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INFLUENCE OF THE FINAL TEMPERATURE OF INVESTMENT HEALTING ON THE TENSILE STRENGTH AND VICKERS HARDNESS OF CP TI AND TI-6AL-4V ALLOY

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ABSTRACT

The aim of the work was to evaluate the influence of the temperature of investment healting on the tensile strength and Vickers hardness of CP Ti and Ti-6Al-4V alloy casting. Were obtained for the tensile strength test dumbbell rods that were invested in the Rematitan Plus investment and casting in the Discovery machine cast. Thirty specimens were obtained, fiftten to the CP Titanium and fifteen to the Ti-6Al-4V alloy, five samples to each an of the three temperatures of investment: 430ºC (control group), 480ºC and 530ºC. The tensile test was measured by means of a universal testing machine, MTS model 810, at a strain of 1.0 mm/min. After the tensile strenght test the specimens were secctioned, embedded and polished to hardness measurements, using a Vickers tester, Micromet 2100. The means values to tensile tests to the temperatures 430ºC, 480 and 530: CP Ti (486.1 – 501.16 – 498.14 –mean 495.30 MPa) and Ti-6Al-4V alloy (961.33 – 958.26 – 1005.80 – mean 975.13 MPa) while for the Vickers hardness the values were (198.06, 197.85, 202.58 – mean 199.50) and (352.95, 339.36, 344.76 – mean 345.69), respectively. The values were submitted to Analysis of Variance (ANOVA) and Tukey,s Test that indicate differences significant only between the materials, but not between the temperature, for both the materias. It was conclued that increase of the temperature of investment its not chance the tensile strength and the Vickers hardness of the CP Titanium and Ti-6Al-4V alloy.

Uniterms: Titanium casting; Tensile strength; Vickers hardnes.

INTRODUCTION

Titanium (Ti) and its alloys are increasingly being used in dental applications, such as implants and restorative castings, present as positive characteristics an excellent resistance to the corrosion[9], low thermal conductivity[4], elastic modulus and ductility similar to the golden alloys[7], besides low density (4,5 g/cm3) when compared to other alloys as Co-Cr (8,9 g/cm3) and Gold (19,3 g/cm3)[5]. The smallest resistance to the passage of the X-ray makes possible the visualization of internal porosity in pieces casting in titanium and its alloys[13]. Silica-based investment is more accessible and have been used for casting of titanium. However, the reaction layer increases in direct proportion with the temperature of the mold in the moment of the injection of the metal, due to the great reactivity of the silica with the titanium, in temperatures above 600ºC[14]. Investments to the base of Al_2O_3, MgO and ZrO_2, such like T-invest, Selevest, Former Titanium, are less reagents, but the low expansion and the high cost limit the use[11]. Besides, the castability of the titanium is very low, difficulting the completion of the mold in the moment of the casting, due to the low density, to the difference between the casting temperature of the metal (1700ºC) and of the investment, that varies between to room temperature and 600ºC.

To improve the completion of the mold, Donovan and

White[2] (1985) suggest to increase the temperature of the investment at the moment of the casting. However, little it is known on the effect of the increase of temperature of the mold in the mechanical properties of the titanium and its alloys. In previous work Oliveira[8] (2003) verified that the increase of 50ºC and 100ºC in the final temperature of the heating cycle manufacturers' recommended , specific for titanium, it improved the castability of the CP Ti and Ti-6Al-4V alloy.

Considering that the increase of the temperature can improve the castability and, on the other hand, it can increase the reactivity of the titanium with the investment to the sílica base, the objective of the work was to evaluate small increases of the temperature of the investment will influence the tensile strength and the Vickers hardness of the CP Ti and Ti-6Al-4V alloy.

MATERIAL AND METHODS

The metal used in this work meet related in the Table 1.

The final temperatures of heating of the investment Rematitan Plus, in which were melted them specimens were: 430ºC (T1) - recommended by the manufacturer of the investment considered control group, 480ºC (T2) and 530ºC (T3). For the accomplishment of the tensile strength test presenting 15 specimens of each material

(5 for each temperature) were prepared in the form of dumbbells, 42 length mm with 3,0 mm of transverse section (Figure 1), in agreement with the norm AND-8M of ASTM. The wax patterns were included in plasctic casting ring # 6 (Dentaurum J.P. Winkelstroeter KG, Pforzheim, Germany), so that the pattern was the a distance of 10 mm, as much of the lateral walls as of the upper portion of the ring.

