# Analysis of Geometric and Dimensional Stability Over Time of Printed Parts by CJP Additive Technique

Sara Giganto, Pablo Zapico, Ana Isabel Fernández-Abia and Susana Martínez-Pellitero

***Abstract*—Among the different additive manufacturing techniques that have emerged in recent years, the CJP (Color Jet Printing) technique has several advantages over the rest of these. Also, there are several disadvantages in terms of the surface finish, density and mechanical properties. On the other hand, the porosity of the parts manufactured by CJP could affect to the geometric and dimensional stability over time, which is analysed in this paper. Therefore, a dimensional study of the different geometries of a designed artefact was carried out. The results show as the CJP parts are dimensionally stable, despite the high porosity and the exposure to usual environments of humidity and temperature.**

***Index Terms*—Additive Manufacturing, CJP technique, Dimensional Control**

## I. Introduction

ADDITIVE manufacturing processes can be used to manufacture prototypes, tools or functional parts. New additive processes appear every day. There is great confusion between the appropriate designation for each technique and a great need to develop specific standards. In this sense, ISO 17296 [1] aims to explain the general working principles for the different technologies and the processing of feedstock into the part geometry. Binder Jetting process allows working with a wide range of materials, by the selective deposition of a binder on a bed of pre-deposited powder. One of these techniques is the Three Dimensional Printing (3DP), which a liquid binder is selectively added in a powder bed to form a green part that has the specifications of the CAD [2]. Each company has its 3DP machines depending on the material used, metal, ceramic or plastic. A commercial 3DP technique is the ColorJet Printing (CJP), which involves two major components: ceramic powder and colour binder [3]. The powder material is spread in thin layers over the build platform with a roller. After, colour binder is selectively jetted from inkjet print heads over the powder layer, which causes the powder to solidify. The build platform lowers with every subsequent layer which is spread and printed, resulting in a full-colour three-dimensional model or green part. Green parts have low consistency; therefore, it is necessary to carry out a drying of the printed parts and an infiltration to improve the mechanical properties. Although initially this technique was used only for prototypes development, nowadays, its use has been extended to other applications, as tooling, jobbing or casting moulds in different industrial sectors as well as in the medical field. Sectors where it is necessary to work with complex geometries and with high dimensional precision.

The main advantage of this technique is the high flexibility of the geometric design without the need for additional supports. In contrast, this technique has several limitations such as poor surface finish, density and mechanical properties. Infiltration and isostatic pressing are used to improve parts quality [4]. Also, the intrinsic properties of the binder play an important role, its molecular weight determines the penetration, its surface tension and viscosity determine the infiltration kinetics and spreading as well as jet stability. Thus, the binder must be penetrable into the powder bed and insoluble after printing, while providing sufficient strength to the printed part. The resolution of the printed parts also depends on the size and shape of the powdered material as well as the interaction between the binder and the powder and the spreading speed of both powder and binder [5]. To date, extensive researches have been carried out on several aspects, including ceramic powder and binder properties, binder-powder bed interaction and process parameters [4].

However, there are other important aspect that has not been analysed yet, such as degradation of the parts over time. This degradation could be due to two possible phenomena caused by the high porosity of the printed parts. One phenomenon may be the loss of material due to poor surface consistency and the other one may be the gain or loss of humidity caused by the environment. These phenomena could produce dimensional and/or geometrical changes in the printed parts. Therefore, the main objective of this work is to check whether these phenomena really exist verifying their effect on the dimensions and geometry of the printed parts. For that, a gauge artefact based on

Manuscript received March 20, 2019; revised March 26, 2019. This work was supported by Spanish Ministry of Economy, Industry and Competitiveness (project DPI2017-89840-R) and by the Junta de Castilla y León and FEDER (project LE027P17).

Sara Giganto is with the Department of Manufacturing Engineering, University of León, Campus de Vegazana, s/n, 24071 León, Spain (phone: (0034) 987291000 - Ext. 3627; e-mail: sgigf@unileon.es).

Pablo Zapico is with the Department of Manufacturing Engineering, University of León, Campus de Vegazana, s/n, 24071 León, Spain (e-mail: pzapg@unileon.es).

