	Rt (μm)
0	0.537	4.294
15	4.188	29.311
30	6.259	44.345
45	8.377	61.807
60	12.425	102.28
75	15.211	140.93
90	18.722	137.54

Table 1: X-Direction measurements (Y Rotation)

degrees	Ra (μm)	Rt (μm)
0	1.985	13.393
15	3.584	25.167
30	5.367	43.641
45	8.729	76.513
60	12.035	80.545
75	14.142	97.445
90	14.496	105.62

Table 2: Y-Direction measurements (X Rotation)

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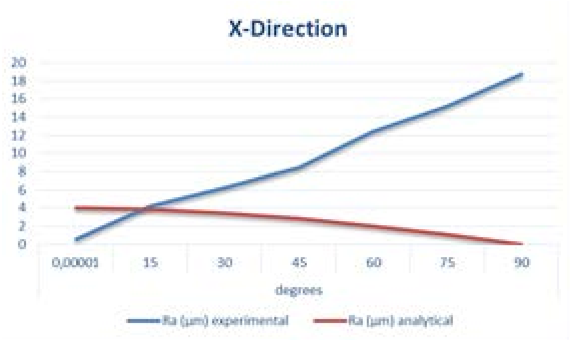

Fig. 9. Experimental and analytical measurements in X-Direction

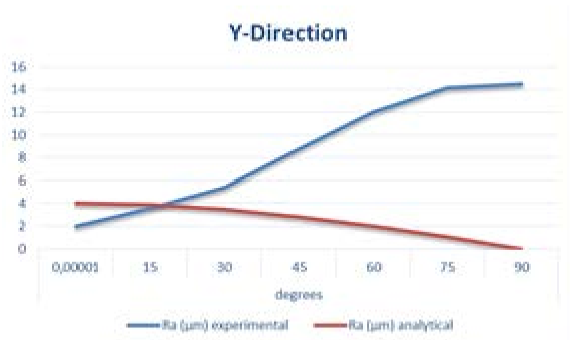

Fig. 10. Experimental and analytical measurements in Y-Direction

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