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CONTACT STRESS SIMULATION FOR MG-0.5CA-XMN ALLOYS USED FOR MEDICAL APPLICATION

In the past decades, Mg alloys have been studied intensively as potential orthopedic applications. The present research work, the FEA of the obtained contact stresses in the case of the load applied on Mg-0.5Ca-xMn alloys has been investigated. It has been used the NCB Curved Femur Shaft Plate type as a model in order to establish the necessary modeling parameters. The objective of the present work was to highlight the strain values at the contact point on the surface of the Mg-0.5Ca-xMn alloys. The results showed that the highest stresses observed near the gaps of the plate and in the screws. It means that all mechanical loads are sustained by the plate and screws, and the patient's femur can be recovered.

Keywords: Mg-Ca-Mn alloys; FEA analysis; Mechanical properties

1. Introduction

In recent years, magnesium alloys had applications in many fields of activity such as: aerospace, automotive or medical. Research on biodegradable alloys has materialized mainly in the orthopedic field, where various models of implants have been made such as plated, screws, rods, etc. [1-3], being a continuation of biomedical applications from classical biocompatible materials based on Ti or Co-Cr alloys [4-6]. Improving the characteristics and especially the biocompatibility of Mg based biodegradable alloys was improved in two directions: alloying with biocompatible elements [7] or coating depostions on the surface of the base material by various methods: APS (Athmospheric plasma deposition), ED (electrophoretic deposition) or PLD (pulsed laser deposition) [8-11].

Biodegradable alloys which contain Ca contributes to the increase of biocompatibility by forming the lamellar eutectic Mg2Ca at the boundary of Mg grains [12]. It is also present in over 95% of the processes of the human body with key functions in bone tissue, muscle contraction or blood clotting [7]. Manganese is the element that improves the mechanical properties, the corrosion resistance properties, refines the microstructure and leads to the dimensional reduction of magnesium grains. In the body it is a trace element and a good activator of enzymes. Mn deficiency leads to osteoporosis, diabetes and atherosclerosis [7].

Vijayakumar et al. [13] conducted studies using FEA analysis in order to identify the sites of propagation of fissures in the femur and the representative values of stresses from different values of loads. Other studies by Chandramohan [14] and Chethan [15] have identified and analyzed the effect of factor variation in the femoral bone by applying loads between 1kN and 8 kN. It has been observed that high stress is predominantly in the medullar area and also the load capacity of the femur rises proportionally to the length of the femur. Also, in the field of FEA analysis studies were performed by Nica et al. [16] and Almasi et al. [17].

The purpose of this paper is to highlight the effect of the stresses of a prosthesis in the Mg-0.5Ca-xMn system (x = 0.5 / 1 / 1.5 / 2/3 wt.%) on a 3D model of the femur by FEA analysis.

2. Research Methodology

The plate FEA model is presented by a NCB Curved Femur Shaft Plate. This plate has 10 holes, with a length of 210 mm and a thickness of 5 mm, having a 20 mm distance between gaps from each other. This model is similar with the model from the NCB catalog [18]. Also, according to the ISO 5835-1: 1985 standard and previous researches [18,19], the study used 8 NCB screws with a 5 mm diameter and 38 mm length. The Figure 1a

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is showing the 3D bone model and Mg plate. Linear tetrahedral elements were used for the meshing. The size of the meshing elements for the bone are 15mm, for the plate the global mesh size is 13,174 mm and for the screws the global mesh size are 2 mm. A local meshing of 0.1 mm was also performed in the contact areas and near the stress concentrators. This resulted in a total of 23964 nodes and 98781 elements, of which 29315 are Non isotropic linear tetrahedron, 62961-Linear tetrahedron and 6505-Contact join, figure 1b it presenting meshing bone model and Mg plate. At the contact between the surfaces of the screws and the plate, the General Analysis Connection and Contact Connection Property commands were used, in which the friction between the surfaces was taken into account, specifying friction ration according to TABLE 1. In order to indentify the static analysis, the Gauss R6 mathematical method of CATIA V5 finite element analysis was used. The initially mechanical properties of the Mg-0.5Ca-xMn used for FEA analysis are presented in TABLE 1.

For obtaining the experimental alloys from the Mg-0.5Ca-Mn system, commercial master alloys were used [21,22], like Mg-15Ca base, respectively Mg-3Mn base. The elaboration of Mg-0.5Ca-Mn alloys was realized in an induction facility under argon protective atmosphere. The casting was performed at a temperature of 670-685°C for 30 min using graphite crucibles. The resulting alloys were cut into rectangular samples having different concentrations in range of Mg-0.5Ca – 0.5wt.% Mn and Mg-0.5Ca – 3 wt.% Mn. According to previous researches performed by Lupescu et al. [20], the simulation take into account the characteristics of a female skeleton left thigh femur [23] with the femur (Lf) dimension of 406 mm, 163 cm height and 53 Kg weight. The femoral bone is known as an elastic anisotropic material having a yield strength of 125 MPa. The femur was considered orthotropic with a density of 1850 kg/m^3 and with mechanical properties presented in TABLE 2 [24].

