DETERMINATION AND EXPERIMENTAL - THEORETICAL VERIFICATION FROM THE POINT OF ENCHASING OF ORTHOPEDIC PINS DEPENDING ON THE METHOD OF ATTACHMENT.

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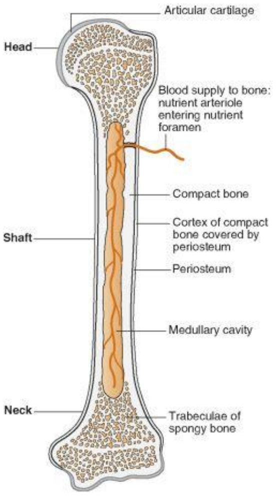
Abstract. *The methodology used for structural analysis in the field of mechanics was used to study the release or loosening of orthopedic pins. This occurrence is not an appropriate situation and dangerous for people with traumopathy, they induce regions prone to infections. The function of the pins is to establish a good support for external fixators whose purpose is the stabilization of bone fractures. These pins have different dimensions with cylindrical or tapered threads whose length depends on the purpose. The setting is made in the walls of the bone tissue in both inner and outer. The proposition for a new design of pin-type Schans, like linear fastener, seeks to show that its mechanical stability refers to the point crimp in the regions of contact is crucial to combat bone loss and infections. For this, Schanz pins with different lengths of thread, were instrumented with strain and inserted into test specimens of nylon, which simulated the rheological behavior in bone tissue. The set was subjected to stresses of rotation, while, on the pin, measurements were made of deformation. The results will have served as a basis for making and validation of a finite element model for the analysis of how best to fix or pin to be used better.*

Keywords: *Structural analysis, Bone anisotropic behavior, Schanz pin*

1. INTRODUCTION

Bone is a solid tissue, highly specialized which forms most of the skeleton and is the main supporting tissue of the body. Bone tissue participates in an ongoing dynamic process of remodeling, producing new bone and old bone degrading. Bone is composed of several different tissues: bone, cartilage, dense, epithelial tissue, nervous tissue and various blood-forming (anatomia, 2010). The "Fig.1" shows the arrangement of tissues responsible for the mechanical strength of bone



Epiphysis - the end of the bone covered with cartilage;
Periosteum - a fibrous membrane that covers the bone externally;
Shaft - a portion of the bone located between the epiphyses and surrounded by the periosteum.
Bony canal - the canal where the bone marrow.

Figure 1. Structure of a long bone (MEDICAL DICTIONARY, 2011)

A common occurrence and known as fracture, which is complete or incomplete rupture of the continuity of a bone or cartilage accompanied by various degrees of injury to surrounding soft tissues, including blood supply, and compromising the function of the locomotor system (Piermattei, apud Barros, 2009). "There are several methods to be used for the reconstruction of a fracture, none of them is completely perfect, they all have advantages and disadvantages" (Durall et al. Soontornvipart et al. apud Barros 2009). The osteosynthesis is a surgical intervention with the goal of uniting the fragments break through a metal part to allow consolidation.

According to Paschoal (2002), the osteosynthesis can be classified into internal and external, the internal is that which employs plates, screws, Kirschner wire and intramedullary nails; the outer is one that employs external fixators. External fixators can be classified as type I, II and III as the "Fig 2.

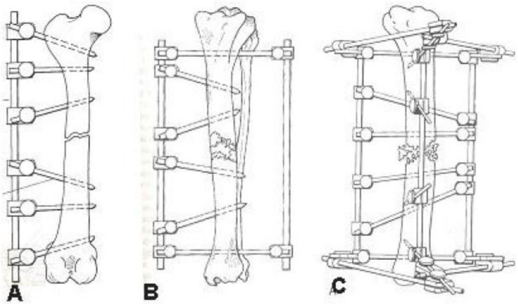


Figure 2. Schematic images. A) type I fixator B) type II fixator. C) fixative type III. Young, apud Barros (2009).

Immobilization involves the fixation of bone fragments so that they stay still in relation to each other during the consolidation process. The objectives are to stabilize the fragments and the prevention of displacement, angulation and rotation (PIERMATTEI, apud BARROS (2009).

One of the components of the external fixator, and theme of this work, are the Schanz screws that may arise in various models as shown in "Fig 3.

