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Procedia Manufacturing 47 (2020) 1078–1083

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

23rd International Conference on Material Forming (ESAFORM 2020)

Additive Manufacturing using UV Polymerization of Complex Surfaces Generated by Two Main B-Splines

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Abstract

In the modern industry the necessity to realize products with given specifications requires the use of proper tools. In particular, the realization of prototypes or the possibility to realize directly the product without customized tools can be allowed with less time consuming by additive manufacturing instead of conventional techniques. The present research aims at investigating the effect of a complex geometry on dimensional and surface quality of a component made by additive manufacturing of UV treatable polymers by a poly-jet system. A semi-ellipsoid surface was generated on two main B-spline lines realized with different curvatures using six control points each. The CAD information was converted into a STL and a slicing interval less than 0.05 mm applied. The effect of the two building directions imposed to the nozzle with respect to the two main profiles of the surface was evaluated in terms of surface waviness and staircase. Due to the complexity of the geometry, the shape information was detected by a 3D SCANNER. The shape of the photopolymerized model was in excellent agreement with that of CAD and the 3D SCANNER was able to detect waviness and staircase. The methodology proposed and results are reported in detail.

Keywords: Additive manufacturing, UV polymerization, Complex geometry, Prototyping, 3D scanner

Nomenclature

AM Additive Manufacturing
CAD Computer Aided Design
NURBS Non Uniform rational Basis Spline
RP Rapid Prototyping
STL Standard Triangulation Language

1. Introduction

In modern industry the shortening and the semplification of process plans are strongly required in order to reduce processing time, tools and fixtures costs. Normally, that semplification can be effectively realized only for simple geometries. The additive manufacturing techniques are characterized by high flexibility levels that allow the obtaining of simple and complex geometries with reduced times to design validation and reduced setup times without the use of conventional tools. Such techniques in the field of polymers allow, using also hybrid supplying material systems, to realize components with geometrical and surface characteristics that sometimes are similar to those of injection molding. One of the difference between conventional processes for polymer made parts and additive manufacturing techniques is represented by the deposition strategy [1] which can influence the shape, the geometry and the mechanical properties. For that reason some researchers are trying to implement hybrid approaches in building models and components [2] with additive manufacturing technologies.

Some other researchers take the effective advantages of such techniques in the prototyping phase in order to validate the design stage of the product and sometimes of some phases of the process. A review on different additive manufacturing

10.1016/j.promfg.2020.04.352

processes for automotive applications in which different materials are taken into account is reported in [3].

When the photopolymers are considered, the application of additive manufacturing can be performed in the direct realization of part. Anyway also in those circumstances some authors [4] tried to investigate the effect of the material composition on the final product properties. In fact, the photopolymerization consists in the transformation of a liquid photopolymer into solid 3D objects. During photopolymerization, the low molecular weight monomers connect to each other to form large molecular weighted solids.

In general, the photopolymerization based additive manufacturing techniques are characterized by a reduction in the layer thickness when compared with other additive manufacturing methods [5]. That behaviour is also due to the reduction of light scattering by the use of light flashing as reported in [6]. However they are very sensitive to high temperature and to light exposition. But, the very low layer thickness generally obtainable allows to manage complex shapes and geometries. This is why, the value of different parameters of UV system affecting the quality photopolymerized parts can be tuned [7]. In particular when the photopolymerization of additive manufactured material is performed with jetting technologies [8].

At the same time, the improvement of the CAD tools in managing complex geometries, built as B-spline surfaces or curves, is always increasing. Some researchers studied the application of B-splines and in particular of B-spline curves in which the shape of the curve is given by different control points. An example of the realization of propeller blades starting from B-spline based curve surfaces is reported in [9]. The potential of that kind of curves also when implemented in CNC controllers is given in [10], while an algorithm to manage the B- Splines is proposed in [11].

