SINGLE POINT INCREMENTAL FORMING OF A MEDICAL IMPLANT


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ABSTRACT- Single Point Incremental Forming (SPIF) is a manufacturing process that enables plastic deformation of metal sheets without resorting to any specific die or punch. Nowadays, the process has still lower implantation in the industry because it is only suitable for small batches or single products. However, this process is very promising to provide customized prosthesis for the medical area, as it allows manufacturing a product that perfect fit the patient. This paper aims to evaluate the SPIF process for producing titanium customized maxillofacial implants and demonstrate the role of this technology in manufacturing customized medical parts.

INTRODUCTION: Prosthesis is an artificial device used to replace missed human body parts (Castelan [2010]) which can occur due to tumors, infections and fractures. Manufacturing thin walled customized prosthesis for each person, like in the case of skull or facial implants, is mostly performed by casting, machining or intraoperative manual dynamic mesh modeling. In the first case, it is very difficult to achieve long thin walls, and titanium (the most widely used material for metallic prosthesis due to its biocompatibility) is very reactive at high temperatures. With machining, one can obtain parts with great dimensional accuracy and high potential for personalization; however, titanium wastes lead to very high production costs. Moreover, the manual forming of titanium meshes is detrimental to the patient for whom implant is intended since it increases the surgical time for prosthesis application and results in prosthesis with less aesthetic fit with the bone defect area. Thus, ISF appears as a challenge alternative process to manufacture custom fit implants (Martins [2008]).

SPIF is a plastic forming process that fits the needs for medical area: small series of products or even single units with high degree of customization. Associated with current medical imaging techniques and CAD/CAM technologies, it is possible to produce thin wall customized metallic parts, such as skulls, jaws or face prosthesis, with low material waste and low tooling costs (preoperative method).
PROCEDURES, RESULTS AND DISCUSSION: Manufacturing a thin-wall implant through SPIF requires the mechanical characterization of the prosthesis material and then following a particular methodology. Considering the requirements of biocompatibility and formability, a grade 2 commercially pure titanium (TiCp Gr2) was selected.

Tensile tests in rolling direction and in 45 and 90º, relative to the rolling direction, and Biaxial expansion tests (*Bulge-Test*) allowed obtaining some fundamental mechanical material properties presented in Table 1.

<table>
<thead>
<tr>
<th>Property</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young Modulus</td>
<td>$E$ (GPa)</td>
<td>123.015</td>
</tr>
<tr>
<td>Yield stress</td>
<td>$\sigma_y$ (MPa)</td>
<td>303.48</td>
</tr>
<tr>
<td>Anisotropy coefficients</td>
<td>$r_{0}/r_{90}/r_{45}$</td>
<td>1.94/3.39/3.00</td>
</tr>
<tr>
<td>Strain hardening coefficient</td>
<td>$n$</td>
<td>0.164</td>
</tr>
<tr>
<td>Coefficient of proportionality</td>
<td>$K$ (MPa)</td>
<td>697.7</td>
</tr>
</tbody>
</table>

Formability tests were also conducted with a conical shape and a variable wall angle. Given the depth of the first fracture that occurred during the forming of the 3D CAM model, it was found that the maximum forming angle ($\Psi$) for a single stage is $56.39^\circ$ (see Fig. 1).

![Figure 1: Determination of the maximum forming angle for a single stage](image)

With the properties of the material and the Forming Limit Diagram with the Forming Limit Curve (FLC) and Fracture Forming Line (FFL), it is now possible to manufacture an implant through the SPIF process. Fig. 2 shows the proposed methodology, since the characterization of the damaged area until the implantation of the prosthesis into the patient body.

Sequences of 2D images were obtained from the patient damaged bones through Computerized Tomography (TC) or Magnetic Resonance Imaging (MRI) (Leal [2011]). These images were processed to obtain a 3D model of the bony area. A prosthesis model is now created using a mirror technique that overrides healthy parts of the skull on the damaged parts. Considering the geometry of the prosthesis model and the $\Psi$, a simplified
3D CAD model of the implant was created without the orbital cavity (due to the complexity of the geometry for the SPIF process) and with walls that allow forming the part. With this model in mind a tool path and the numerical code were generated for a 3 axes CNC milling machine. Using a 12mm hemispherical tool with free spindle rotation and a PTFE based lubricant, a physical model was obtained in a CNC milling machine (SPIF). A CNC machine with a milling tool was used to cut the perimeter of the implant.

![Figure 2: Production cycle of an implant in the preoperative method (adapted from Rocha [2010])](image)

The results obtained were very satisfactory considering that a final part with low surface roughness was obtained and that the only fracture occurred in the prosthesis was due to wall angles higher than the \( \Psi \) determined. For this situation multistage is demanded.

**CONCLUSIONS:**
Single Point Incremental Forming is a promising process to produce customized prosthesis. It was demonstrated that using an integrated methodology that uses medical images, 3D CAD models and a CNC machine enables the production of tailored titanium parts for the medical area.

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**REFERENCES:**

