MECHANICAL AND METALLURGICAL EVALUATION TO VALIDATION OF ASTM F136 6Al- 4V ORTHESIS´S FORMING MANUFACTURING FOR SURGICAL IMPLANTS

Michelon, Marcelo Dall´ Onder
UFRGS-LDTM-CT, Porto Alegre, Brazil, Marcelo.michelon@ufrgs.br

Silveira Netto, Sérgio Eglan
UFRGS-LDTM-CT, Porto Alegre, Brazil – Eglan.Silveira@ufrgs.br

Malveira, Nixon Vieira
LABMETRO-DEMEC / UFPR- UFRGS-LDTM-CT, Porto Alegre, Brazil – maqferra@ufpr.br

Schaeffer, Lírio
UFRGS-LDTM-CT, Porto Alegre, Brazil – schaefer@ufrgs.br

Abstract: *In this paper was searched to evaluate Mechanicals and metallurgical properties of orthopedics implants using Alloy Ti 6Al-4V. These implants have a form of plates and were used in surgiries to rebuild Thorax column traumatized with purpose of adjust and fix the borne fractures in Humans. These implants were imported early with a expensive price and today are manufactured in Brazil . The manufacturing process is by Hot Stamping at 600 °C. The metallurgical analysis were realized to know the behavior in service of plates influenced by submission at heating and forming. Metallografics and microHardness tests were realized to metallurgical characterization, confronting with anothers manufacturing processes and evaluating qualitatively the grain growth and modification of phase a e b of Ti. The results of Metallografic by Optics microscopy analysis appointed the presence of formed grains , but without phase modification by low heating used. Mechanical analysis using 3 points Bending tests was used to determine the Bending Strenght and calculate the equivalent Stiffness of plates, as according to NBR ISO 9585. The specimens tested have satisfactory mechanical behavior and the effect of thermomechanical treatment influence, with slight increase of micro-hardness values of specimens heated and formed.*

KeyWords: *Bending tests, Micro-Hardness, Surgical implants, Ti 6Al-4V Alloy.*

1. NOTATION

CP	test specimen
E	stiffness equivalent to the bend (N.m^2)
F_{max}	maximum load (N)
h	distance between the inside and outside rollers (m)
k	distance between inside rollers (m)
n	size of sample
P	test load (N)
q	displacement (mm)
RD	bending strength (N.m)
S	slope of load vs. deflection curve (kN.m)
t	Student factor
w	uncertainty in microhardness measure
$\bar{x}$	mean microhardness measure (HV)
x_i	a value of microhardness
x_{max}	sum of the mean values of microhardness and uncertainty of measurement
x_{min}	difference between mean values and uncertainty of measurement
s	standard deviation

2. INTRODUCTION

Bone fractures are among the most common health problems and may occur in young, healthy people. Care of fractures concentrates on identifying type and extent of the trauma and creating a biological environment that will maximize the normal bone repair processes. Although most fractures heal properly, many may result in significant and permanent loss of function and long-term invalidity.

The bone plates were developed by a Swiss team of surgeons and engineers who created a research group called Association for Scientific Research on Fractures (AICF), according Dutra et al. (2004) . In the 1970s there were already plates, screws and other instruments to enable fracture fixation with metal plates that compress the bone ends against each other, leading to fast and aggressive rehabilitation of the patient.

3. DESCRIPTION OF THE PROCEDURE

To perform the mechanical and metallurgical evaluation (metallography and microhardness) the plates were divided into 12 samples, which were subdivided into 3 sets. This division is due to the fact that there are three basic differences between the pieces tested. The first set corresponds to the machined plates purchased from the suppliers. The second set consists of plates submitted to thermal treatment, heating at 600°C for one hour and cooled at room temperature. The third set are plates that, after thermal treatment, were submitted to a mechanical forming process. The nomenclature adopted is shown in tab. 1.

