Development of a Tool for Indirect Extrusion of a Preform in Commercially Pure Titanium Gr 4 for Dental Implants

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Abstract

The aim of this study is to design, manufacture and test a tool of indirect extrusion for preform forming. This preform will be employed in subsequent operations for the manufacturing of dental implants. Parts produced by this particular forming process higher functioning mechanical properties and metallurgical characteristics. Commercially pure titanium Gr 4 is the material used in the preform. For the definition of the preform to be constructed, an identification was performed of the dental implant on the basis found in the technical literature. A characterization the titanium based on the flow curve, metallographic analysis and microhardness was also performed. Initially, a tool was designed (tool proposal) based on calculations of force and work. The tests exhibited specific deficiencies, principally concerning the need for reduced dimensional features. Following this test, based on the needs described, an improved proposal tool was developed to align the tool and the punch during job execution. The results of the test exhibited dimensional symmetry featuring an alignment of the tool guides, as well as a uniform displacement of the punch during indirect extrusion.

Key-words: Indirect Extrusion; Commercially Pure Titanium Gr 4; Tool; Dental Implants.

1. INTRODUCTION

The demand for dental implants is growing in Brazil. In these applications, titanium and characteristically similar alloys are useful. Although possessing excellent application characteristics, processing and achieving ideal transformation of these materials is complex. In applications where the relationship between weight and resistance is very important as in the case of dental implants, components produced by forming exhibit better mechanical properties and metallurgical characteristics aside from the structural reliability, with respect to those produced by casting or machining [10].

Extrusion is a mass-forming process in which a billet or ingot inserted in a container is forced to flow, due to high pressure, through an die of special shape to undergo a plastic deformation . The deformation performed at room temperature (cold extrusion) produces parts with good dimensional accuracy and low roughness [3, 11].

According to the disposal of the material flow, the extrusion process can be separated into direct or indirect, and is combined in the junction of the two cases. In direct extrusion, the punch movement and the flow of material occur in the same direction. In indirect extrusion, the material flows in the opposite direction to the displacement of the punch, Fig. 1. During both direct and the indirect extrusion, the material is forced to flow through the tool due to high pressure exerted by the punch which exceeds the yield strength of the material.

There is a reduced friction force for direct extrusion as compared with indirect due to no relative movement between the work piece and the tool containing the billet [3].

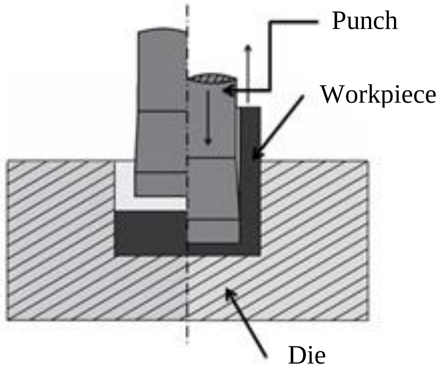


Figure 1 - Extrusion process, inverse or indirectly, with principal components and relative motion in the extrusion [11].

The extrusion tools, depending on the size of the part to be produced, are subject to high stress. Because of this, the proper selection of tooling makes a big difference in the process. Several variables define the design of a tool, material, surface finish, geometry, temperature between others [9].

The sizing of the extruded part's volume, by your conserving, especially in closed dies, is the starting point for the other tool´s settings. The calculation used in this work is currently supported by software such as SolidWorks®.

The definition of the application's center of force influences the concentration of effort belonging to the tool, and also the flow of material within the cavity.

The punch, set to reverse cold-extrusion, is presented in Figure 2. The variable d represents the diameter of the hole extruded. This variable represents the dimension responsible for the internal geometry of the extruded part. The angle a identifies the slope associated with the flow of material when compressive forces act in billet. The height b and angle c are associated with the area that will promote friction between the punch and the part material, completing the diameter d_2 which is smaller than the diameter d, while suffering no contact with the material disposed.

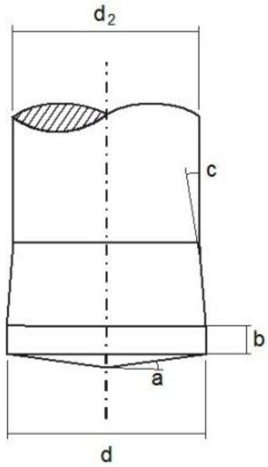


Figure 2 - Standard dimensions punch extrusion [5].

Hosford (2007) provides parameters and viable conditions for applying the indirect extrusion process, Table 1.

Table 1 – Parameters for indirect extrusion [5].

a [º]	c [º]	b [mm]	d [mm]	d_2 [mm]
6 to 15	5 to 6	0.79 to 1.59	Diameter of hole extruded	$d + \frac{0.20}{0.25}$

The parameters to be analyzed in the selection of implant materials are associated with defining the type and level of tension that will be submitted, corrosion resistance and biocompatibility. It is important that the material displays high tensile strength and fatigue associated with good resistance and physical degradation [1].

Table 2 shows the comparison between two materials, including cortical bone (bone compact piece), serving as a reference for the analysis of mechanical properties.

Table 2 - Comparison between titanium and other materials. Adapted from [4].

Alloy specification	Microstruture	Modulus of elasticity E [GPa]	Yield start σ_s [N/mm^2]	Yield strength σ_b [N/mm^2]	Rupture stress σ_r [N/mm^2]
Commercially Pure Ti	α	105	290	692	785
Cortical bone	Viscoelastic composite	10 to40	-	-	90 to140

As shown in Table 2, the modulus of elasticity possessed by commercially pure titanium Gr 4 is considerably higher than that of compact bone. This property emphasizes the importance of design in the distribution of transfer of mechanical stress [6].

The chemical composition of commercially pure titanium, in accordance with ASTM F67-00, is illustrated in Table 3.

Table 3 – Chemical composition of commercially pure titanium Gr 4, wt% [2].

Ni [%]	C [%]	H [%]	Fe [%]	O [%]	Ti [%]
0.05	0.08	0.01 to 0.015	0.5	0.4	Remainder

In this context, the main objective of this work is to design, manufacture, and test a tool for use in the indirect extrusion process, producing a small piece of pure titanium Gr 4 for application in dental implantation.

2. EXPERIMENTAL PROCEDURE

Figure 3 is a flow chart displaying the steps required to develop a direct extrusion tool. For the execution of steps 5 and 7, the universal testing machine EMIC DL10000 was used with a capacity of 10,000 kgf in both directions (tensile or compressive).The technical characteristics of the equipment allow for the control of process parameters such as maintaining the constancy of punch speed at 0.5 mm/min within the test.