In [8, 12] the authors found a method based on artificial intelligence in which the slicing mode is optimized in order to reduce the gap between the CAD information and those obtained after slicing. The solution proposed is represented by the possibility to slice directly the CAD model following the optimization described. In that way the disadvantage is related to the instability generated by the direct slicing of the CAD surfaces in which too much information than required are reported. Some other authors described some simulations of the additive manufacturing process in order to predict the quality of the AM part [13], very promising technique for metals, or the use of the in service simulation of the component during the design phase [14].

So, it appears that the main attitudes of the additive manufacturing are related to the design stage of each component in which some concept, ergonomic and sometimes in service properties need to be verified before the definitive project [15]. However, under some conditions in terms material and process parameters the properties of the definitive component, in particular for polymers, are very similar to those realized by other techniques. In general, the success of the prototype realization depends on the data computing.

The STL (Standard Triangulation Language) represents the initial standard to manage CAD information in order to get the input file for additive manufacturing. The surface of the object to be realized is approximated by triangles identified with the coordinates of the their vertices and the orientation of the normal of each triangle surface. The STL, derived initially by the name of the input file for STereoLithography, can be supplied as binary or ASCII. In [16] the potential of that format in describing complex geometries as well as the possibility to use that for Finite Element Analysis is shown. Some methods related to the smoothing of STL file information [17,18] and some modification algorithms [19,20] to improve surface description of input file are under investigation.

Few papers in scientific literature are available in which the effective realization of complex shapes and geometries is really performed and described from the quality point of view.

The present paper aims at proposing a methodology to investigate the effect of different phases from the CAD realization of a geometry based on two B-spline curves to the physical prototype model through the STL standard. The quality of the realized prototype in which two different building directions are used is verified comparing the STL geometry obtained by 3D scanning with the initial STL and CAD geometry. The methodology proposed and the results are described in detail.

2. Methodology and details of the experiment procedure

2.1. Methodology

The methodology proposed in this investigation is reported in Fig. 1. It consists initially in generating a complex geometry, by means of the CAD tool, starting from to main B-splines. Once generated, a three dimensional surface approximating the curves was built and converted into a STL file from which the slicing phase including the support generation took place. The physical model was realized by means of a poly-jet system in which the photopolymerization was performed considering two deposition directions of nozzle.

Due to the geometry complexity, the evaluation of the respect of requirements was performed using a non – contact 3D SCANNER. The cloud data points were converted in a STL file and compared with that generated by the CAD and with physical model. This kind of methodology allows to detect some sources of deviation from the desired geometry.

2.2. Details of the experiment procedure

The semi-ellipsoidal surface was generated on two main B-spline lines realized with different curvatures using six control points each. In Fig. 2 the characteristics of the B-spline curves and their composition in order to get the structure of the input digital model are reported. The initial CAD information (Fig. 3), related to a solid with maximum planar dimensions of 100x80 mm^2 and an height of the dome equal to 18.75 mm plus a basis of 5 mm, was converted into STL.

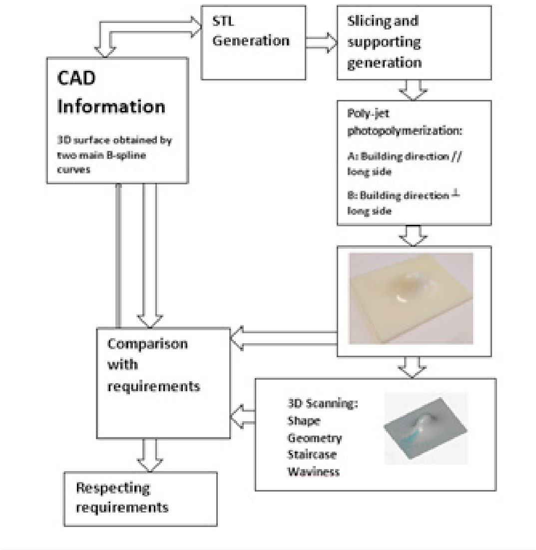

Fig. 1. Methodology.