Table 1 Plates sent for testing

Item	Description
1	Anterior cervical 50
2	Anterior cervical 58
3	Anterior cervical 66
4	Anterior cervical 78
5	Anterior cervical 90
6	Posterior cervical 5 holes
7	Posterior cervical 6 holes
8	Thoracic 6 holes
9	Thoracic 8 holes
10	Thoracic 10 holes
11	Thoracic 12 holes
12	Thoracic 14 holes
13	Thoracic 16 holes

Figure. 1 Example of a thoracic plate

Deep drawing was performed conventionally in Hydraulic press using a simple die with concave curvature and punch profiled. The proves were prepared to metallographic attack after sawing in Cut-off with Diamond Wheel to avoid heating. In Polishing Step, a diamond paste with grain sizes of 1μm and 0.3μm were used for polishing. Chemical attack was done for 90s using cotton wool soaked in the attack solution. The reagent used was Kroll, According Britto (1989) and Tailor (2002). Spim *et al (*2004) appointed to neutralize the attack, to use deionised water followed by isopropylic alcohol and drying with warm air.

Micro hardness tests were performed with a 1600-4980 Buehler micro hardness meter with an indenter to measure Vickers hardness. Measuring was done at about 4 different points on the sample surface. A load of 100gf was used applied for 20s.

The general array of the bending test was set up, according NBR ISO 9585 (2003). Figure 2 is showed a test beginning with 12-hole thoracic plate and fig.3 is showed a final results test with 90mm anterior cervical plate. The rollers used were cylindrical, with a grinding nominal diameter of 9.50mm. Epoxi resin was used to glue the internal rollers to the upper bar. Since the rollers were used attached to the bar, distance *k* (equal to 27mm) was kept constant. Therefore distance *h* was adjusted according to the length of each test specimen, always seeking to position the test specimen under the rollers and over the lower device, preventing contact between the parts where the holes were.

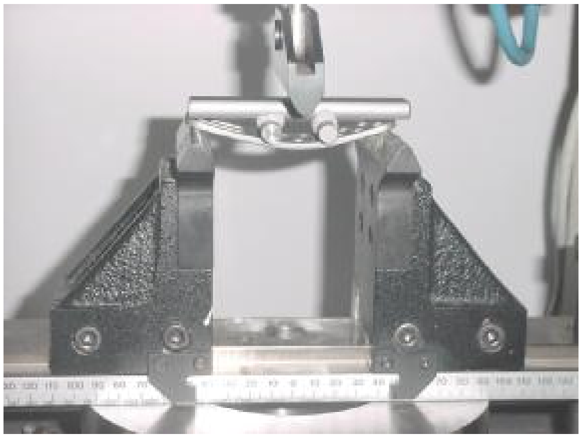

Figure 2. View of the bending test. Test specimen: 12-hole thoracic plate.

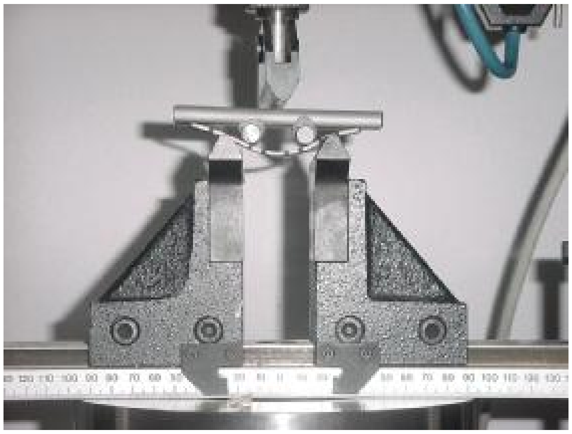

Figure 3. End of the test. Test specimen: 90mm anterior cervical plate

The bending test was performed on instrumented EMIC DL500 universal testing machine, to which a 500kgf load cell was adapted. The machine has a maximum capacity of 5kN. There is a displacement sensor adapted to the machine, which measured the bend or transverse strain of each test specimen.