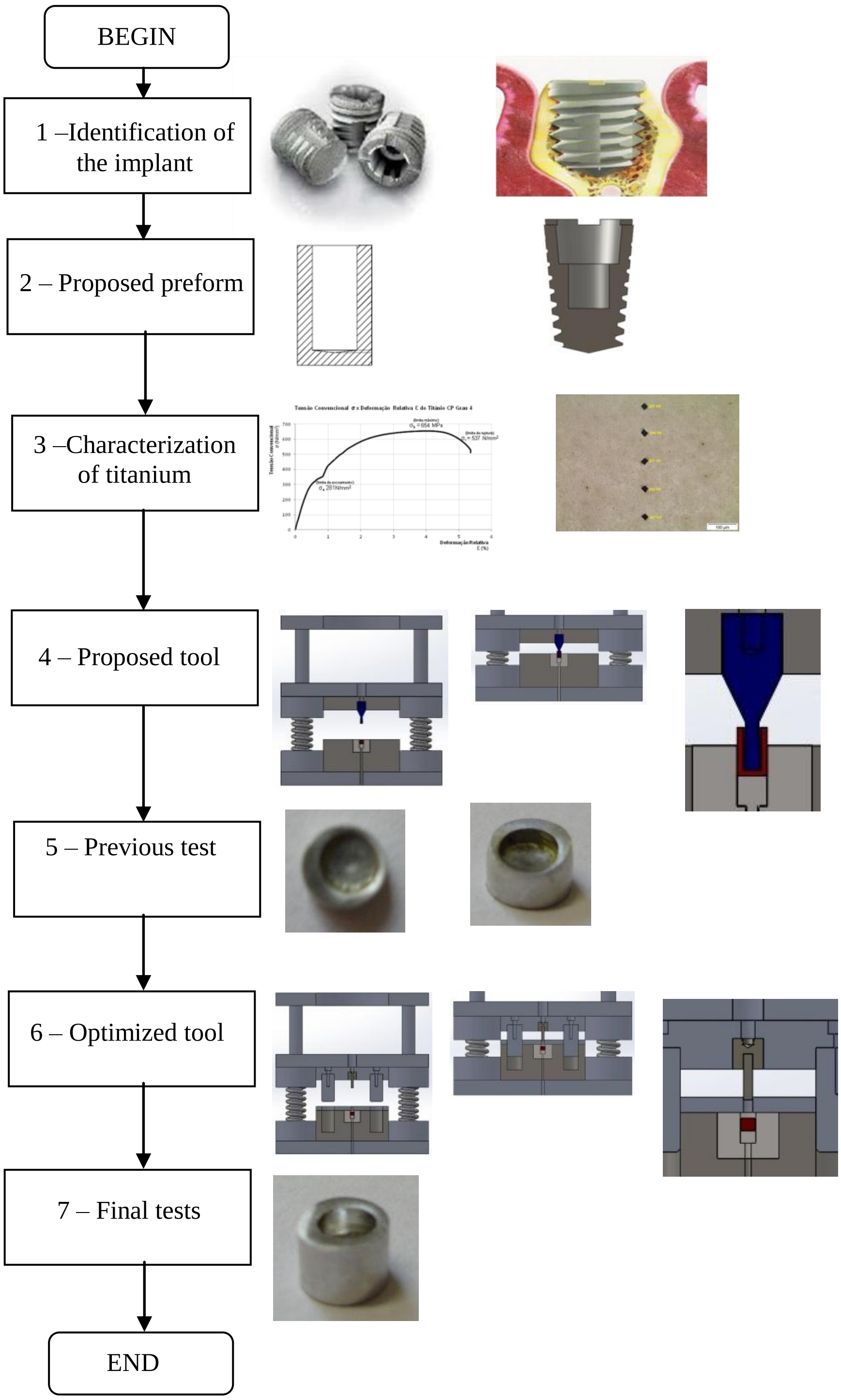


Figure 3 - Steps of development.

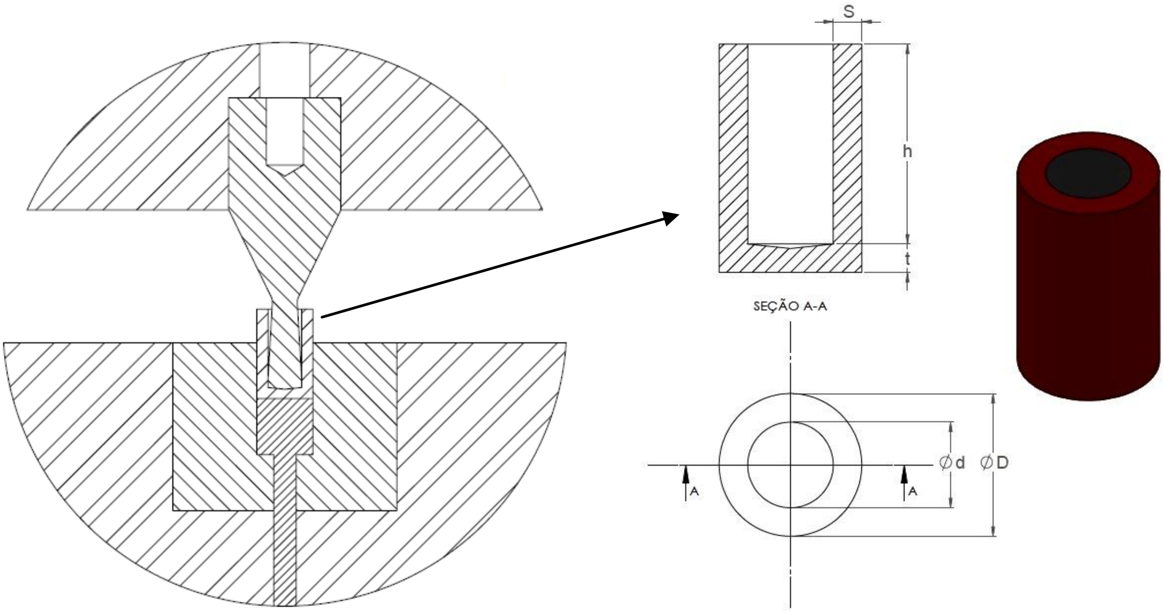
2.1 Identification of the Implant

Regarding related reactions with the human immune system, titanium has a specific passivity and promotes such behavior when used as implants in humans [7, 8].

Commercially pure titanium without alloys present in the composition is regularly used in instances where corrosive agents are present, and there is the need for fatigue resistance such as in dental implantation [12].

2.2 Proposed Preform

Based on preliminary studies, the preform and proposal tool were designed for indirect cold extrusion. The first stage of this work was to generate a part in the desired dimensions presented in Figure 4.



(a) (b)

Figure 4 - Work piece generated by indirect extrusion: (a) detail of the punch and the extrusion die, (b) work piece extruded.

Figure 4a displays the detail of assembly, where the indirect extrusion is in final stroke by setting the size of the part generated, as in Figure 4b.

Tests were performed to verify if the project would require adjustments, allowing the analysis and interpretation of results, leading to the understanding of relevant variables in the indirect extrusion process of small parts.

The proposal is to conduct studies on the indirect extrusion process of small parts. Explained below are variables adopted to enable the use of the equipment proposed in forming. When sizing the equipment for the experiments, it is important to identify the force required. The specimen then develops a preform which originates from cold working indirect extrusion, according to Figure 4b.

The characteristics of material deformation are influenced by several variables, including yield stress, speed of deformation, strain, friction between the material and the tool, and geometry. The ability to correct sizing of the entire system promotes effective quality control of the finished product.