Figure 3. Schanz screws (Francis, 2010)

The first (model A) is a pin with tapered angle of 37° diameter greater than 5.0 mm, 2.0 mm pitch thread length 50,0 mm and overall length of 200,0 mm pin. The second (model B) is a cylindrical pin with a diameter greater than 5.0 mm, smaller diameter of 3,2 mm, 2,0 mm pitch thread length 36,0 mm and total length of the pin 200,0 mm. Both models have a screw fixed in the two cortical bone, the cortical or cis entrance, adjacent to the fastener, and cortical cross or opposite, located after the bone marrow. The third (model C) has the same basic thread model B but with a thread length of 15,0 mm so that in this configuration, the fixing pin to the cortical bone occurs only in the cortical trans, cis while the cortical is simply the support of the smooth rod of 5,0 mm.

The external fixator stability is crucial for the treatment of fractures. The Schanz screws, when part of an external fixator are subjected to stresses both radial and axial loads. But surely those applied perpendicular to its axis are the most important (EVANS et al, apud FRANCISCO, 2010). The pin-bone interface is the point of maximum stress concentration, the understanding of the events in this place are decisive to choose the type of pin to be used. Thus, the purpose of this study is to analyze the pin-bone interface with force applied perpendicularly to the pin Type B "Fig 3 "of national production and use of colloquial and model type C" Fig 3 "also manufactured in Brazil but with a new configuration.

2. EXPERIMENTAL PROGRAM

The pins were mounted on a backing of nylon to replace bone tissue. Both were inserted according to the guidance from an orthopedic specialist and with appropriate surgical instruments. The pins were instrumented with electrical resistance strain gauges, glued on its surface, to an automatic data acquisition for deformation, whose equipment was used to model ADS500 Lynx technology. At the same equipment were connected to a load cell and a potentiometric displacement meter. The support assembly and pin were fixed to the output of a speed reducer which can rotate it with constant torque, when applied at the entrance (in), at a constant speed by means of a crank. The "Figure 4a" shows the layout of the set, and the pin placement on the load cell, the “Figure 4b” shows the free body diagram showing the position of force and geometric parameters of the pin. Where L-length of the pin, x - location of the strain gage, V - the applied force (the force measured by load cell).

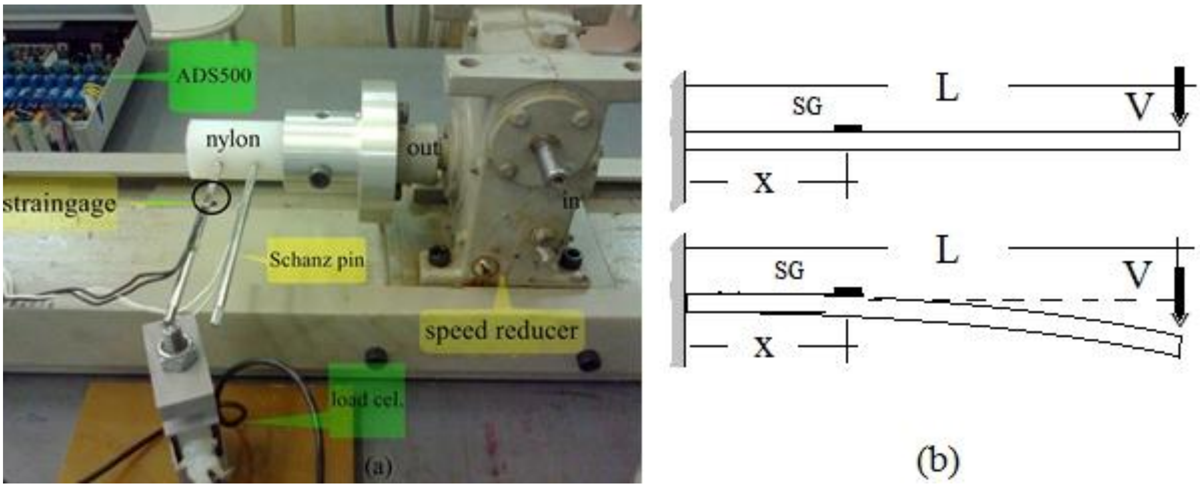
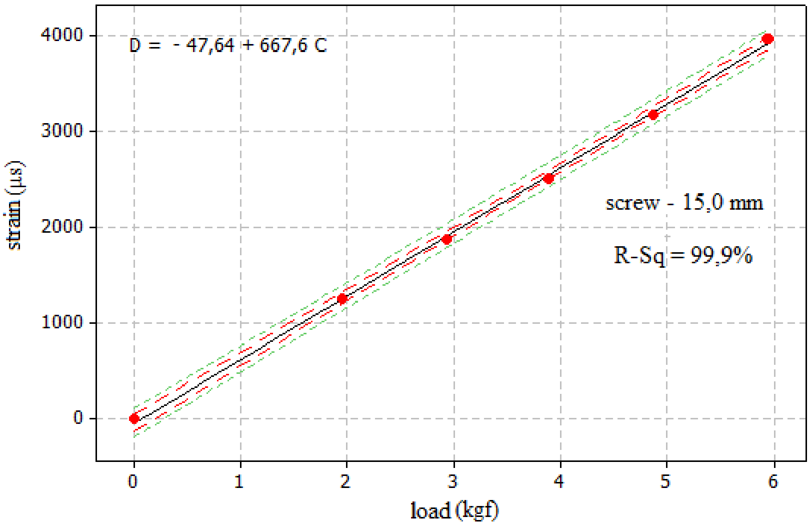