The finite elemental analysis was performed with loads that took into account the patient's weight (BW) and for the most undesired situations, for the condition in which the patient moves

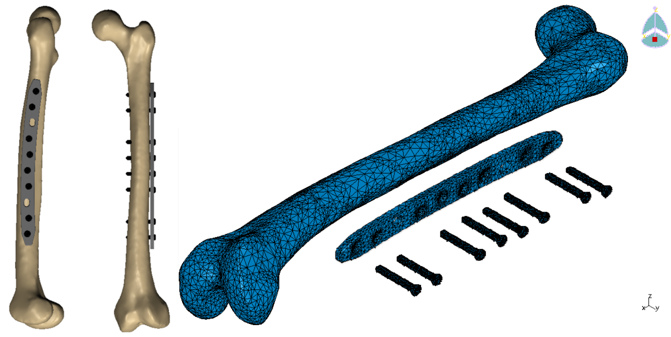


Fig. 1. (a) 3D bone pattern and Mg plate. (b) Meshing bone model and Mg plate

normally without using crutches, thus resulting in a vertical load of 1,643 · BW. In paper [20] are presented in more detail and are explained how the position and direction were chosen and how the internal forces and the moments exerted on the femur were calculated.

3. Result and Discussion

Taking into consideration the real stress situations, the loads applied on the femoral bone take into account the forces that occur due to the weight of the body and the contact forces of the ligaments to all the muscles. The results showed that in the femoral bone stresses are below the strength limit of the bone (120 MPa), with some average values between 42.2 and 21.1 MPa. The maximum value of the stress is about 70.2 MPa and is presented in stress concentrators area, near the gaps, as is shown in Figure 2a.

In Figure 2b is presented the von Misses stresses resulted in the Mg-0.5Ca-3Mn plate. The results present isolated stresses that exceed or are similar to yield strength (approximately 278 MPa). These values near the holes where a stress concentrator is created, and the average values are between 94.1 MPa and 187 MPa, values that are 1.5 times lower than the limit value.

Figure 3a shows the von Misses stress for sample 5 of Mg-0.5Ca-3Mn, all values exceeding the yield strength (278 MPa for magnesium alloys) are represented by red, these areas are isolated and are found only in the screw rod, the maximum values are 1.66 higher than the limit value. The predominant stresses have

TABLE 1

Initially mechanical properties of the Mg-0.5Ca-xMn

Mg-0.5Ca-xMn	Sample 1 Mg-0.5Ca-0.5Mn	Sample 2 Mg-0.5Ca -1Mn	Sample 3 Mg-0.5Ca-1.5Mn	Sample 4 Mg-0.5Ca-2Mn	Sample 5 Mg-.5Ca-3Mn
Rigidity [N/µm]	3.863	4.145	4.199	3.767	4.256
Young Modulus [GPa]	29.457	34.084	32.132	27.528	35.148
Hardness [GPa]	0.369	0.421	0.374	0.346	0.423
Density [kg/m^3]	1767	1795	1822	1847	1899
COF (coefficient of friction)	0.124	0.199	1.046	1.322	0.812

TABLE 2

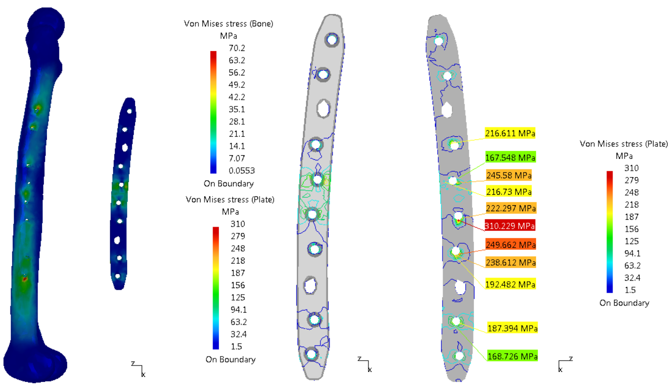
Femural bone mechanical properties [19]

Young Modulus [MPa]	Poisson coefficient	Shear Modulus [MPa]
Longitudinal $E_1 = 1600$	xy plane $\mu_{12} = 0.30$	$G_{12} = 3200$
Transverse $E_2 = 6880$	xz plane $\mu_{23} = 0.45$	$G_{23} = 3600$
Normal $E_3 = 6300$	yz plane $\mu_{13} = 0.30$	$G_{13} = 3300$

