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DEVELOPMENT OF A METHODOLOGY FOR THE MATERIALISATION OF CERAMIC RAPID PROTOTYPES BASED ON SUBSTRACTIVE METHODS

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ABSTRACT

The concept of obtaining Rapid Prototypes build up on Ceramic materials is increasingly being an object of study due to the multiple applications of different Ceramic compounds, for instance, in the biomedical or in the aerospace industries. However, technical ceramics are much difficult to machine than other materials due to special characteristics such as fragility, dustiness and abrasive behaviour. As a difference to studies that approach the realisation of Ceramic prototypes by the application of layered manufacturing technologies, the purpose of this work is to analyse the specific features of technical ceramic materials and to develop a methodology for the materialisation of ceramic rapid prototypes based on subtractive methods. In the present study, the ceramic material is compacted on a cylindrical pre-form and then machined into a geometry that will then be sintered, deforming to the final shape required. The study presents the most relevant points of the methodology and the potential outcomes of its application.

Keywords: Technical ceramics, subtractive methods, sintering processes, universal fixing.

1. INTRODUCTION

The technical ceramic compounds[1,2,3] yield a large number of benefits over other sorts of metallic materials. In particular, in the biomedical industry, the ceramic prostheses have the benefit of higher biocompatibility than titanium implants and a longer expected life that leads to a reduction on medical interventions and therefore to a better quality of life for the patient. However, as a difference with the conventional ceramic parts, the geometries requested for such applications are much demanding thus complicating the manufacturing process and -in most cases- making unfeasible the materialisation by means of moulding processes.

In this field, most of the present efforts are being made in order to obtain ceramic prosthesis utilising Rapid Manufacturing techniques in the families of the Layered Manufacturing Technologies [4,5]. In the cases where additive methods are applied, the research focuses on the implementation of the materials in the common RM machines and/or on the development of new RM machines more appropriate for the use of ceramic materials.

On the contrary, the present study focuses on the development of a methodology for obtaining pieces made of technical ceramic compounds by means of the application of subtractive methods to pre-sintered material (i.e.; machining of green material)[6,7,8]. This approach encounters some problems due to the properties of the green material, such as fragility, dustiness and abrasive behaviour that have to be properly addressed.

2. UNIVERSAL FIXTURE DEVICES

The raw material utilised in the present study is Zirconia yttria in the form of compact cylinders, as shown in Figures 1 and 2. As stated in the introduction, the fragility of the technical ceramic makes it unfeasible to use regular subjection fixtures when machining the blocks. In particular, due to the particularities of the specific Zirconia used in the tests, this restriction applies to most of the rigid chucks, being it hard (metallic) or soft (plastic).

To overcome this issue, two subjection techniques can be applied. Firstly, the wax immersion consists on the complete subjection of a raw part immersing it in a wax bed (Figure 1). This technique is specially aimed to the subjection of small parts of raw material and when the pre-form shape is close to the final desired part. However, the wax immersion can cause the pre-form to collapse if the wax dilatation coefficient during the solidification diverts from Zirconia's. Alternatively, the wax bed technique (Figure 2) consists on the subjection of the part by a small contact, taking the function of an adherent. This technique is especially efficient because technical ceramic require to be machined at a small feed rate and always against the material, thus loading the wax bed just with compression stresses.