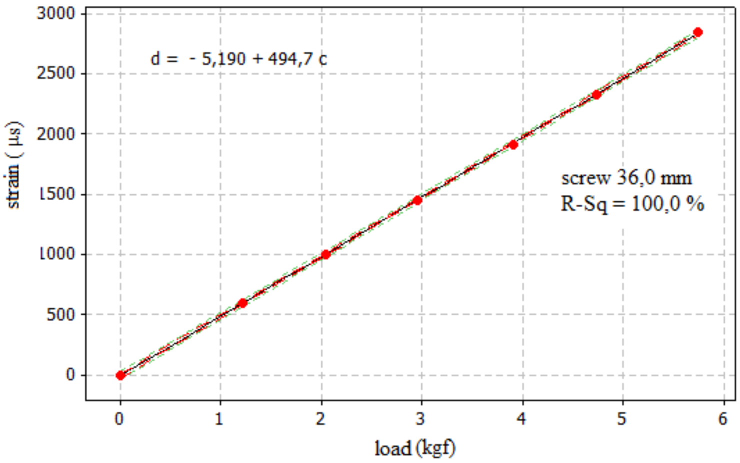
Figure 4. Experimental arrangement for collecting data of deformation and displacement that occurred on pins. (a) actual layout, (b) free body diagram.

Initially, the pins were subjected to loads up to 58,6 N (6,0 kgf) with subsequent measurement of deformations. The data were statistically analyzed and represented in a graph, which represents the behavior of pin C.



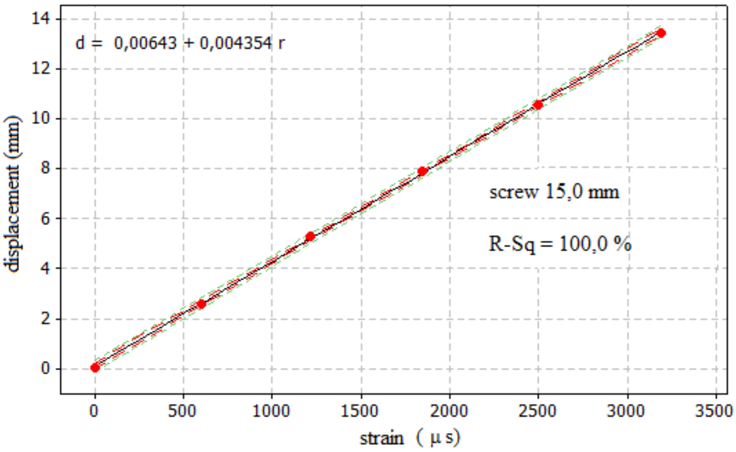
Graphic 1. Behavior of the pin C when subjected to loads imposed by the reducer.

Pin Type B was also requested in the same way, and the results are shown in chart 2.

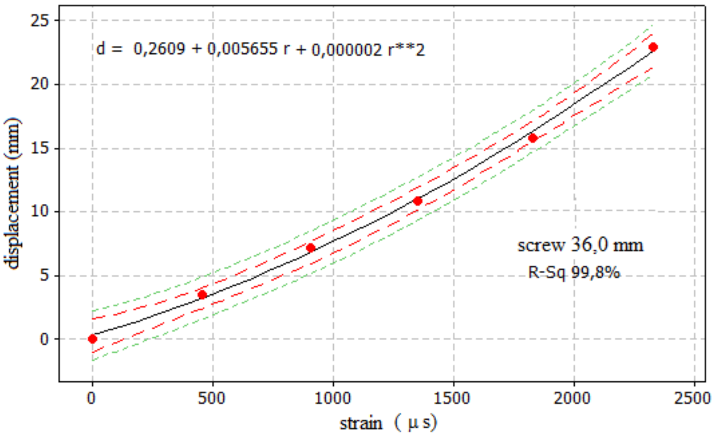


Graphic 2. Behavior of the pin B when subjected to loads imposed by the reducer.