TABLE 3

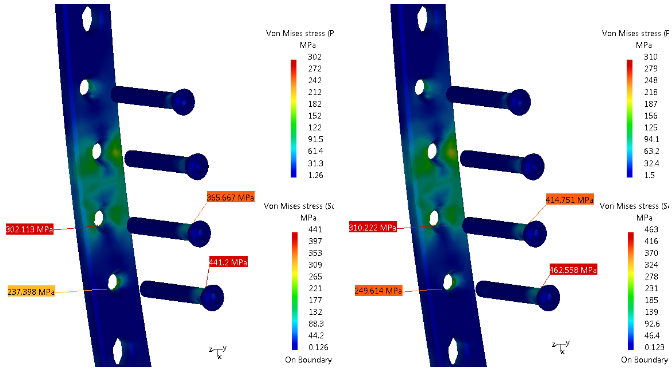
Mechanical properties of the Mg-0.5Ca-xMn after simulation process

Mg-0.5Ca-xMn		Sample 1 Mg-0.5Ca-0.5Mn	Sample 2 Mg-0.5Ca -1Mn	Sample 3 Mg-0.5Ca-1.5Mn	Sample 4 Mg-0.5Ca -2Mn	Sample 5 Mg-.5Ca-3Mn
Von Misses stress in bone [MPa]	Maximum	68.9	70	69.6	68.3	70.2
	Medium	20.7-41.4	21-42	20.9-41.8	20.5-41	21.1-42.2
Von Misses stress in plate [MPa]	Maximum	304	309	307	302	310
	Medium	92.2-183	93.7-186	93-185	91.5-182	94.1-187
Von Misses stress in screws [MPa]	Maximum	446	459	453	441	463
	Medium	134-268	138-275	136-272	132-265	139-278



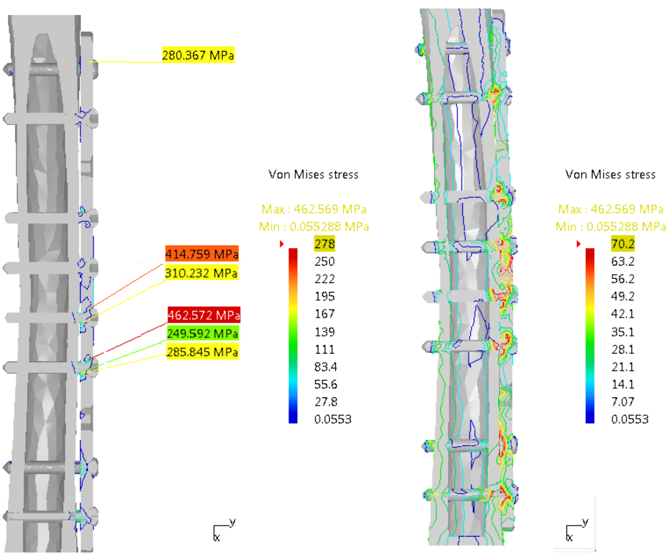
a) b)

Fig. 2. Von Misses stress in the femur and plate, (case for Mg-0.5Ca-3Mn, Sample 5)



(a) FEA analysis for Mg-0.5Ca-2Mn case (b) FEA analysis for Mg-0.5Ca-3Mn case

Fig. 4. Von Misses stress comparison between lower case (Mg-0.5Ca-2Mn case) and higher case (Mg-0.5Ca-3Mn case)



a) (b)

Fig. 3. FEA results for Mg-0.5Ca-3Mn case

average values between 83.4 MPa and 167 MPa, values that are below the yield strength.

In Figure 3b it can be can observed the location of the stresses, which are higher than the maximum value in the femur (red tensions), they are present only in the plate and in the fixing screws, which proves that all the stresses created by the forces and moments.

The Figure 4 presents the von Misses stresses for the Mg-0.5Ca-2Mn and Mg-0.5Ca-3Mn samples and it can be shown that the stress values for the Mg-0.5Ca-3Mn screws are about 5% higher than for Mg-0.5Ca-2Mn screws. This aspect can be associated to the fact that the Mg-0.5Ca-3Mn alloy has a higher young modulus and higher material density.

4. Conclusion

Biodegradable biomaterials have significant applicability in the orthopedic field. According to specialized studies, the alloying elements increase the mechanical characteristics. In our case, Mn leads to improving mechanical strength and corrosion resistance, due to the microstructure refining, and Ca improves biocompatibility. FEA studies performed on these alloys with known chemical composition and mechanical properties, lead to the identification of critical points in the material and an ideal implant geometry. The results obtained in the Mg-0.5Ca-xMn alloy system showed that stress values for the Mg-0.5Ca-3Mn screws are about 5% higher than for Mg-0.5Ca-2Mn screws. This aspect can be associated to the fact that the Mg-0.5Ca-3Mn alloy has a higher young modulus and higher material density. The average stress values for Mg-0.5Ca-3Mn (higher case) for the plate are between 94.1 MPa-187 MPa and for the screws are 139 MPa-278 MPa. The average stress values for Mg-0.5Ca-2Mn (lower case) for the plate are between 91.5 MPa-182 MPa and for screws are 132 MPa-265 MPa. Also, the FEA simulation presented a value of 463 MPa on the thread screw near to the geometric stress concentrator.

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