2.2.1 Estimate of Force and Work

The dimensional data of the preform extrusion consists of: part volume, blank dimension, true strain, force and work. The volume of finished product V (extruded part) is expressed by [9].

$$V = d^2 . \frac{\pi}{4} . t + (D^2 - d^2) . \frac{\pi}{4} . h \quad [\mathrm{mm}^3] \qquad (1)$$

Where:

d [mm]: Internal diameter

t [mm]: Base thickness

D [mm]: External diameter

h [mm]: Tube height

The dimensions of the blank, initial area A_0 and initial height h_0 are calculated by:

$$A_0 = \frac{\pi - {D_0}^2}{4} \qquad [\mathrm{mm}^2] \tag{2}$$

$$h_0 = \frac{V}{A_0} \qquad [\mathrm{mm}] \tag{3}$$

Where:

D_0 [mm]: Initial diameter

V [mm^3]: Volume

A_0 [mm^2]: Initial area

True strain in area φ_A is defined by:

$$\varphi_A = \ln\left(\frac{D_0}{D_0 - d}\right) \qquad [---] \tag{4}$$

Force of inverse extrusion is expressed by:

$$F = \frac{A_0 . k_{fmedim} \cdot \varphi_A}{\eta} \qquad [\mathrm{N}] \tag{5}$$

Where:

$k_{fmedium}$ [N/mm^2]: Medium flow stress for pure titanium Gr 4 is 467.5 N/mm^2

η [---]: Efficiency≈0.7

Work in inverse extrusion is defined by:

$$W = F.h \quad \text{[N.mm]} \tag{6}$$

Employing equations 1 to 6 have the resulting in according to Table 4.

Table 4– Results of calculations.

V [mm^3]	A_0 [mm^2]	h [mm]	φ_A	F [N]	W [N.mm]
107.60	19.63	5.48	0.75	9,832	39,330

2.3 Characterization of Titanium

The characterization of titanium is presented in the sequence through the tests of the flow curve and the hardness.

2.3.1 Flow Curve

Concerning analysis engineering, the flow resistance is a quantity dependent on the material, microstructure, temperature and strain. Figure 5 shows the flow curve of commercially pure titanium Gr 4, showing the initial flow stress k_{f0} = 281N/mm^2.

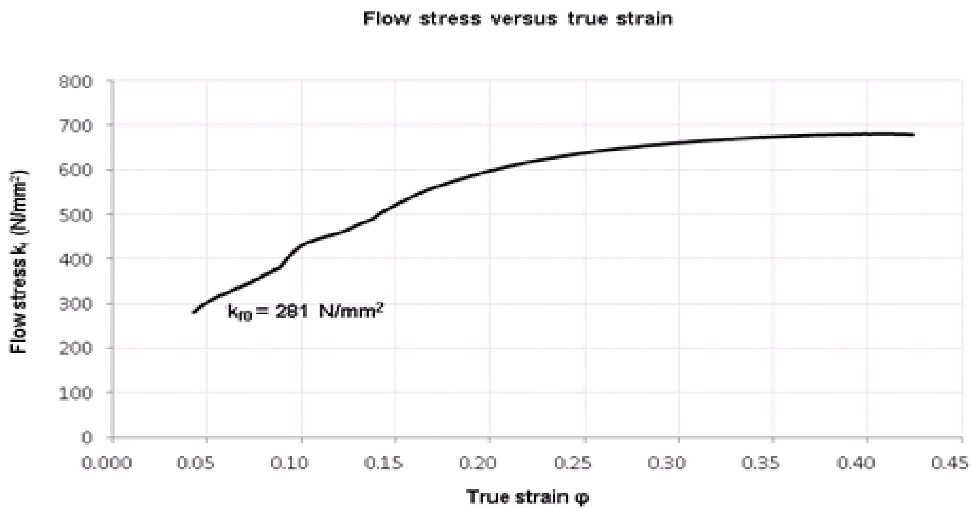


Figure 5 - Flow curve of pure titanium Gr 4.

The flow stress k_f as function of Constant *C* and the strain hardening *n, can be* expressed by:

$$k_f = C \cdot \varphi^n \tag{7}$$

For pure titanium Gr 4can be expressed by:

$$k_f = 952 \cdot \varphi^{0,31} \tag{8}$$

Where the obtained values are generated by statistical trend curve for a potencial curve. A satisfactory correlation of 0.94, as shown in Figure 5, promotes good reliability in the approach.

A universal testing machine also promotes, in this work, the conformation of the specimen, involving force data and strain rate, speed variation of the punch, among others.

2.3.2 Hardness Test

A microhardness test was used with variables set for static load at 100 gf for 15 seconds. Five experiments were run in the sample, as shown in Figure 6. Table 5 presents the mean and standard deviation of the samples along the cross-sectional of the part according to Vickers microhardness test. The average value obtained ranged from 254 HV to a standard deviation of 15 HV.

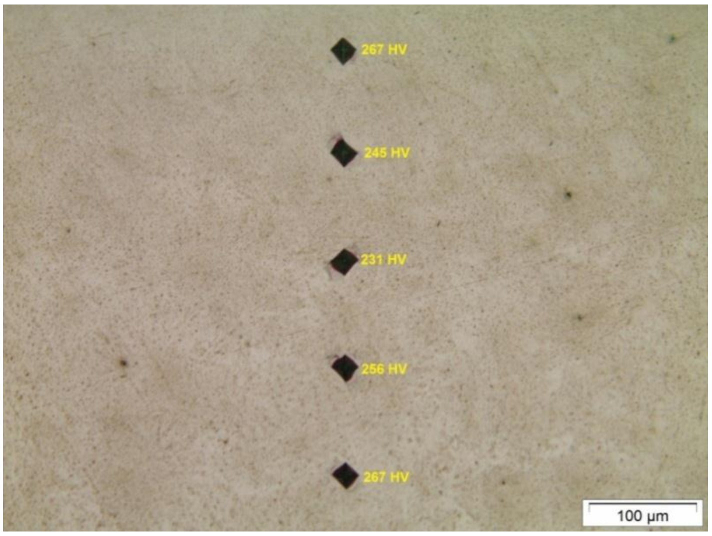


Figure 6 - Micro-hardness of raw material.

Table 5 – Micro-hardness values of the raw material.

Test nr.	Hardness [HV]
1	268
2	245
3	231
4	256
5	268
Average	254
Standard deviation	15

3. RESULTS

The following are the obtained results of the proposed and optimized tool.

3.1 Proposal Tool

The tool developed for the extrusion test was designed by SolidWorks®. The extrusion experiments were performed in a universal testing machine. To meet and match the equipment, the tool has a structure that enables the simple positioning of the mobile portion of the machine’s actuator. The main parts and purposes are displayed in Figure 7.

1 –Fixed upper base: aims to align the guides and promote uniform alignment in other parts.

2 - Fixation guides: promote the aligned movement of the intermediate base, and also ensures the symmetrical assembly of the tool components.

3 - Intermediate Base: executes the movement of extrusion and fixes the assembly of the punch in position.

4 – Fixed lower base: aims to align the guides and promote uniform alignment in other parts. It also promotes die and extractor attachment. The extractor is made of two pieces, the extraction base and extraction pin.

5 – Die the cavity in which the work piece is forming within the desired dimensions defined by the experiment.