Thereafter the pins were subjected to loads up to 58,6 N (6,0 kgf) with dead weight placed on the free end of the pins and immediate measure of the displacements. The data were statistically analyzed and illustrated in Graphic 3 and Graphic 4, which represent, respectively, the pin C and pin B.



Graphic 3. Behavior of the pin C when subjected to loads imposed by the reducer.



Graphic 4. Behavior of the pin B when subjected to loads imposed by the reducer.

This process allowed to relate the displacement measured from the end of the pin, with specific deformations at a known point, and can transform an offset information on deformation in a section of interest. Moreover, this process enables the effective length crimp pin, provided that the deformations are measured on a section transversal, distant (L-x) (Fig. 4) the point of load application. Using the data obtained and based on equation 1, the point proved to be clamped in the same position of the insertion of pins. The value of V was measured by the load cell, ε was measured by the system ADS500, L is the length of the pin and the pin diameter. Manipulating the equation (1) it was obtained the value of x, which according to the accuracy of the measurements presented location at the insertion point. Showing that the cantilever occurs at the site of attachment of the pin. For validation and confirmation of the results it was carried out a study based on finite element method.

$$V = \frac{\varepsilon L^3}{3d\,(L - x)} \tag{1}$$

Where: ε - specific deformation, L - length of the pin, x - position of the extensometer, d - diameter of the pin

3 MECHANICAL BEHAVIOR OF MATERIALS

3.1 Mechanical behavior of bone

The bone has an excellent resistance to compression, as well as good tensile strength, despite being about 30% lower. Bone resistance depend significantly on the measured direction, ie show anisotropic behavior, as shown in Tab.1. These results will be used to interpret the results of finite element model and assessing the integrity of the bone or the occurrence of failure by cracking or crushing.

Table 1 Resistance of human cortical bone (Nordin, 2001)

Compressive strength (MPa)			Tensile (MPa)		
LONGIT.	TRANSV.	RADIAL	LONGIT.	TRANSV.	RADIAL
190	130	130	135	50	50

The bone has a low capacity to absorb torsion due to low shear strength, representing about a third of the compressive strength and half the tensile strength. The torsion tests performed with several bones indicate the rupture accompanied by small strains, which can be characterized as inherently fragile, as sketched in Figure 5 (NORDIN, 2001).

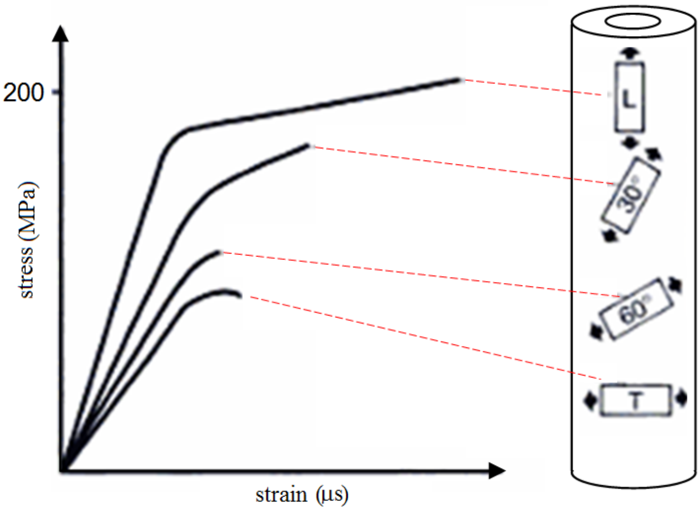


Figure 5. Stress-strain diagrams for uniaxial tensile tests in specimens with different orientations (Nordin, 2001).

It is observed that the bones also exhibit anisotropic elastic properties, as in the case of resistance. The research conducted by Reilly and Burstein (1975) showed that the modulus of the fibular bone is about 18% higher than the femur while the tibia bone is about 7% higher than the femur. These results are presented in Tab.2. The relationship between stress and strain of a material is established by means of elastic properties of bone. In the case of use of computer systems for analyzing structures, which are usually implemented according to the finite element formulation, it should provide the material constitutive matrix that relates stress and strain. In the case of anisotropic materials with a flat matrix which relates the tensor of deformations (linear and angular) with the Cauchy stress (normal and shear) is given by equation 2.