The equivalent stiffness *E* was calculated according to eq. (1):

$$E = \left(\frac{4h^2 + 12hk + k^2}{24} \right) Sh \qquad (1)$$

where the terms *h* and *k* are geometrical parameters and term *S* is the slope of the load vs. deflection curve, according NBR ISO 9585 (2003).

The resistance to bend *RD* was calculated according to eq. (2):

$$RD = 0,5Ph \tag{2}$$

where P is the load value at the point where there is the intersection of the load vs. deflection curve, with a line of equal slope displaced from the origin to a distance q [**6**].

4. RESULTS

4.1. Bending and metallographic analysis

The values measured in the bending test are detailed in table 2.

Table 2. Results of the bending test

Item	RD [N.m]	E [N.m^2]	q [mm]	F_{max} [N]	P [N]	h [m]	S [kN/m]
1	6.18	1.05	0.92	1493	1307	0.01	638
2	4.12	0.54	1.00	933	720	0.01	226
3	4.17	1.08	1.20	640	507	0.02	221
4	4.39	1.04	1.20	586	533	0.02	213
5	6.11	1.52	1.00	1093	1067	0.01	638
6	5.77	1.72	1.20	753	701	0.02	350
7	6.82	0.88	1.40	660	636	0.02	103
8	29.83	5.10	1.32	3200	3067	0.02	733
9	36.85	6.77	1.52	3120	3013	0.02	600
10	25.75	4.99	1.60	2160	1947	0.03	373
11	33.64	6.78	1.80	2229	2139	0.03	347
12	26.73	5.08	2.00	1493	1467	0.04	187
13	32.57	6.89	2.00	1973	1787	0.04	253

Figure 4 shows photos of the samples where the metallographic analysis was performed. The analysis was done in the cross-section of the samples. Titanium is an allotropic element, i.e., it has two distinct phases, alpha phase, compact hexagonal, and beta, centered body cubic. The alloys studied contain aluminum (6%) and vanadium (4%). The presence of aluminium stabilizes the alpha phase, while vanadium, the beta phase, are both stabilized at room temperature.

In fig. 4a the presence of the equiaxial alpha phase (lighter region) and the intergranular beta phase (dark region) is seen. This configuration is also known as ***duplex***. In fig. 4b it is seen that due to thermal treatment there is a small coalescence of the beta phase, i.e., the beta phase presents a slightly spheroid appearance. This structure is typical, when the alloy is submitted to aging, which is the thermal treatment used. Figure 4c shows that due to the forming process imposed on the piece, mechanical hardening occurred through the deformation of grains, but no changes in phase.