The Rematitan Plus investment (Dentaurum J.P. Winkelstroeter KG, Pforzheim, Germany) was used in the powder / liquid ratio recommended by the manufacturer (250g /40ml). After the mixing was carried out under vacuum mechanical mixer Multivac 4 (Degussa-Huls, Hanau, Germany) for 45 seconds. The mixture was poured into the trough level with its upper surface and allowed to set at room temperature for 1h whem were removed of the plastic casting ring and carried in furnace EDG 7000 (EDG Equipamentos, São Carlos, Brazil). Heating of the moulds was carried out in a programmed eletric furnace at a heating rate of 10ºC / min to the target recommended temperatures. Reached the final temperature (T1, T2 or T3), the specimens were casting in a machine Discovery Shapes (EDG Equipamentos, São Carlos, Brasil). This procedure involved argon-arc-melting in a copper crucible, followed by pressurized casting between two chambers; The upper chamber was used for the melting process and the lower for casting. The melting chamber was evacuated and purged with argon three times and the filled with pure argon gas to a pressure of 1.5 to 2.0 atm. For the casting operation, a copper crucible with a central hole was used. The metal ingot on the copper crucible in the melting chamber served as a gas seal during this stage. When the metal was molten, the mold was filled by the pressure difference caused by argon gas flow from the upper side and vacuum suction from the lower side through the investment mold. The casting operation was automated so that the total process was completed within two to three minutes. The casting was then cooled in the machine for more five minutes under flowing argon. After the casting the specimens were carefully removed from the mould, scrubbed under running water, and sandblasted (Multijet III - EDG Equipamentos, São Carlos, Brazil) with aluminum particles (50mm), to remove remains of investment and the layer of reaction of the titanium. The feeding conduits were cut and the x-rayed specimens to detect internal defects on the casting. The specimens were submitted to the tensile strength in the

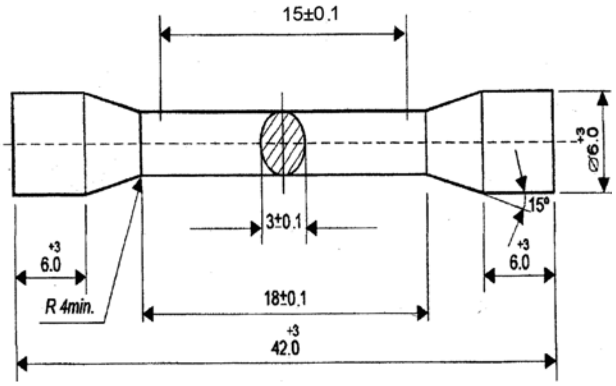

FIGURE 1- represents illustrative of the specimen for the traction test and the respective dimensions (mm)

TABLE 1- Metals, chemical composition (%) and manufacturer

Metal	%	Manufacturer
CP Titanium Grade II	Ti (99.56), Fe(0.18) O(0.15), C(0.08) N(0.02), H(0.007)	RMI Company Ohio, EUA
Ti-6Al-4V alloy Grade V	Ti(88.57), Al(6.2), V(3.8) Fé(0.22), O(0.17), C(0.01) N(0.02), H(0.003)	RMI Company Ohio, EUA.

Universal Testing Machine MT model 810 (MTS System Corporation, Minessota, USA), to the speed of 1,0 mm/min, and when it happened the rupture of the specimens, the softwaer Test Work 2 (MTS System Corporation, Minnesota, USA) coupled to the machine supplied the value of the maximum tension.

The hardness testing was accomplished in the head of specimens after the tensile strength. The samples were built-in in acrylic resin and the surface regularized with sandpapers of silicon carbide in the following granulation sequence: 320, 400, 600, 1000 and 1200 "grift" and polished with felt disk and alumina paste Metaserv 2000 (Buehler Uk Ltd., Coventry, England). The Vickers hardness was accomplished in a Vickers test Micromet 2100 (Buehler, Lake Bluff, Illinois, USA), with load of 300g and time of application of 15 seconds. In each specimens 8 were accomplished and calculated the medium values.

The data of the tensile strength and Vickers hardness were submitted to two-way ANOVA (materials and temperatures) and Tukey test for individual comparison with a 0.05 significance level.

RESULTS

In the Table 2 they are the medium values and the standard deviation of the tensile strength and hardness of the CP Ti and Ti-6Al-4V alloy, in the three studied temperatures.

The variance analyses for the resistance data to the tensile strength and Vickers hardness (Tables 3 and 4) demonstrated there to be significant differences just among the materials.

TABLE 2- Mean values of tensile strenght (MPa) and Vickers hardness and standard deviation to both materials in the three temperatures (TI, T2 and T3)

	CP Ti T1 *	**CP Ti T2**	**CP Ti T3**	**Ti-6Al-4V T1 ***	**Ti-6Al-4V T2**	**Ti-6Al-4V T3**
Tensile strength	486.10	501.16	498.14	961.33	958.26	1005.80
Standard deviation	(58.87)	(26.74)	(61.01)	(11.96)	(19.33)	(63.12)
Vickers hardness (VHN)	198.06	197.85	202.58	352.95	339.36	344.76
Standard deviation	(19.23)	(21.85)	(29.12)	(17.58)	(12.54)	(16.26)

* Control groups

TABLE 3- Analysis of variance for tensile strength between material and temperature