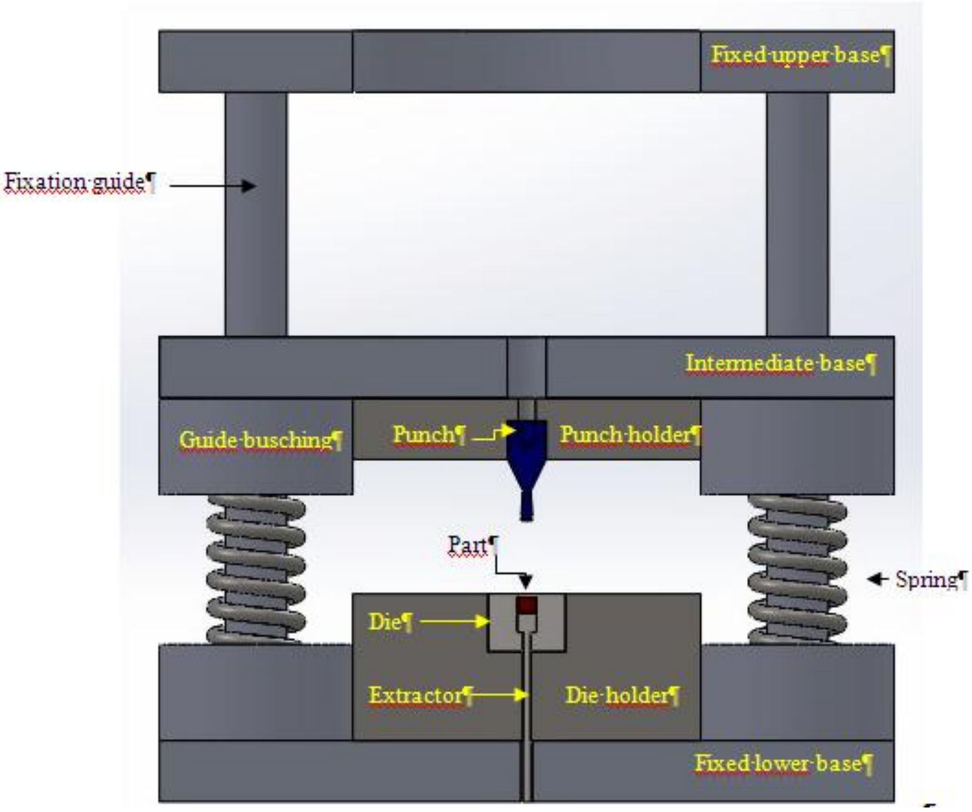
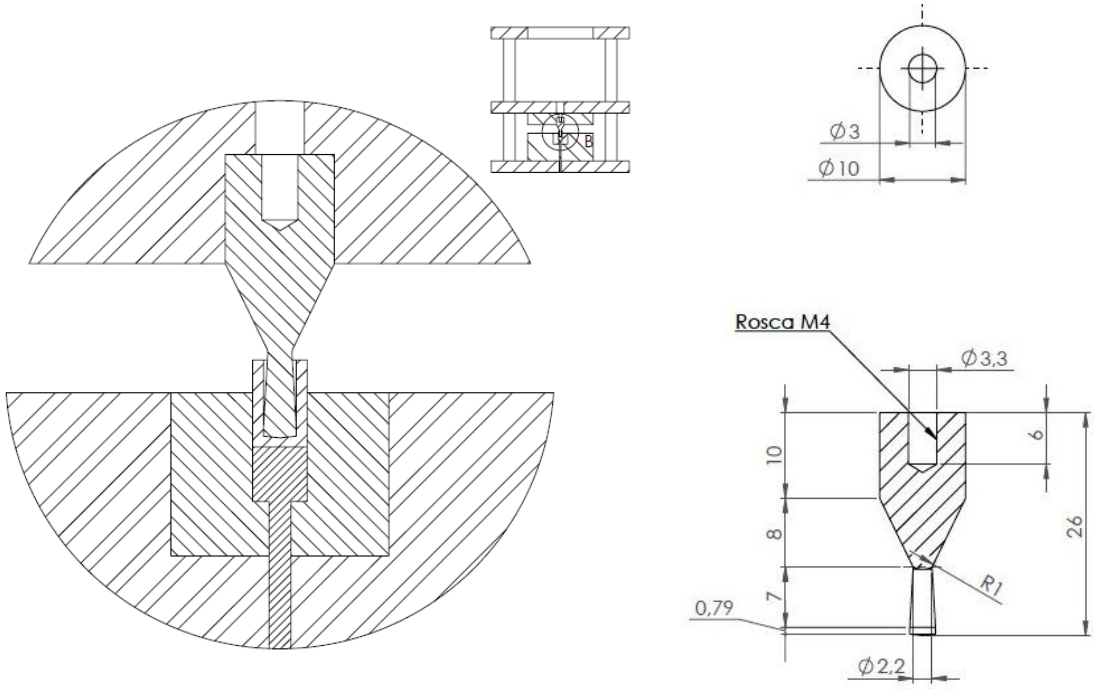


Figure 7 - Proposed tool - view assembly.

The tool, Figure 7, was developed in AISI-SAE 1020 steel, excluding the regions of contact and friction (punch and die) between the mechanical elements where SAE-AISI D6 steel was utilized.

The punch, Figure 8, has been designed to run in reverse extrusion effort in the raw material within the dimensions referenced in said Figure 8b.



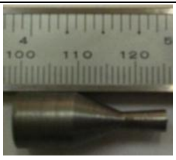
(a) (b)

Figure 8 - Dimensions of the 3 mm diameter punch: (a) mounting position, (b) detail of the punch

3.1.1 Previous Tests

Table 6 displays the results of the punch creating the work piece in the extrusion process. Tests were performed to detail tool operation, as well as the geometry of the extruded work piece. In all tests, the preform designed was not fully achieved due to significant errors in concentricity between the die and the punch, the absence of specific support for the punch during the extrusion execution, and misalignment of the work piece.

Table 6 – Results of preliminary tests.

Test nr.	Punch problem	Punch	Work piece problem	Work piece
1	Eccentricity of the work piece cavity and impossibility of extrusion		Misalignment of the guides, inadequate geometry of the punch	
2	Eccentricity of the work piece cavity		Increase in the rake angle of punch in the material, with the occurrence of the plunger buckling	
3	Eccentricity and partial extrusion of the work piece		Flexion and breakage of the plunger caused by excessive increase in the load.	

3.2 Optimized Tool

Considering the problems presented in previous tests, solutions were sought out to center the punch over the central and lateral guides, Figure 9.