Ana Isabel Fernández-Abia is with the Department of Manufacturing Engineering, University of León, Campus de Vegazana, s/n, 24071 León, Spain (e-mail: aifera@unileon.es).

Susana Martínez-Pellitero is with the Department of Manufacturing Engineering, University of León, Campus de Vegazana, s/n, 24071 León, Spain (e-mail: smarp@unileon.es).

primitive geometries built on inclined planes was designed and later printed using this technique. The artefact was printed and scanned by means of an optical scanner, a year ago, and has been scanned now to compare the dimensional evolution.

## II. Equipment and Methodology

A CJP 3DSystems ProJet 660Pro machine (Fig. 1) was used to manufacture a ceramic artefact. Main features of ProJet 660Pro are shown in Table I. The materials used were VisiJet PXL Core and VisiJet PXL Binder.

Fig. 1. 3DP 3DSystems ProJet 660Pro machine.

TABLE I
ProJet 660Pro features [6]

| Property | Units | Value |
|---|---|---|
| Net Build Volume (xyz) | mm | 254 x 381 x 203 |
| Resolution | DPI | 600 x 540 |
| Layer Thickness | mm | 0.1 |
| Minimum Feature Size | mm | 0.5 |
| Max. Vertical Build Speed | mm/h | 28 |
| Build Material | - | VisiJet PXL |
| Operating Temperature Range | ºC | 13 - 24 |
| Operating Humidity Range | % | 20 - 55, non-condensing |

After manufacturing and cleaning the part, it was infiltrated with cyanoacrylate in order to give it specific properties such as strength and durability. Then the part was left to dry for two hours.

In order to analyse geometrically and dimensionally the built artefact, a structured blue-light scanner was used. In particular, the 3D Breuckmann smartSCAN$^{3D}$-HE model (Fig. 2), now known as the AICON SmartScan. This equipment can work with different fields of view (FOVs). In this work, taking into account the size of the reference artefact, 125 mm FOV has been used. Table II shows the optical scanner specifications. With the purpose of the adequate three-dimensional acquisition of data, the scanner was calibrated before measuring.

Fig. 2. Breuckmann smartSCAN$^{3D}$-HE.

TABLE II
Breuckmann smartSCAN$^{3D}$-HE specification [7]

| Property | Units | Value |
|---|---|---|
| FOV | mm | 125 |
| FOV size | mm | 95 x 95 |
| Measuring depth | mm | 60 |
| X, Y resolution | μm | 50 |
| Z resolution | μm | 5 |
| Triangulation angle | º | 32.5 |
| Working distance | mm | 370 |

To design the artefact, recommendations expressed by Moylan have been taken into account [8]. Among them, the artefact must be greater enough to check the printer performance, containing both outgoing and incoming geometries, manufacturing time should not be very long and consume of material low. Also, artefact should be easy to measure.

In consequence, the artefact has dimensions of 135 mm x 88 mm x 88 mm. It has six different planes with orientation of 0°, 30°, 45°, 60°, 75° and 90° with the base plane of the printing bed (XY plane) respectively (Fig. 3). In each plane the following geometrical features have been included:

- A semi-spherical protrusion of 20 mm diameter.
- A conical protrusion of 24 mm diameter and 60° angle.
- A cylindrical protrusion of 20 mm diameter and 20 mm height with an internal cylindrical hole of 14 mm diameter.
- A cylindrical protrusion of 20 mm diameter and 20 mm height with an internal cylindrical hole of 16 mm diameter.

In addition, the artefact has a perpendicular plane, which has an angle of 90° with respect to XY plane and has a semi-spherical hole, one cylindrical and one conical.

Fig. 3. Test artefact.

The artefact was lightened at the bottom to decrease cost and printing time. The printing time was 4 hours and 59 minutes, and the volume of material used was 316.99 cm$^3$.