$$\boldsymbol{\varepsilon} = \boldsymbol{D}^{-1} \cdot \boldsymbol{\sigma} \qquad \rightarrow \qquad \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{12} \\ \gamma_{13} \\ \gamma_{23} \end{bmatrix} = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{12}}{E_2} & -\frac{\nu_{13}}{E_3} & 0 & 0 & 0 \\ & \frac{1}{E_2} & -\frac{\nu_{23}}{E_3} & 0 & 0 & 0 \\ & & \frac{1}{E_3} & 0 & 0 & 0 \\ & & & \frac{1}{G_{12}} & 0 & 0 \\ & \text{(sim)} & & & \frac{1}{G_{13}} & 0 \\ & & & & & \frac{1}{G_{23}} \end{bmatrix} \cdot \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{12} \\ \tau_{13} \\ \tau_{23} \end{bmatrix} \tag{2}$$

characterized by nine parameters. The subscripts 1, 2 and 3 correspond respectively to the directions longitudinal and circumferential and radial indices 12, 13 and 23 correspond respectively to the longitudinal-circumferential, longitudinal, radial and circumferential-radial. The data presented in Tab.2 are used in the simulation by finite elements. Given this consideration anisotropic material, to describe more realistically the stress concentration in the femur in the region of insertion of the Schanz screw.

Table 2 Tensile properties of human femur bone (Reilly, 1975)

Modulus of longitudinal elasticity (GPa)			Modulus of transversal elasticity (GPa)			Poisson ratio		
LONGIT.	TRANSV.	RADIAL	LONGIT.	TRANSV.	RADIAL	LONGIT.	TRANSV.	RADIAL
17	11,5	11,5	3,6	3,3	3,3	0,58	0,31	0,31

3.2 Mechanical behavior Schanz pin

The mechanical properties of stainless steel alloy, which is made of the Schanz screw were obtained through a uniaxial tensile test, performed in its own laboratory at the School of Engineering. The stress-strain curve obtained in the experiment presented in Figure 6, allows the mechanical characterization of stainless steel. The modulus of longitudinal elasticity was calculated for the third point of the curve to the voltage level of 382,0 MPa associated with the deformation of 0,002, and the fourth point, with the stress of 565,0 MPa and strain of 0,003. Similarly, the Poisson's ratio was obtained from the diametral reduction of 0,0006 measured to the voltage level of 382,0 MPa. The flow resistance was obtained graphically, considering the residual stress of 0,2% (conventional), due to the lack of landing outlets. Figure 6 shows the graphical construction for determining the limit of flow resistance. The yield strength of stainless steel is the level of tension associated with the collapse of the pin. The type of breakdown observed is a ductile type. The Table 3 gathers the results of the analysis of the diagram obtained experimentally. It is assumed that the compressive strength is equal to the tensile strength.

Table 3 Mechanical properties of stainless steel pin for axial tensile test

Modulus of elasticity (GPa)	Poisson ratio	Resistance flow (MPa)	Limit Resistance (MPa)
190,0	0,3	845,0	1024,0

Figure 7 shows the approximate bi-linear function assumed to represent mathematically the elastic-plastic behavior of stainless steel pin. It takes three parameters to define the material assumed: elastic modulus, the plastic module (post-yield) and resistance to flow. Thus, the plastic module is the slope of post-yield given by the difference of the tensions $\Delta\sigma$ = 1024,0 –952,0= 72,0 MPa divided by the difference of the deformations $\Delta\varepsilon = 18\text{x}10^{-3} - 5\text{x}10^{-3} = 13\text{x}10^{-3}$,resulting in value E^{pl} = 5,5 GPa.