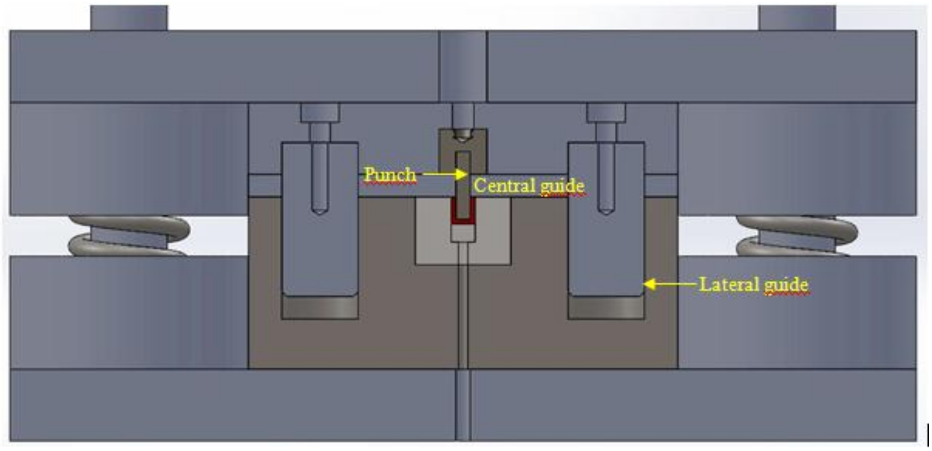
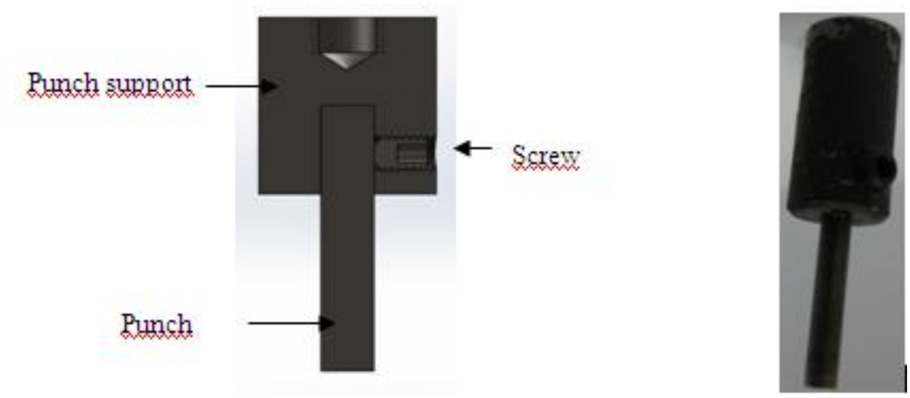


Figure 9 - Optimized tool - assembly view.

In the new method of construction, the punch is guided by the central guide, which in turn works closely with the lateral guide. The punch was manufactured in M2 High Speed Steel, 3mm cylindrically, and possessed a hardness of approximately 60 HRC.

Figure 10 shows the fixation system of the punch. Figure 10(b) shows the detail of the punch fixation belonging to the optimized tool, and the system that supports the efforts generated in the extrusion respectively.



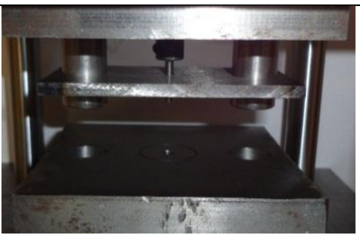
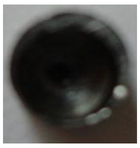
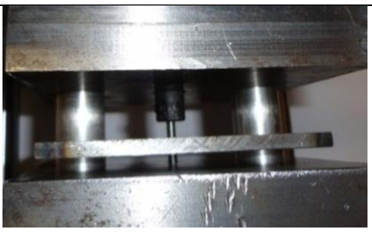
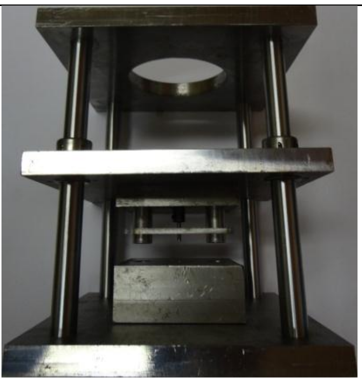
(a) (b)

Figure 10 – Optimized punch:(a) assembly view with the description of the components, (b) photo.

The punch is mounted with a support screw, promoting the interchangeability of this component in need of replacement.

The Table 7 shows the summary of the results from the punch belonging to the optimized tool.

Table 7 – Results of the tests.

Test nr.	Optimization	Tool	Solution	Work piece
1	Alignment of the tool guides		Appropriate clearances and alignment in the holes	
2	Punch's direction in the extrusion		Extrusion with uniform displacement material	
3	Concentricity in the test		Work piece geometry with satisfactory symmetry.	

4. CONCLUSION

Tools for the indirect extrusion of small parts in commercially pure titanium Gr 4 have specific mechanical characteristics that do not apply to tools with parts having greater dimensions. The dimensional accuracy is rigorous and minimal misalignment of the tool can derail the execution of the experiment.

Despite the high strength of titanium, the material reached plastic deformation in carrying out the tests. For small size, it was possible conformation of the preform at room temperature.

The possibility of manufacturing the preform by reverse extrusion may promote interesting mechanical characteristics with respect to mechanical strength, due to alignment of the mechanical grain flow.

The tool offers many possibilities through the use of different parameters in the extrusion process including both punch speed and lubrication. This facilitates the understanding of the indirect extrusion mechanism of small parts in commercially pure titanium Gr 4.

Once the extrusion process is controlled, tests with other preform geometries, including those within the same scale of manufacturing (small pieces,) may be carried out.

ACKNOWLEDGEMENT

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APPENDIX

Symbol	**Unit**	**Description**
α	[---]	Alpha phase
σ_s	[N/mm^2]	Yield start
σ_b	[N/mm^2]	Yield strength
σ_r	[N/mm^2]	Rupture stress
φ	[---]	True strain
φ_A	[---]	True strain in area
η	[---]	Efficiency
a	[º]	Rake angle
A_0	[mm^2]	Initial area
b	[mm]	Height
c	[º]	Clearance angle
C	[---]	Constant
d	[mm]	Diameter of hole extruded or internal diameter
d_2	[mm]	Punch diameter
D	[mm]	External diameter
D_0	[mm]	Initial diameter
E	[GPa]	Modulus of elasticity
F	[N]	Force of inverse extrusion
h	[mm]	Tube height
h_0	[mm]	Initial height
k_f	[N/mm^2]	Flow stress
k_{f0}	[N/mm^2]	Initial flow stress
$k_{fmedium}$	[N/mm^2]	Medium flow stress
n	[---]	Strain hardening coefficient

t	[mm]	Base thickness
V	[mm^3]	Volume or volume of finished product
W	[N.mm]	Work

Figure captions

Figure 1 - Extrusion process, inverse or indirectly, with principal components and relative motion in the extrusion [11].

Figure 2 - Standard dimensions punch extrusion [5].

Figure 3 - Steps of development.

Figure 4 - Work piece generated by indirect extrusion: (a) detail of the punch and the extrusion die, (b) work piece extruded.

Figure 5 - Flow curve of pure titanium Gr 4.

Figure 6 - Micro-hardness of raw material.