Fig. 4 shows the work methodology followed. Once the test artefact was designed, it was printed using the CJP machine. The material used in this study was a plaster based powder ($CaSO_4.1/2H_2O$) with a binder solution of 2-Pyrrodone. This material gives the part a matte white colour that favours the subsequent three-dimensional digitalization by means of the structured light system. As it is known, in

ISBN: 978-988-14048-6-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

order to carry out an accurate measurement by optical techniques it is necessary to avoid the reflections produced by light. In addition, the process of infiltration with cyanoacrylate doesn´t colour the part. Then, the artefact was digitized by the optical scanner using Optocat® software. Finally, the measurement and analysis of results was carried out by means of Geomagic Control® software.

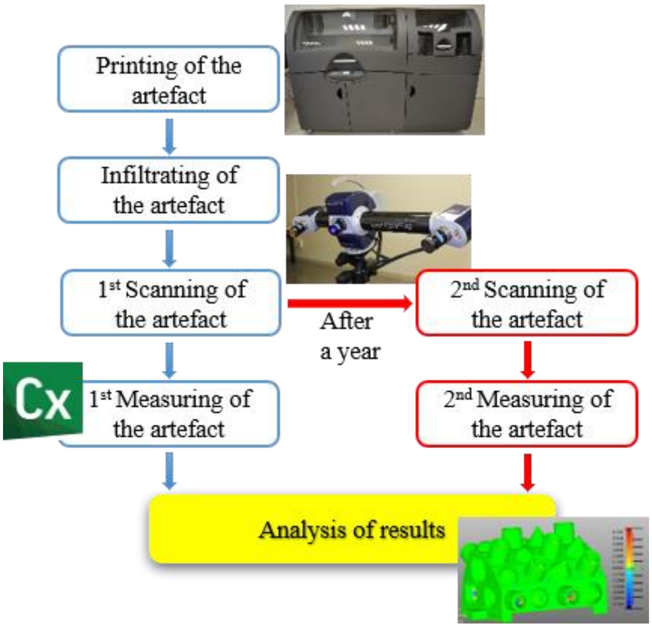
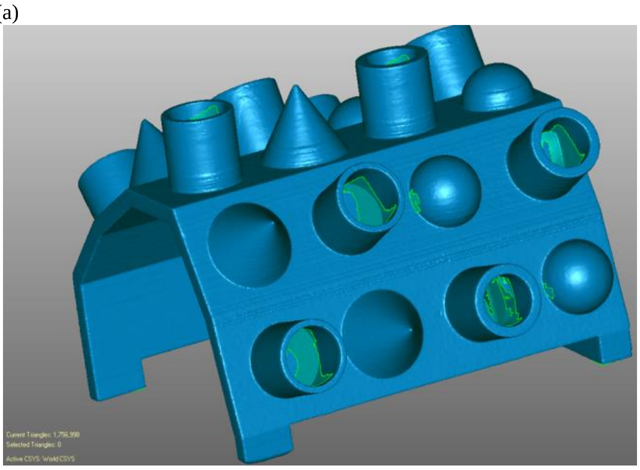



Fig. 4. Methodology.

(a)



(b)