Figure 1. Cilinder fixed by wax immersion

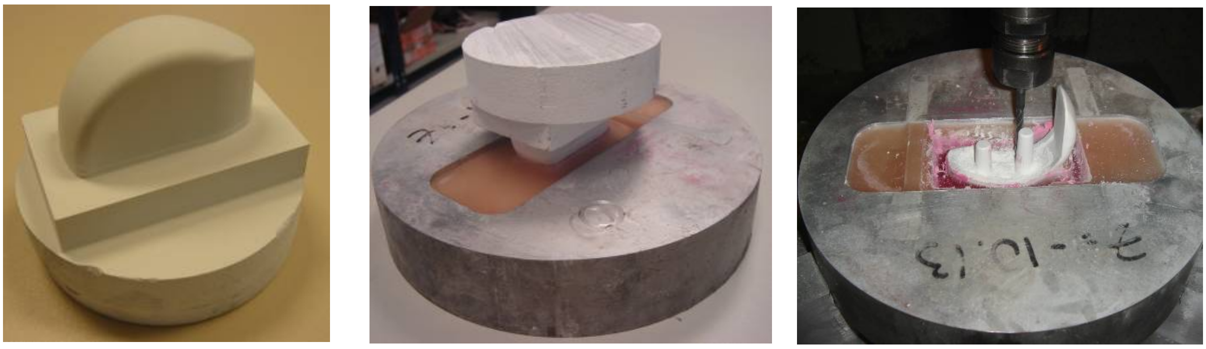
Figure 2. Cylinder fixed with a wax bed.

3. PARTS MACHINING AND SINTERING

The manufacture of biomedical prostheses from raw cylinders requires the machining of the complete surface and, as a consequence, when subjecting the part with wax techniques a double stage machining strategy it is required. Therefore, after machining the upper half it is necessary to remove the part from the wax fixture and to turn it upside down to machine the lower half, formerly unreachable.

The best part's position in the subjection device is that which minimises the initial volume of material required. This result yields on the fact that the initial cylindrical pre-form is obtained by hydrostatic compression, so the material can be considered as homogeneous and isotropic. This hypothesis has been confirmed by the results of experiences of parts machining in different pre-form directions (as shown in Figures 3, 4 and 5). Also, it possibilities the machining of the parts in different steps; i.e., from different directions (upper and lower).

Finally, the machined piece is taken into an oven and sintered reaching 1.450ºC.



Figures 3, 4 and 5. Different steps in prostheses machining

4. MEASURES AND ANALYSIS OF THE RESULTS

During the sintering process it is expected a change in the part geometry; particularly a volume reduction and a shape deformation. This fact has to be taken into account during the machining process; where a scale factor and an offset have to be applied. The rationality for this is as follows: the scale factor forces the parts to be machined with larger dimensions than required, so the desired geometry is finally achieved when sintering; while the offset ensures an excess of material than can be removed from certain part places in order to tune the final geometry.

Following to the hypotheses of homogeneity and isotropy and the parameters to applied are identical in all material directions (axial and radial). The particular parameters used for the Zirconia composition used in the tests performed are as shown in Table 1.

Table 1. Parameters applied to the dimension of the parts machined.

Material compression ratio measured experiencing with the cylinders	**Scale factor applied**		**Offset [mm]**
21,98%	1,280		0,5

The geometry of the sintered parts is measured with a three-dimensional measuring machine, (Mitutoyo BHN710) and a 3D model is built to compare the part obtained against the desired geometry. To illustrate the comparison, Figure 6 shows the superposition of the radial cuts of a biomedical prosthesis; where it is possible to evaluate the geometry desired against the part obtained

Regarding to this, Figure 6 clearly demonstrates that the geometry of the part obtained diverts from the expected results; thus showing that the parameters applied have to be adjusted. A reduction in the scale factor serves to precise the volume obtained. Also, the deformation occurred can be overcome with a redesign of the machined geometry.

Once the scale factor is adjusted, and the prostheses properly redesigned, the offset parameter it is not required anymore.