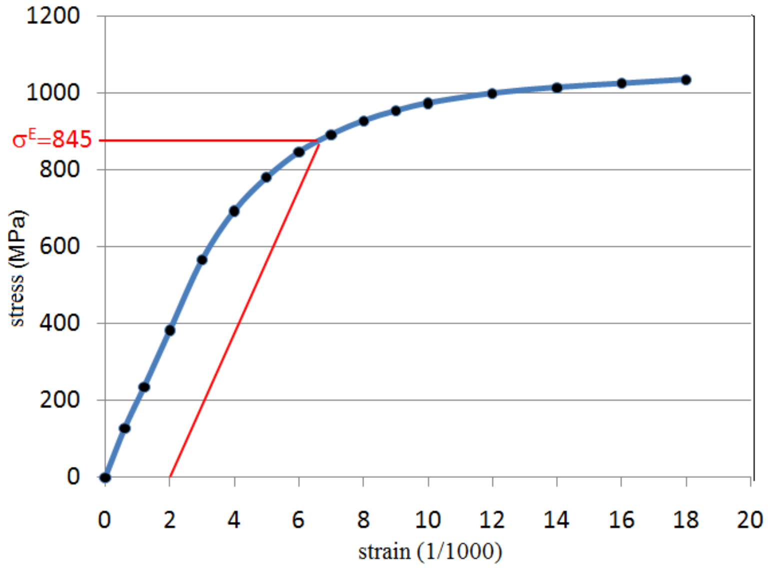


Figure 6. Stress-strain curve of stainless steel in pin

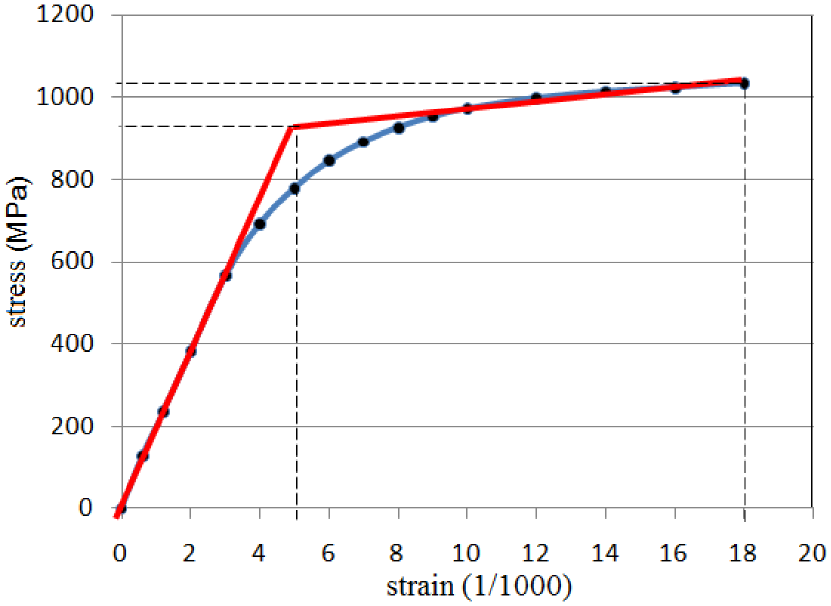
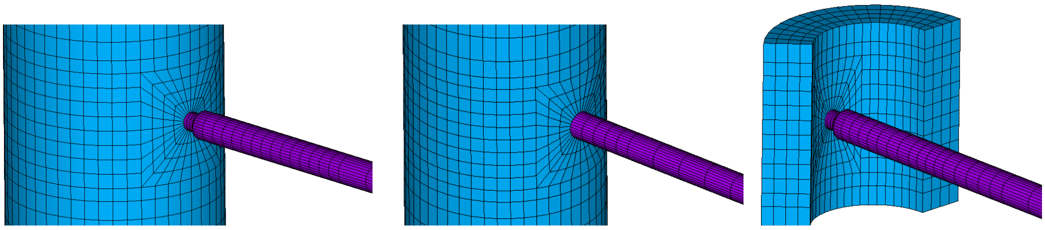


Figure 7. Approximation of the curve by a bi-linear function

4. MATHEMATICAL MODELING

The finite element models for the studs wide (36,0 mm) and small screw (15,0 mm) inserted in the bone were prepared using approximately 10.000 solid elements with eight nodes hexahedral (3D). This can be seen in Fig 8.



(a) (b) (c)

Figure 8. Hexahedral finite element model for (a) threaded pin high (fixed)
(b) threaded pin small (mobile) (c) detail of the pin small thread

For the case of the threaded pin high, its that we are interfacing the bone on both sides of the bone will be coupled thereto in order to simulate the setting offered by the thread. Moreover in case the pin small thread, its that we are interfacing the bone on the inner wall will be attached to them, while those near the outer wall will be free to develop radial displacements. It was considered the bezel of the bone in a section a distance of two times the outer diameter (above and below), distant enough from the region of insertion of the pin so it does not affect the stress distribution observed in the region of interest. We considered the two situations described in the experimental program: concentrated load and imposed displacement, both at the free end of the fixed pin 135,5 mm from the wall of the bone, or pin the mobile wall 137,7 mm of bone. Loads and displacements were applied slowly (statically) and therefore was not considered an impact factor for the applied loads.

4.1 Linear elastic behavior

For describing the behavior of linear elastic materials we used the following physical parameters: modulus of elasticity of steel pin E = 190,0 GPa and Poisson's ratio 0.3, modulus of nylon (representing bone) E = 4,0 GPa and Poisson's ratio 0,35.

From the analysis of the results of linear elastic model can be said, comparatively, that the short threaded pin (mobile) will significantly lower voltages. Figure 9 shows the stresses acting on the criterion of Von Mises.