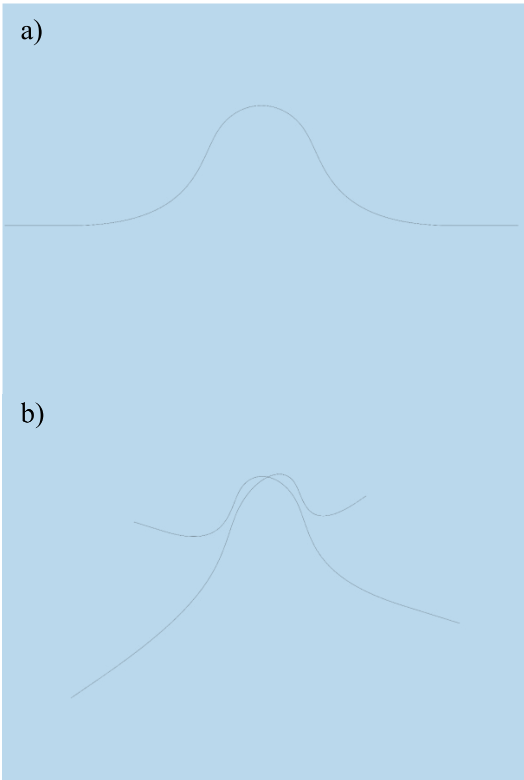

Fig. 2. B-spline source curves (a) and their composition (b).

The mathematical and the STL surfaces were overlapped to each other (Fig. 4). The difference in triangulation density between the planar surface and the curved ones can be clearly observed.

In fact, the STL conversion was performed in order to get [21] the shortest distance (d) between the point at the surface of the triangle ($P_{TRIANGLE}$) approximating the CAD surface and the point on the surface itself ($P_{SURFACE}$):

$$MIN(d) = \left| P_{TRIANGLE} - P_{SURFACE} \right| \tag{1}$$

The slicing interval of 0.014 mm was applied and a plane of about 1 mm was used as supporting volume. The building of the model was performed with a OBJECT30 using a white photopolymer with the poly-jet technology consisting in the deposition of a liquid polymer in which the solidification in order to get physical model (Fig. 5) was obtained by the UV polymerization.

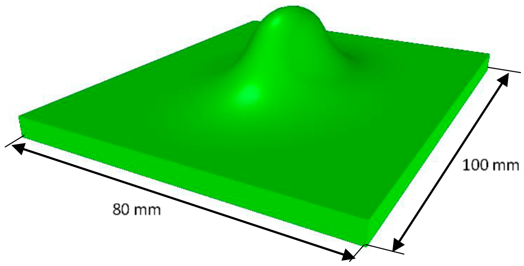

Fig. 3. CAD 3D model.

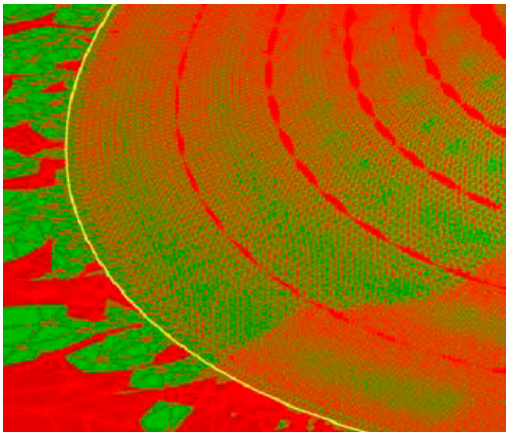

Fig. 4. Characteristics of the STL model: difference in triangulation density between planar and curved surfaces of the STL model got by the CAD.

The strategy used in the building phase was chosen in order to perform the main deposition in the direction parallel (A) and perpendicular (B) to the long side (Fig. 6). A typical global surface generated by the 3D scanning method is shown in Fig. 7. The synthesis of the digital models used is reported in Table1.

Table 1. Sinthesys of the considered digital models.