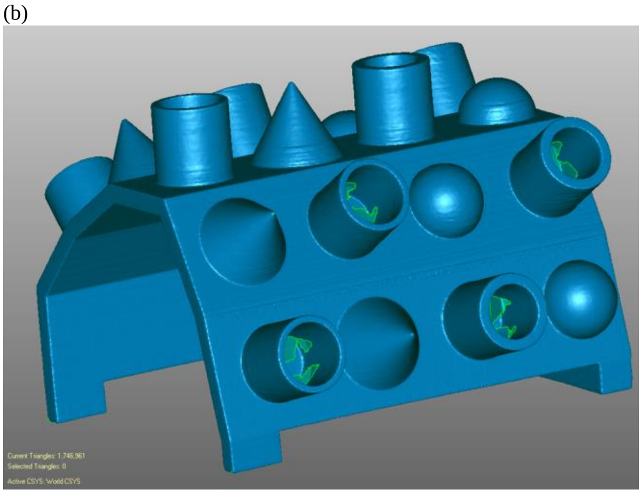
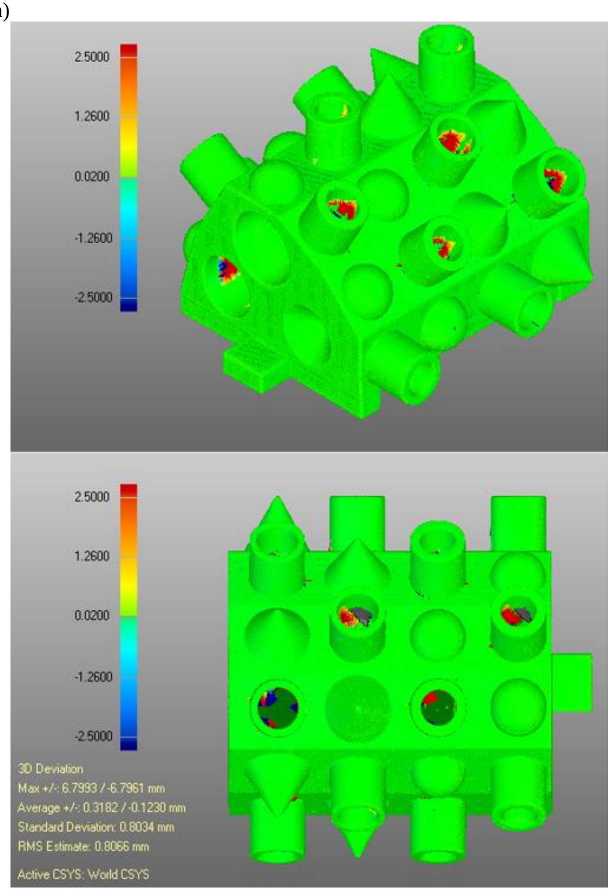


Fig. 5. Meshes: (a) Reference mesh; (b) Test mesh.

The scanning of the artefact on both occasions has been done in the same way, the resulting meshes are shown in Fig. 5. These meshes have a similar number of triangles and the few problems of occlusion that have occurred have also been very similar, mainly inside the geometries. The first scan, which was obtained a year ago, has been named as "Reference" (Fig. 5a) and the second scan has been named as "Test" (Fig. 5b).

## III. Results

(a)




(b)

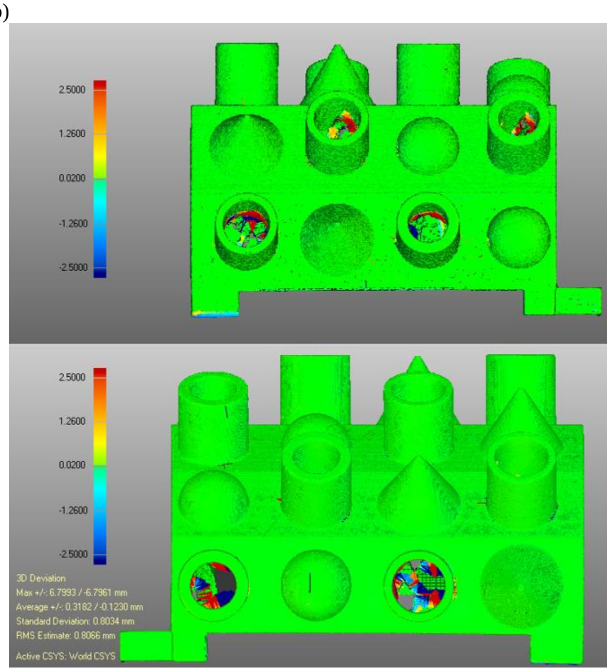



Fig. 6. 3D comparative: (a) Isometric and Top views; (b) Front and Back views.

ISBN: 978-988-14048-6-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Each mesh has been aligned by defining three orthogonal planes (0º plane and both 90º planes). Then, a 3D comparative was made, using the planar features which were defined individually for the Feature-Based Alignment. Results of this 3D comparative are shown in Fig. 6. As can be seen, there are no appreciable deviations in the defined spectrum. The entire comparative shows green colour, indicating that the deviations between Test and Reference are less than 0.02 mm, which is lower than the resolution according to X/Y axis of the scanner in the FOV used.