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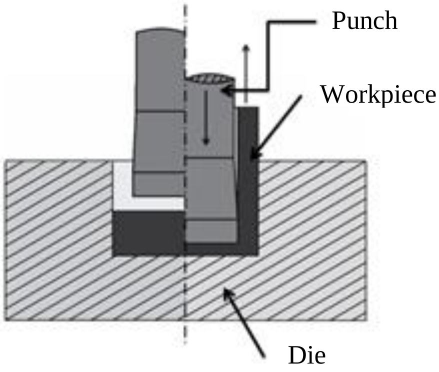

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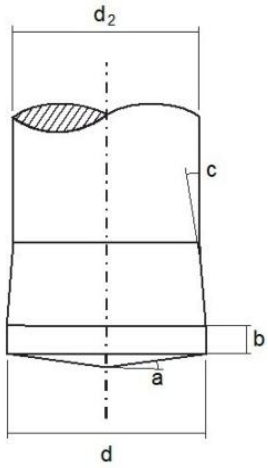

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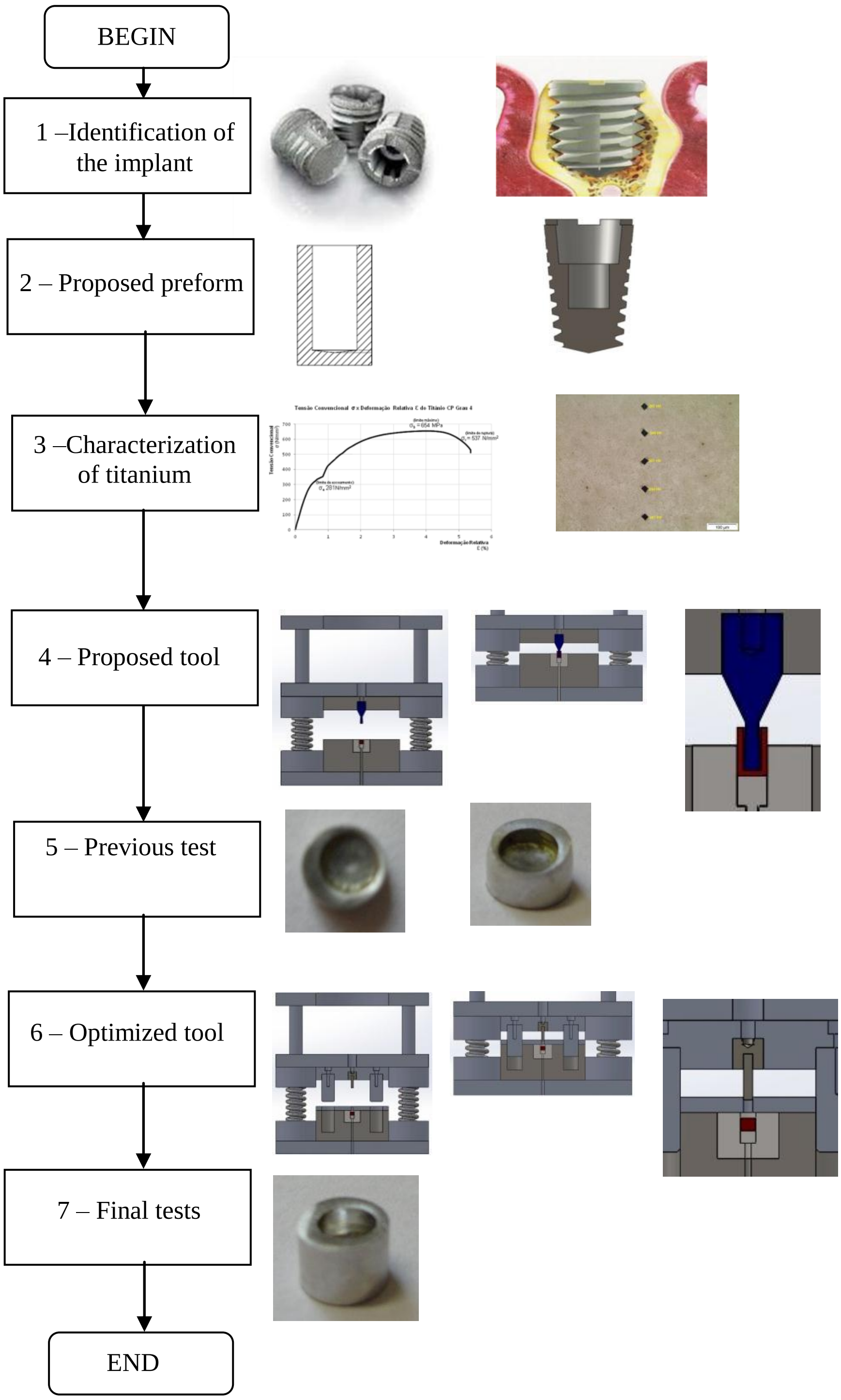

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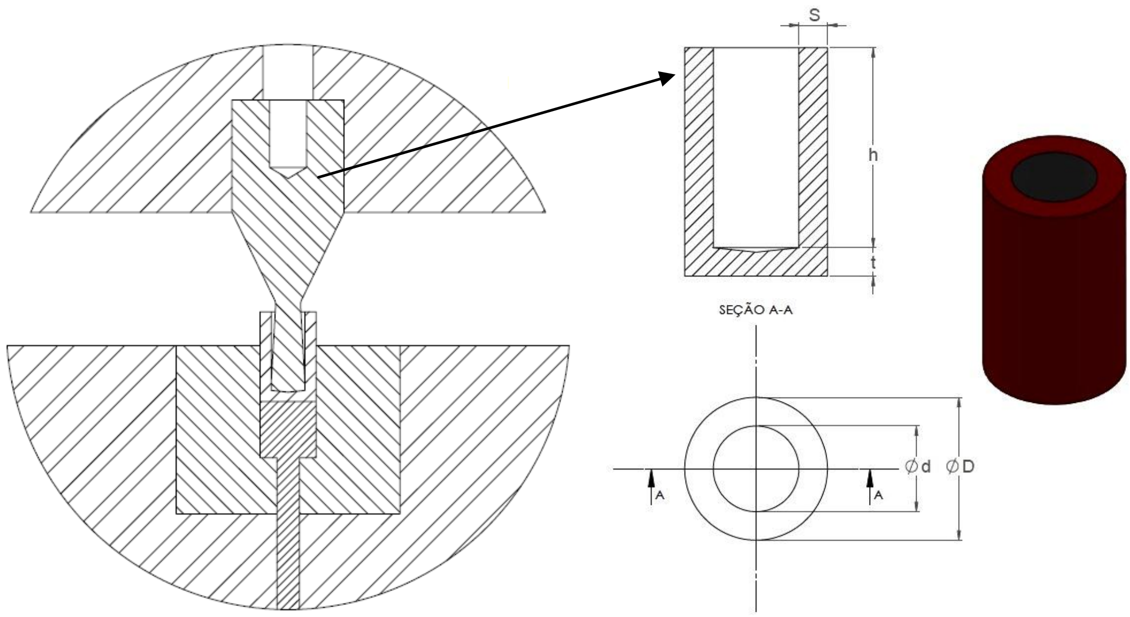

(b) (b)