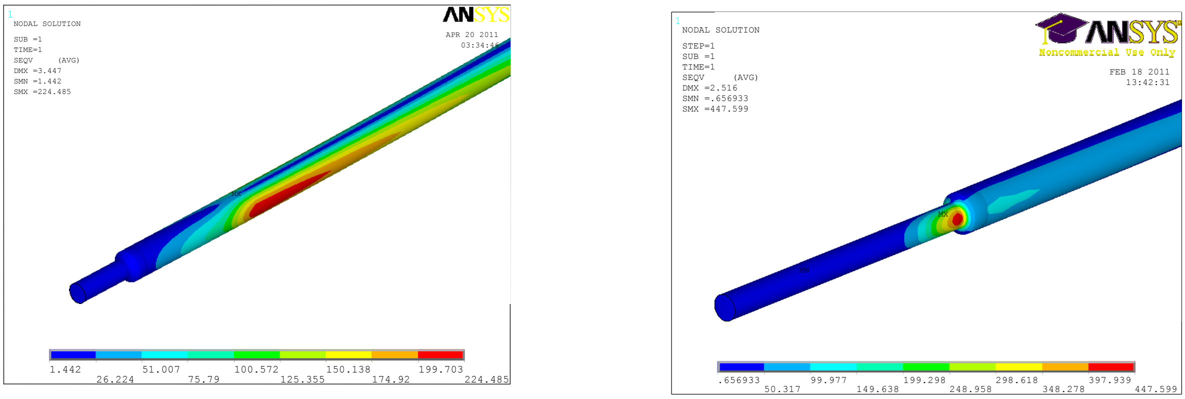


Figure 9. Von Mises Criterion (yield criterion) (a) threaded pin small (mobile)
and the large pin screw (b) (fixed) for a load at the other end

4.2 Elasto-plastic behavior

To describe the elastic-plastic behavior of steel pin used the following physical parameters: modulus of elasticity of steel pin E = 190,0 GPa and Poisson's ratio 0.3, yield stress σ^E = 845,0 MPa and modulus plastic Ep = 5,5 GPa, modulus of elasticity of nylon (replacing the bone) E = 4,0 GPa and Poisson's ratio 0,35. The strength criterion of Von Mises (maximum distortion energy) will be used to verify the occurrence of flow stainless steel pin. Data represented in Fig 10.

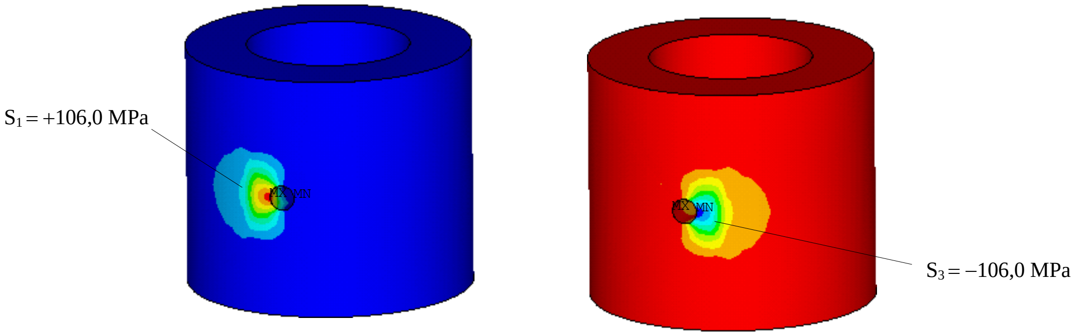


Figure 10. σ a maximum normal stress (tensile) and minimum normal stress σ 3 (compression)
nylon for the dislocation tax 22,98 mm at the free end of the pin

The adoption of the elastic-plastic material in the mathematical model, despite the computational cost is higher, it gave a better grip of the numerical results with experimental ones for the big screw pin (fixed). In Figure 11 we can see a higher correlation of elastic-plastic model with the experimental results.