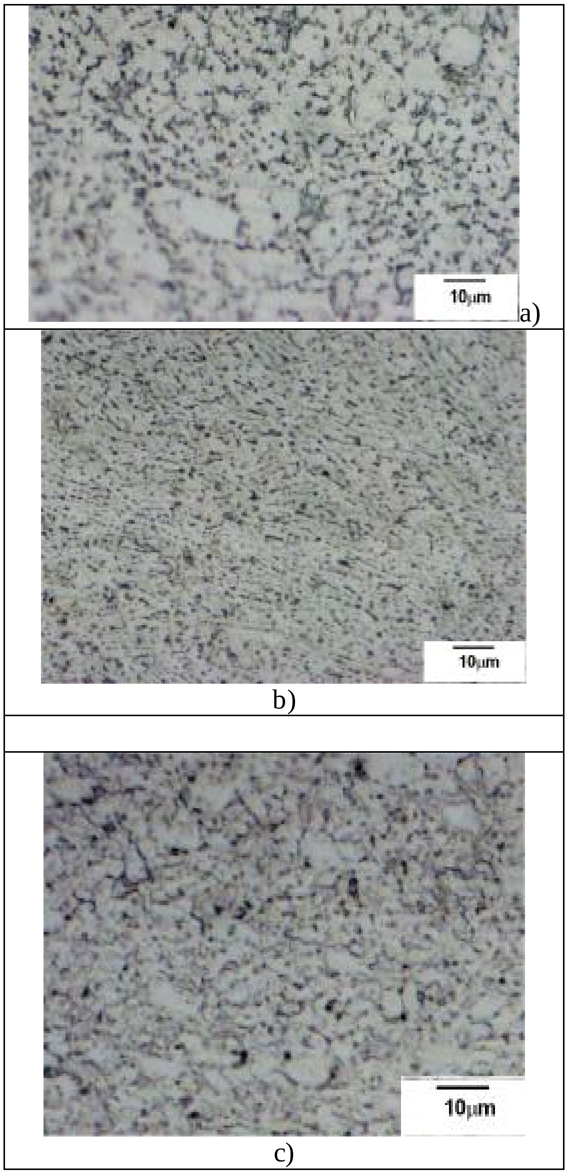

Figure 4. a) Plate without thermal treatment; b) Plate with thermal treatment; c) Below plate with thermal treatment and forming. Attacked with Kroll reagent

4.2. Micro hardness

Four measurements were performed per sample, totalling 16 measurements per lot. Tables 3, 4 and 5 indicate the results of Vickers micro hardness. For the statistical procedure, the mean, standard deviation, and uncertainty of measurement demonstrated in table 6 were calculated.

Table 3. Micro hardness (HV) measured in plates that were not thermally treated

CP1	318.0	350.0	297.0	274.0
CP2	322.0	303.7	297.0	273.7
CP3	285.0	264.0	285.0	281.0
CP4	363.0	297.0	309.0	266.0

Table 4. Micro hardness (HV) measures in plates that were thermally treated

CP1	354.0	336.0	265.0	261.0
CP2	285.0	284.0	274.0	251.0
CP3	394.0	370.0	366.0	364.0
CP4	309.1	309.0	287.0	333.0

Table 5. Micro hardness (HV) measured in plates that were thermally treated and formed

CP1	322.0	336.0	322.0	335.0
CP2	373.5	396.5	322.5	336.0
CP3	336.0	366.0	350.0	285.0
CP4	350.2	368.0	320.3	331.5

The calculation of uncertainty of measurement took a confidence interval of 95% into account. In order to eliminate spurious values which could lead to errors at the time of calculating the mean, the Chauvenet criterion was used. By means of this procedure, the ration between the difference between measured value and mean are looked for the deviation. The result should not be higher than a given value that is the function of sample size. In these tables 3, 4 and 5, the values highlighted were eliminated at the time of calculating the mean and standard deviation. The mean and deviation for the micro hardness values obtained are shown in table 6.

Table 6. Mean result of Vickers micro hardness

	Machined	Thermally treated	Formed
$\bar{x}$	289.7	309.9	340.6
s	15.1	41.3	18.1
w (95%)	9.5	23.7	10.9
x_{max}	299.2	333.5	351.5
x_{min}	280.2	286.2	329.8

5. CONCLUSIONS

Using the bending tests, it was found that the material utilized to make the posterior cervical, anterior cervical and thoracic plates, present a satisfactory mechanical behaviour, since under conditions of excessive transverse loading, no rupture or catastrophic failures of the plates occurred. This goes for all test specimens assayed, independent of geometry or the number of holes presented by each plate.

Table 6 shows that there is a significant increase in micro hardness due to thermal and mechanical forming treatments. For the untreated condition, the real mean value is between 280.2 and 299.2. When the piece is submitted to thermal treatment, the mean real value of micro hardness lies within the range that goes from 286.2 to 333.5. And for plates that, besides the thermal treatment are also formed, the mean real value of micro hardness goes up slightly more, one might say that it lies between 329.8 and 351.5.

Analyzing the micro hardness values measured on the plates that were only machined, with thermal treatment and formed, it is observed that there is an intersection zone between them. This means that the greatest hardness that can be found for an untreated sample is greater than the minimum micro hardness of a piece treated thermally. The same can be said for plates treated thermally and formed. But the micro hardness of formed plates is greater than that of plates without any treatment whatsoever, since there is no intersection between the extreme values.

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