Digital model data	CAD	3D SCANNER
Source	Shape	Cloud
Conversion	STL	-
Delivery	STL + slicing +supporting	-
Comparison	CAD-STL	STL

3. Results

3.1. Results on physical model realization

In Fig. 2 the two main B-splines considered as the main structure of the surface CAD model can be seen. In Figures 4 and 8, the details of the comparison between the CAD surface shape and that got after data conversion into the STL is reported. Some deviations arise in particular in the part of the dome in which the maximum difference in the height between the original geometry information and that of STL can reach 1 μm that is in agreement with that found in [22]. Anyway, such type of deviation is evidenced by the inverted normal of triangles that appears as a continuity solution. In Fig. 9 the dome of the physical model obtained by the additive manufacturing can be observed.

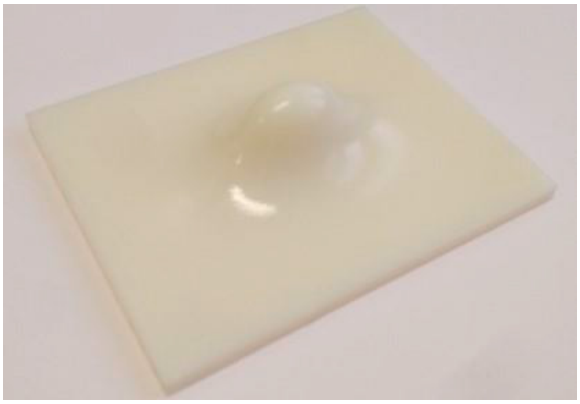

Fig. 5. Realized photopolymerized model.

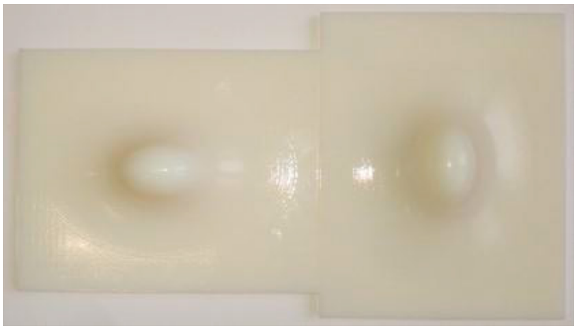

Fig. 6. Deposition direction of the photopolymerized model (←).

Fig. 7. Surface of the realized object detected by the 3D SCANNER.

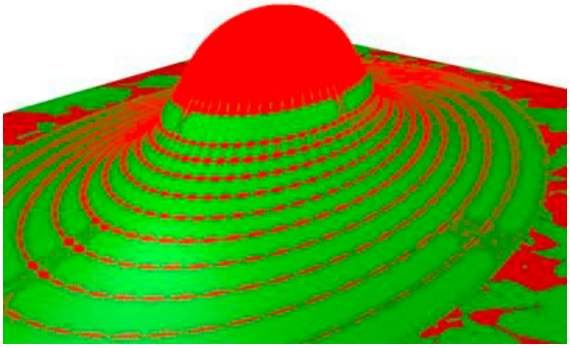

Fig. 8. Details of the STL model: continuity solutions in the dome.

Fig. 9. Particular of the dome of the realized physical models.

From the global point view the shape and the geometry of the physical model respect the specifications of the CAD model. In particular, the height of the dome in the two conditions of deposition directions A and B can vary between 18.73 and 18.78 mm. In detail, some texture due to the deposition direction is appreciable. The waviness produced could be much less than 0.1 mm and in anycase this is confused with a smoothed staircase effect produced by the slicing in this kind of additive manufacturing technology applied on photopolymers.

3.2. Results on physical model detection

In Fig. 10, the comparison between the physical surface of the model and that of the STL obtained by the 3D SCANNER is observed. The surface obtained by the SCANNER seems to copy the curvature of the object. From the global point of view the geometrical differences that arise by the comparison between the STL generated by the CAD and that obtained by the 3D SCANNER can be reported as follows. The model with deposition direction parallel to the longest side got an height of the dome equal to 18.60 mm while the other one an height of 18.852 mm. It means that the surface of the dome appears very difficult to detect and the digital points are probably dependent on the reflectance and on the diffusive modes of the reflected lights.