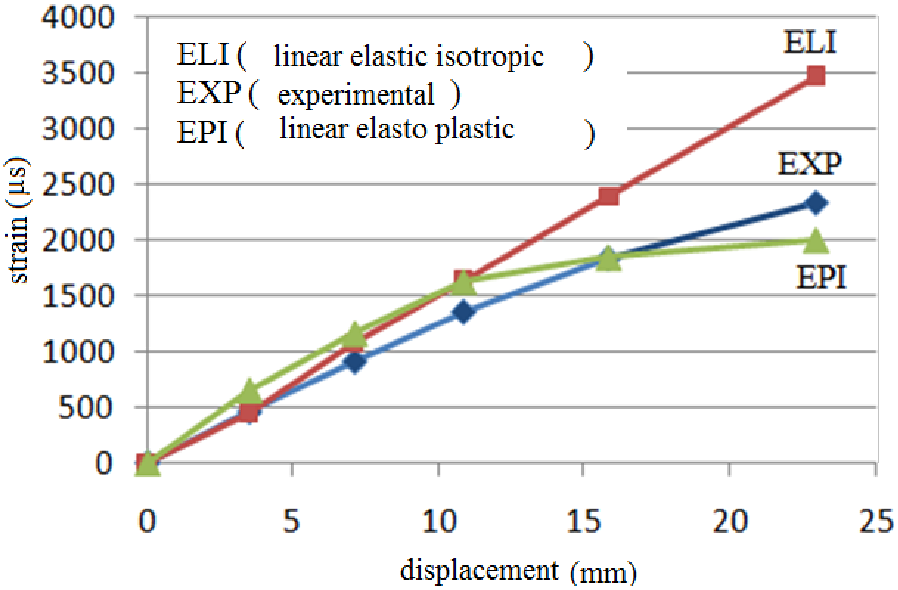


Figure 11. Imposed displacement (mm) by the deformation (micro-strain) in the major thread of the pin (fixed)

4.3 Anisotropic elastic-plastic behavior

To check the tension transmitted to the bone, applying a load due to the free end of the pin, more realistic mathematical model were used in the anisotropic elastic properties of bone in human femur obtained experimentally (REILLY, 1975). The Coulomb criterion (maximum normal stress) and the experimental results published by Nordin (2001) will be used to verify the occurrence of failure (crushing or cracking) in the bone. For the steel pin parameters used were: modulus of elasticity of steel E = 190,0GPa and Poisson's ratio 0,3, yield stress σ = 845.0 MPa and plastic modulus E^p = 5,5 GPa

Comparing the Fig 10 and 12 can verify a significant increase in principal stress due to shift to a more rigid material. It is observed that the tensile stress reached the limit of rupture, the second, Nordin (2001) may lead to excessive cracking along the wall of the hole. The Figure 12 shows that the anisotropic characteristics, with greater stiffness in the longitudinal direction, affect the distribution of principal stresses.

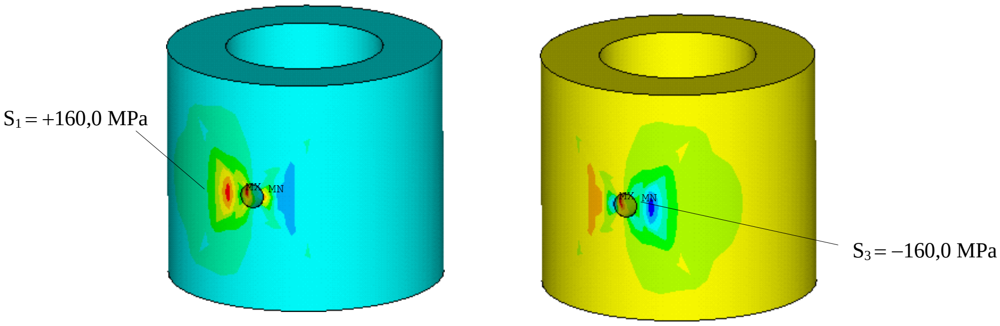


Figure 12. σ a maximum normal stress (tensile) and minimum normal stress σ 3 (compression) in human bone with characteristic anisotropic for the tax offset 22,98 mm at the free end of the pin.

5 FINAL CONSIDERATIONS

Lamination located in the fixed pin in the transition of the screw, due to the reduction in diameter, leads to loss of mechanical performance and thus compromise the life of the pin. Given this fact, the solution considering the threaded pin is little more favorable and should be recommended. It was also noted that tensions in the small threaded pin are smaller than those in relation to the threaded pin high. This fact is due to surface contact between pin small screw and bone is larger and more efficiently transmits the efforts to the bone.

Pointing out that the use of nylon in place of human bone for mechanical testing does not reflect the real tensions that occur in bone. In the model that considered the anisotropy observed a maximum tensile strength of 160,0 MPa, while the model that considered the properties of nylon were obtained voltages order of 106,0 MPa. Clearly, the tensile strength of 160,0 MPa leads to cracking the bone. The material selection should be based on criteria of strength and anisotropy. Some wood species may be the closest human bone. The discrepancies observed between experimental and numerical pin large thread is mainly due to lack of accuracy in modeling the transition with the screw shaft of the pin.

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