	G.L.	**S.Q.**	**Q.M.**	**F**
Material	1	1726306.0154	1726306.0154	833.9151 **
Temperature	2	4505.7635	2252.8817	1.0883 ns
Material X Temperature	2	3234.5132	1617.2566	0.7812 ns

** - significantly different *(p<0.05)*
ns - not significantly

TABLE 4- Analysis of variance for Vickers hardness between material and temperature

	G.L.	**S.Q.**	**Q.M.**	**F**
Material	1	154746.2448	154746.2448	1779.4659**
Temperature	2	145.2831	72.6416	0.8353 ns
Material X Temperature	2	63.0976	31.5488	0.3628 ns

** - significantly different *(p<0.05)*
ns - not significantly

DISCUSSION

The largest difficulties in the process of casting of the titanium and their alloys are related to the high coalition temperature with the main present gases in the atmosphere: oxygen, nitrogen and hydrogen mainly in high temperatures[10]. For being highly reagent with those elements it cannot be casting in atmosphere adapts, being necessary to do in camera filled out with inert gas (argon). Therefore, the choice of a investment that doesn't to cause this interaction with the metal and consequent contamination is of great importance[10,12].

Silica-based phosphate bonded, so thoroughly used in the investments, it is contraindicated in high temperatures in any of their forms, because its reacts with the titanium forming titanium oxides and solid solutions, forming a thick reaction layer that tends the if it diffuses for the interior of the casting metal, what can cause alterations in some of their mechanical properties[14].

The investments to the zirconia base, alumina and magnesium produces small amount of free energy, that reduce the formation of the oxide layer in the casting titanium, unlike what it happens in the investment to the silica base. Ida, et al.[3] (1982) in a study on special investment for the casting of titanium to the base of magnesium, agglutinated phosphate for sílica and their derivations observed that the investment to the base of magnesium (96% of MgO) presented the best results as for the Vickers hardness and to tensile strength. Togaya, et al.[12] (1985), told have obtained success in the casting of titanium using a investment to the base of agglutinated magnesium for alumina cement (CaO - Al_2O_3) and 5% of zirconium. Miyakawa, et al.[6] (1989), analyzed the interface of the titanium obtained in castings that used investment agglutinated for sílica and for alumina, ending that the agglutinated investments for sílica produced a surface of larger reaction than the other. Watari[15] (1989) showed that a inv estment to the base of SiO_2 was more reagent with the metal casting than a investment to the base of Al_2O_3. Takahashi, et al.[11] (1993), after studies with five marks of agglutinated investment for silica phosphate concluded that the variation in the amount of cristobalita and quartz in the investments increased the layer reactivates between the invetment mold and the casting, committing the final result, mainly when the invetment was heated up above 600ºC. Therefore, most of the invetments used in the casting of the titanium presents an inferior final temperature to the 600ºC.

In the present work, took place the tensile strength of the CP Ti and Ti-6Al-4V alloy, in order to if it evaluates possible alterations in the resistance among the materials, as well as among the different temperatures of the investment, although the studied maximum temperature (530ºC) it is inferior to the critical temperature for the contamination (600ºC)[1].

In agreement with the results of the table 3, there was just significant difference in the resistance to the traction among the materials, with medium values of 495.30 MPa and 975.13 MPa for the CP Ti and Ti-6Al-4V alloy, respectively. The temperatures of injection of the metal in the investment didn't interfere in the resistance of the CP Ti and Ti-6Al-4V alloy. The same it occurred in the test of hardness, where they were obtained the averages of 199.49 VHN for the CP Ti and 343.14 VHN for the Ti-6Al-4V alloy, has not occurred difference statistics for the factor temperature.

Considering those results, it can be verified that the Ti-6Al-4V alloy it presents better mechanical properties than the CP Ti and that the increase of 50ºC and 100ºC, above the temperature recommended by the manufacturer of the investment, for the injection of the metal melted in the mold (430ºC), don't interfere in the resistance to tensile strength and Vickers hardness. These discoveries signal for the possibility of obtaining better completion of the covering mold without the damage of the mechanical properties. However, other aspects need to be explored, as studies of the resistance to the corrosion and of the influence of the thermal expansion promoted by the increase of the temperature in the adjustment of the casting pieces, among others. Being the titanium and Ti-6Al-4V alloy materials of recent use in the dentistry, when compared with gold alloy, Pd-Ag, Ni-Cr, Co-Cr among other, new researches they are necessary, so that they are developed materials and casting techniques that can turn viable the use of these important materials in wide climbs in the making of fixed and removable partial prostheses.

CONCLUSIONS

In agreement with the results and the limitations of this study it was conclued that the tensile strength and Vickers hardness of the Ti-6Al-4V alloy it is superior to the one of the CP Ti and that the elevation of the temperature of the investment to 480ºC and 530ºC, not change the mechanical properties of these metals.

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