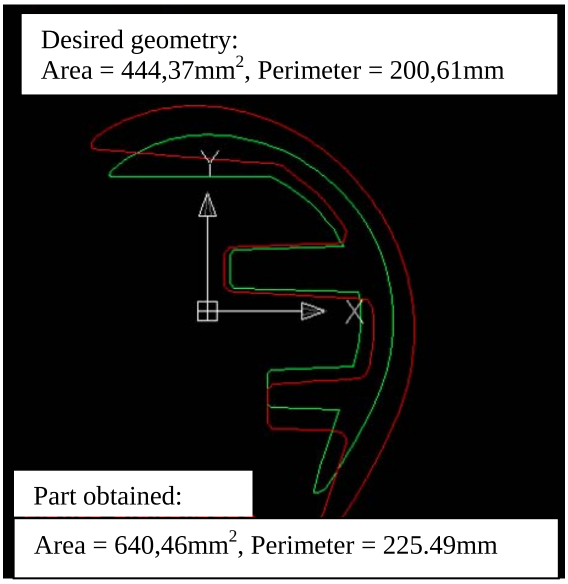


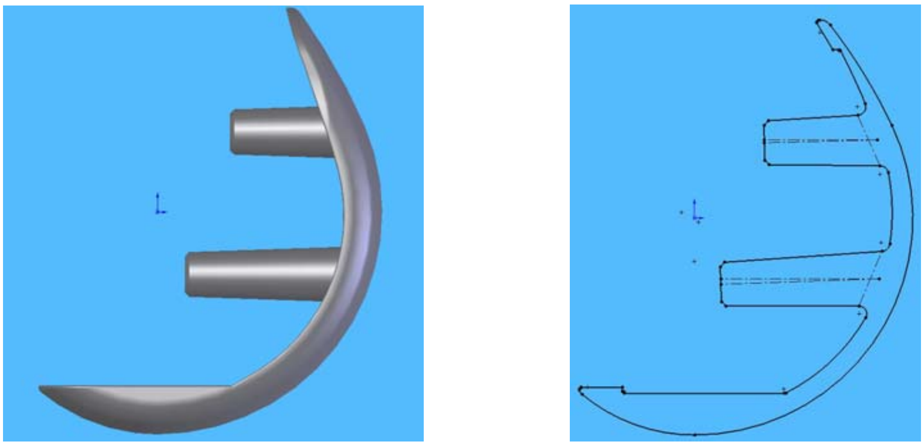
Figure 6. Superposition of radial cuts of the Desired geometry (light green) and the Part obtained (dark red).

5. REDESIGN OF PARTS GEOMETRY

As confirmed in the previous chapters, the methodology derived from the present study achieves to resolve the challenge of manufacturing technical ceramic parts. However, depending on the geometry, in order to reach accurately the geometry desired it is necessary to redesign some specific features.

As a general pattern for different prostheses geometries, it is found that during the sintering processes, the material tends to distribute in the most spread manner possible; in other words, causing the open geometries to enlarge the inner angles (as demonstrated in Figure 6).

For the particular prostheses machined in the present study, the features to be redesigned are concreted as a slight deviation of the inner columns, determined as an angle referenced to the flat horizontal inner face. By taking the results form the 3D model the modification needed is a reduction of the overture angle as demonstrated in Figures 7 and 8.



Figures 7 and 8. Redesign of prosthesis geometry. Initial shape and profile redesigned

6. CONCLUSIONS

The materialisation of technical ceramic prostheses by the machining of compressed pre-forms before sintering can yield many benefits as it is a methodology that saves from the expensive and time consuming moulding technologies and –contrarily as in LMT- material is not a restriction for the machine. Nevertheless, the materialisation of such prototypes is not as straightforward as could initially seem, due to the properties of the technical ceramics. In effect, to overcome the fragility, dustiness and abrasive behaviour it is necessary to machine at a low feed rate and always following strategies against the material, thus avoiding ceramic wear and crumbling. Notwithstanding, the tool expected life is low and many efforts have to be made to deal with the dust generated.

Regarding the wax fixture techniques, the utilisation of a wax bed benefit the machining by applying homogeneous pressure in the entire contact surface, not leaving marks on the part's surface and absorbing the tool's vibrations. As the Zirconia used can be considered homogeneous and isotropic, the disposition of the material in the block has only to respond to a minimisation of the raw material used.

Finally, the sintering process is prone to reduce the material volume and to deform the machined part. As a consequence, the geometry to be machined from the pre-form it is expected to require the application of a scale factor and –depending on the geometries desired-, also some specific redesign.

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