The red or blue areas that are appreciated, are the result of the differences in the scans. These differences are due to the occlusion problems, typical of the optical techniques, so they don´t have to be taken into account in the final results.

A 2D comparative was done for each defined geometry. In this paper, the results of cylinder with external diameter of 20 mm and internal diameter of 14 mm are shown. Section was taken 4 mm from the top surface to decrease the occlusion effect in the internal cylinder. Fig. 7 shows the sections for each cylinder printing with different angle. As can be observe, green colour is representative in all the external cylinders, which verifies the 3D comparative results. In internal sections appears orange and yellow areas because the cited occlusions problems.

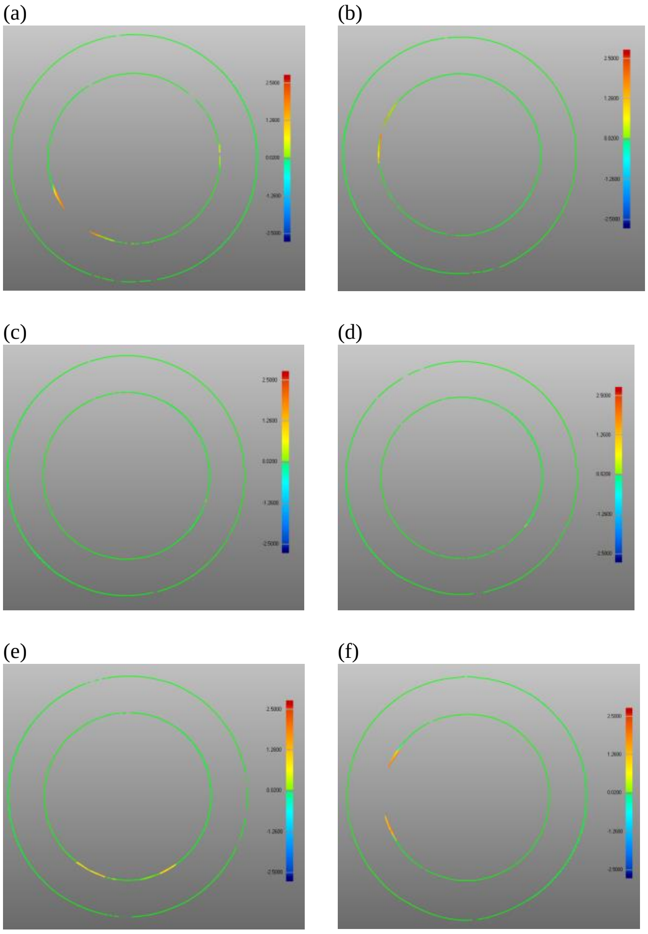



Fig. 7. 2D comparative of the Cylinder with 20 mm external diameter and 14 mm internal diameter: (a) 0º plane; (b) 30º plane; (c) 45º plane; (d) 60º plane; (e) 75º plane; (f) 90º plane.

## IV. Conclusions

In this work, the influence of the time in the geometric and dimensional stability of the parts manufactured by means of CJP additive technique was analysed. An artefact was designed to this study. The artefact has several planes with different orientations and each plane have some features as cylinders, cones and semi-spheres. An optic scanner was used to measure the artefact. Thus, poor consistency of these parts is not altered by the effect of contact with mechanical systems. In addition, these systems allow to obtain a high number of points in a short time, which allows a reconstruction of the captured features with high precision. On the other hand, due to the properties of the printing material (matte and white), there are no problems of reflections with the light and false points disappear.

The artefact was measured twice. The first time (Reference scan) a year ago, and the second time (Test scan) at present.

The analysis had two parts:

- A 3D comparative between the Reference scan and the Test scan.
- A 2D comparative for each feature.

Regarding the obtained results, we can conclude that this material has a good behaviour and printed parts by CJP maintain geometric and dimensional properties.

We are working on the analysis of the dimensional precision of the parts built using this material and technique. In order to assure the quality of printed parts by this CJP process, is necessary to know and quantify the tolerances and deviations with respect to nominal or design values. This becomes important when these parts have high requirements, for example in automobile and aerospace industrial sector. The results of this work will be presented in futures papers.

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