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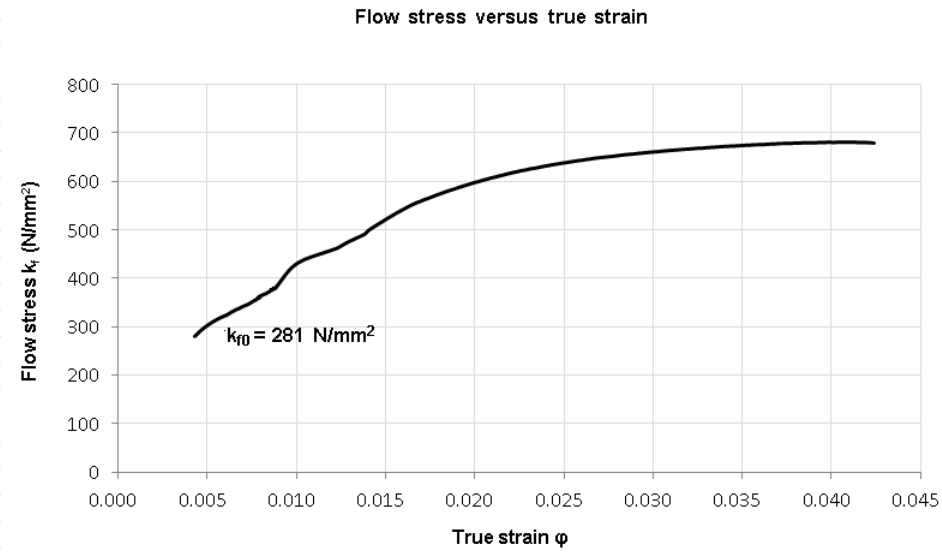

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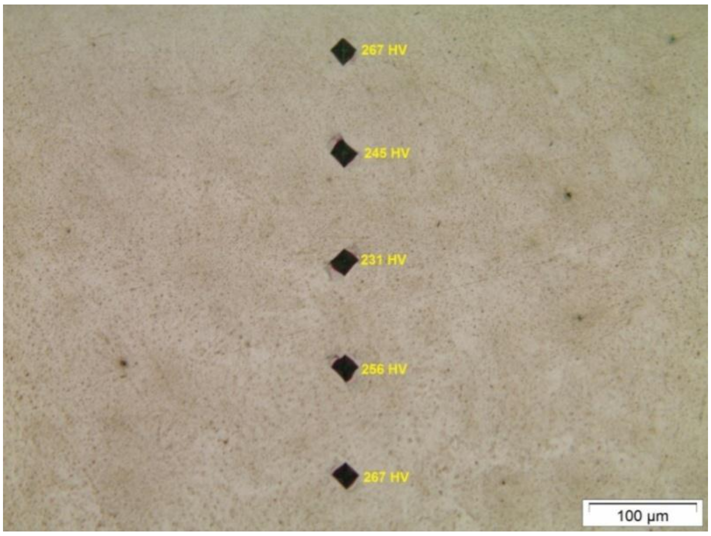

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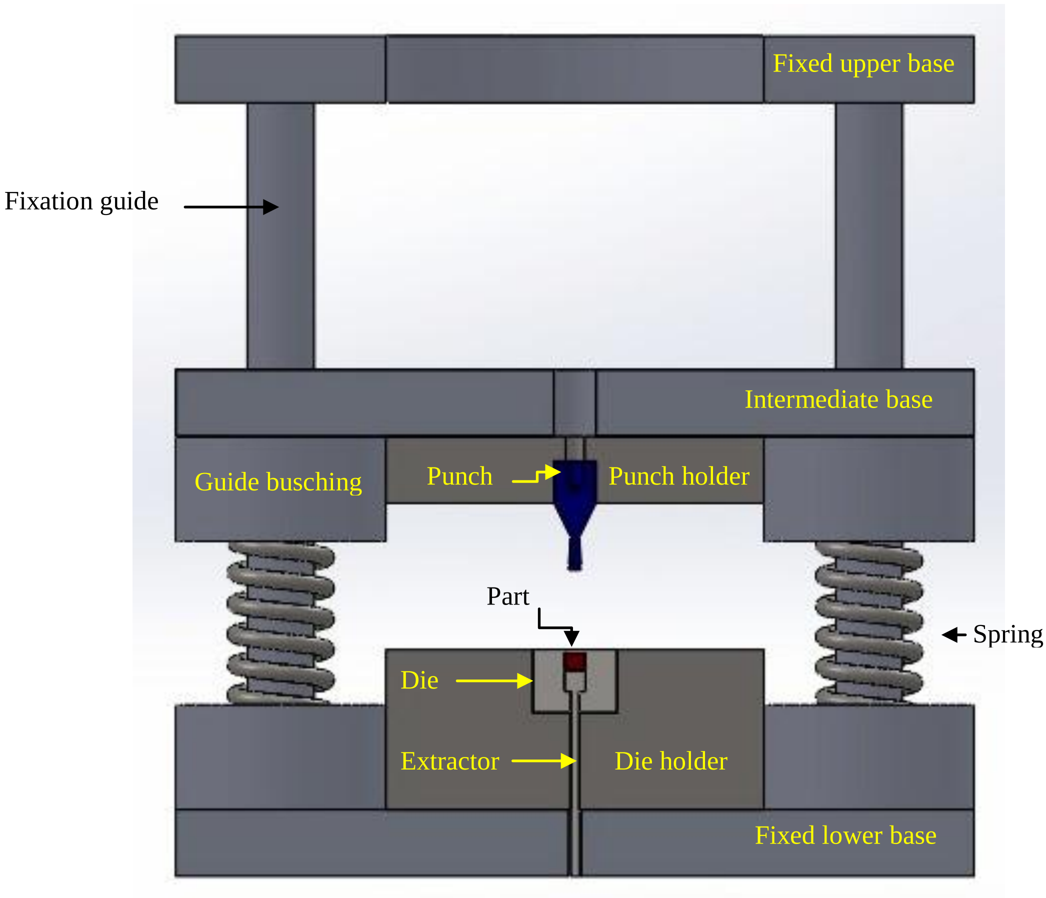

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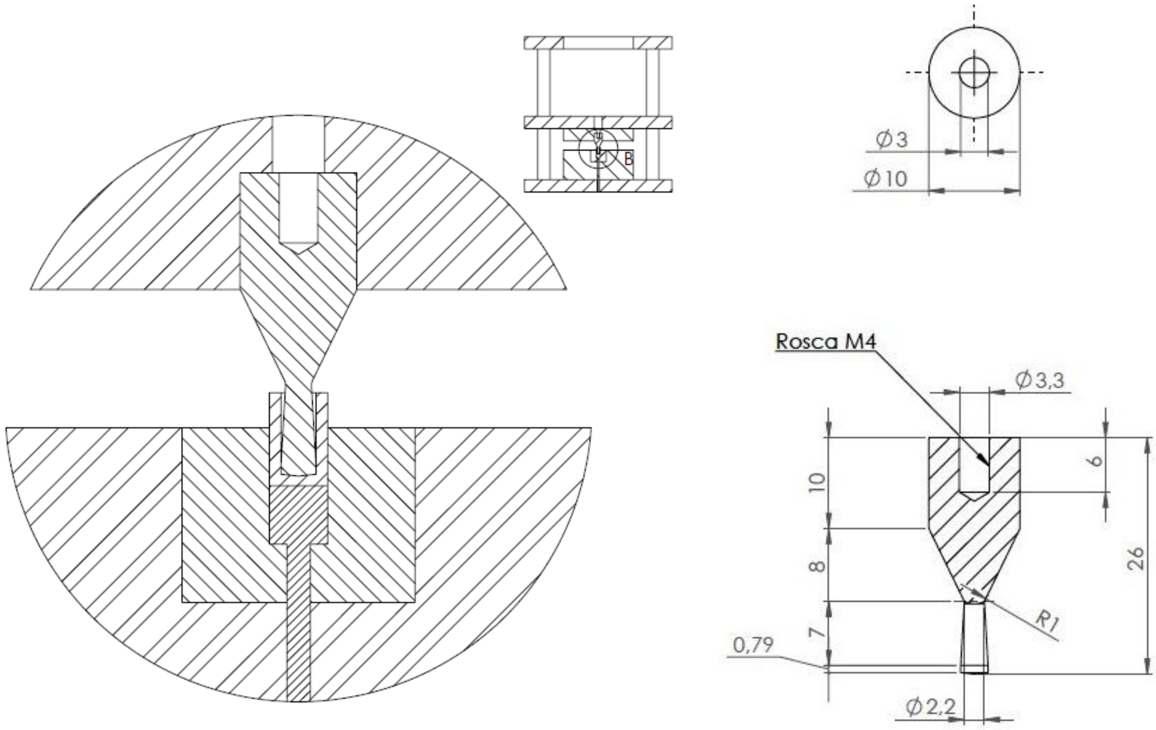