Anyway, the 3D SCANNER is able to detect the waviness and the staircase [21, 23, 24] of the surface at the basis of the models and sometimes the deposition direction like reported in Fig. 11.

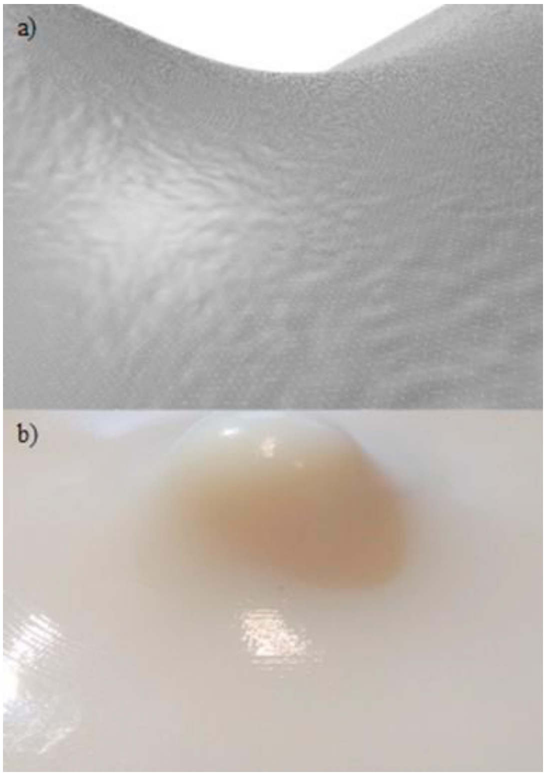

Fig. 10. Details of the surface STL obtained by the 3D SCANNER (a) and the real one (b).

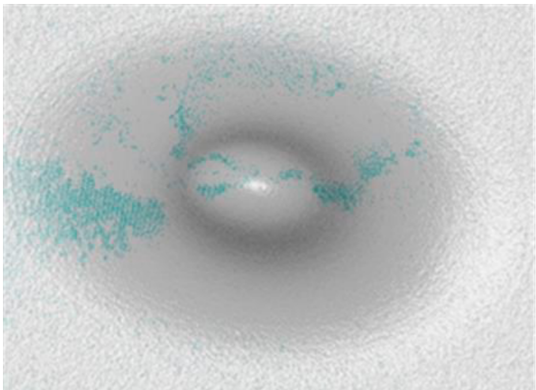

Fig.11. Waviness and staircase effect detected by the 3D SCANNER.

4. Conclusions

The present paper aims at investigating the effect of the different phases on the dimensional and surface quality of models realized by means of an additive manufacturing technology based on the poly-jet deposition of photopolymer filament solidified by UV. Two deposition directions were considered. The one parallel and the other one perpendicular to the long side of the physical model.

It can be concluded that:

- The comparison between the CAD mathematics of surfaces and those obtained by the STL conversion got a maximum deviation of about 1 μm;
- The slicing phase introduces a further discretization on the surface of the realized model independently of the deposition direction;
- The physical model is characterized by a waviness and a smoothed staircase effect independently of the deposition direction with a deviation of some hundredths in terms of the height of the dome;
- The 3D SCANNER and the conversion of the surface into a STL file allows to detect the shape of the part and allows to evidence the waviness produced by the poly-jet technology;
- The comparison between the STL information got by the CAD and those generated by the 3D SCANNER allows to detect a maximum deviation from requirements of about 0.15 mm for the height of the dome.

It results the potential of such type of Additive Manufacturing Technology in realizing complex models as well as that of 3D SCANNER in detecting complex shapes.

Acknowledgements

Authors wish to acknowledge the special work performed by technical staff of the Università Politecnica delle Marche in particular to prof. Lucchetta. The UNIVERSITA' POLITECNICA DELLE MARCHE is also acknowledged for funding this research.

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