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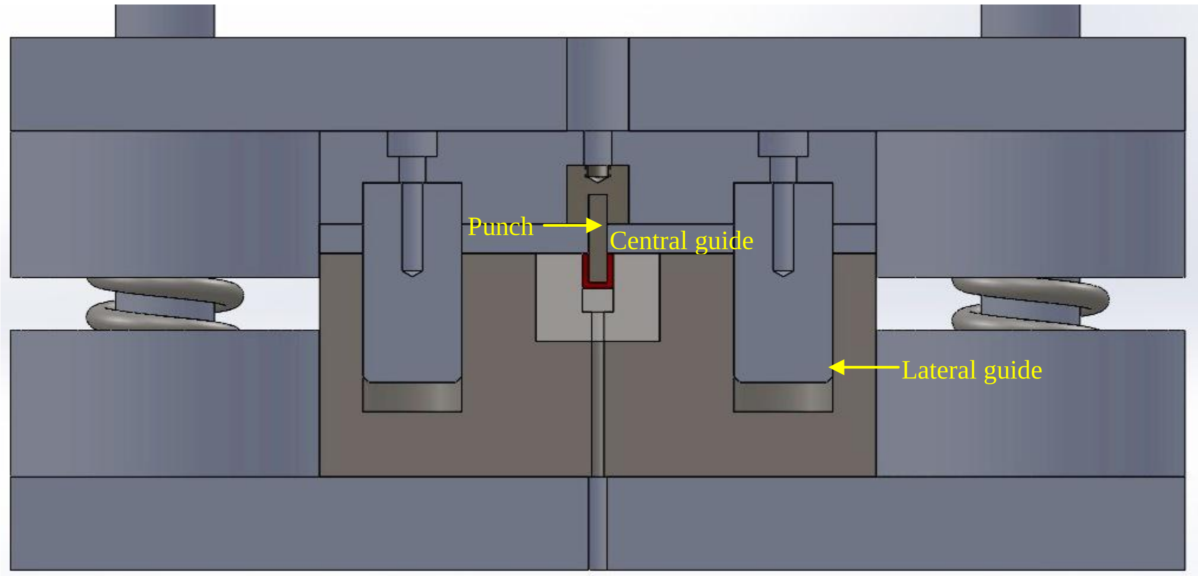

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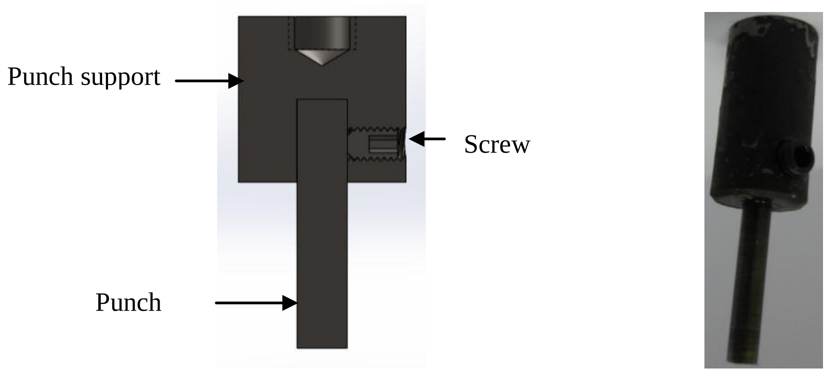

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6 to 15	5 to 6	0.79 to 1.59	Diameter of hole extruded	$d + \frac{0.20}{0.25}$

Table 2 - Comparison between titanium and other materials. Adapted from [4].

Alloy specification	Microstruture	Modulus of elasticity E [GPa]	Yield start σ_s [N/mm^2]	Yield strength σ_b [N/mm^2]	Rupture stress σ_r [N/mm^2]
Commercially Pure Ti	α	105	290	692	785
Cortical bone	Viscoelastic composite	10 to40	-	-	90 to140

Table 3 – Chemical composition of commercially pure titanium Gr 4, wt% [2].

Ni [%]	C [%]	H [%]	Fe [%]	O [%]	Ti [%]
0.05	0.08	0.01 to 0.015	0.5	0.4	Remainder

Table 4– Results of calculations.

V [mm^3]	A_0 [mm^2]	h [mm]	φ_A	F [N]	W [N.mm]
107.60	19.63	5.48	0.75	9.832	39.330

Table 5 – Micro-hardness values of the raw material.

Test nr.	Hardness [HV]
1	268
2	245
3	231
4	256
5	268
Average	254
Standard deviation	15

Table 6 – Results of preliminary tests.

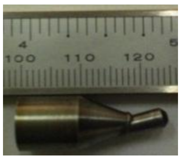
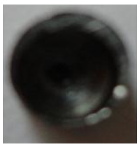
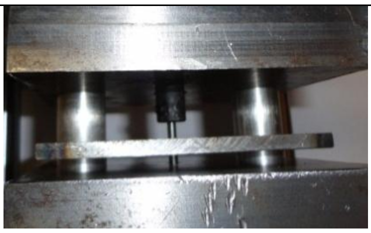
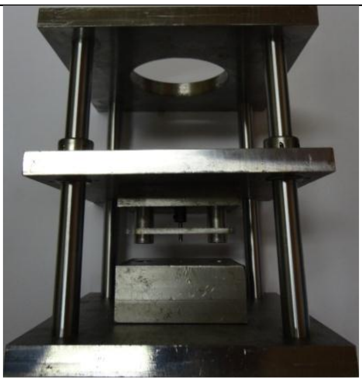
Test nr.	Punch problem	Punch	Work piece problem	Work piece
1	Eccentricity of the work piece cavity and impossibility of extrusion		Misalignment of the guides, inadequate geometry of the punch	
2	Eccentricity of the work piece cavity		Increase in the rake angle of punch in the material, with the occurrence of the plunger buckling	
3	Eccentricity and partial extrusion of the work piece		Flexion and breakage of the plunger caused by excessive increase in the load.	

Table 7 – Results of the tests.

Test nr.	Optimization	Tool	Solution	Work piece
1	Alignment of the tool guides		Appropriate clearances and alignment in the holes	
2	Punch's direction in the extrusion		Extrusion with uniform displacement material	
3	Concentricity in the test		Work piece geometry with satisfactory symmetry.