Mechanical properties and microstructural analysis of a NiCr alloy cast under different temperatures

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Abstract
The purpose of this study was to evaluate the chemical and metallurgical aspects, mechanical properties and hardness of the NiCr dental alloy when it was submitted to different castings temperatures. An NiCr alloy was cast, with lost wax technique, 20 specimens, separated in two groups of 10 each one, in two different casting temperatures: a) in accordance with the manufactures’ instructions (T1); b) above manufactures’ instructions (T2). It was done chemical and metallographic analysis with scanning electron microscope in the alloy in these conditions: no cast, T1 and T2. It was determined mechanical properties and hardness, too. The microstructures were similar to no cast, T1 and T2. There was no significant difference between chemical analysis and to mechanical properties. The hardness of the T1 and T2 groups was greater than no cast group. Clinically, it may predict that when elevated temperatures were used, above manufacture’s recommendations (more than 100ºC), there will be failures in the prosthesis, like porosities, fissures or cracks.

Key Words:
NiCr alloy, casting temperatures, mechanical properties.
Introduction

The cast metal restorations have been used in Dentistry since last decade. Nowadays, several resources are available to obtain more precise castings due to the introduction of new materials, more accurate techniques, and especially to a more scientific approach of the casting process\(^1\).

The choice of an alloy is based on several factors. Cost is a serious consideration due to the high price of gold. Other factors that shall be considered are biocompatibility and corrosion resistance\(^2\). These factors in particular limit the use of alloys for dental prostheses, and the choice of an specific application is primarily determined by their mechanical properties, such as hardness, mechanical strength and ductility, as according to Van Noort\(^3\).

Due to the worsened economical situation and consequent increase in the price of gold, the use of these alloys became impractical and inaccessible for many practitioners\(^4\)-\(^5\).

The non-noble metal alloys are chemically and metallurgical complex, with critical and more precise laboratory procedures than gold-based alloys, especially regarding fabricating and casting procedures. Hence, the choice of a prosthetic laboratory and technician by the dental practitioner is important for the casting quality. In 1972 the American Dental Association\(^6\) (ADA) proposed a Program for Acceptance of Metal Alloys in the EUA aiming at evaluating all metal alloys for cast restorations, including those not included in its specifications, all alternative alloys to the gold-based alloys and those which apart from their composition, demonstrated biological compatibility and adequate physical, chemical and mechanical properties.

The inferior qualities of non-noble metal alloys when compared to gold-based alloys led to the introduction of quantitative and qualitative modifications in their chemical composition, either in fabricating and casting procedures or in laboratory techniques, all of which had the objective of allowing their use as eventual substitutes for cast gold restorations, at the same time that \textit{in vivo} and \textit{in vitro} studies were performed with comparative purposes\(^6\)-\(^7\).

Due to the absence of literature research that may support the influence of dental alloy casting temperature on their microstructure and mechanical properties, it was the purpose of this \textit{in vitro} study to evaluate this influence on a NiCr alloy used for fixed partial and single prostheses.

Material and Methods

The Wiron 99 alloy (BEGO–Wilcos-Brasil) is specifically applied for dental use in Fixed Partial Prostheses. This alloy has 65% of nickel (Ni), 22.5% of chromium (Cr), 9.5% of molybdenum (Mo), besides other chemical elements, such as C, Nb, Si, Fe and Ce, and has a specific mass of 8.2 according to data supplied by the manufacturer.

Twenty specimens were obtained by means of lost wax casting technique and divided in two groups of ten, so that each one was submitted to a different temperature: T1 – recommended by the manufacturer, and T2 – above the recommended temperature. Table 1 shows the temperatures used for alloy casting in the two studied conditions.

The templates that originated the specimens in this study were built in a laboratory specialized in dental prostheses using blue wax for inlay casting using a usinated stainless steel matrix, according to the International Standards Organization (ISO) specification number 6871, as it can be seen in Figure 1.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Casting Temperature* (T1)</th>
<th>Above of casting temperature (T2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wiron 99</td>
<td>1420(^\circ)C</td>
<td>1520(^\circ)C ± 20(^\circ)</td>
</tr>
</tbody>
</table>

* in accordance with the manufacturer’s instructions

Wax templates were invested in a metal ring previously underlain with amiantus. Then the phosphate-based investment (Micro- Fine 1700- Talladium - USA) was poured according to the manufacturer’s recommendations. After the final investment setting, models were placed in an EDG furnace (model EDGCON 3P – 3000) for wax elimination under temperatures between 600\(^\circ\) and 900\(^\circ\) C for 90 minutes.

Casting was performed in a centrifuge by argon gas induction (model DUCATRON – Series 3 – France) using a digital optical infrared pyrometer (M-GULTAN- Pirograt-IS-3D- Germany) for temperature control.

Upon casting completion, rings were left at room temperature for cooling. Specimens were separated from...
their investments and submitted to blasting with glass micro balls and subsequently with aluminum oxide. External machining using mounted tips and abrasive rubbers was performed for final finishing.

The chemical composition analysis of the alloys in this study was performed in the Center for Materials Characterization and Development (CMCD at the Federal University of São Carlos UFSCAR).

Samples with approximately 3mm of thickness were obtained from the tensile strength test specimens and embedded in transparent chemically activated acrylic resin. They were then mechanically polished using 360, 400, 600, 1000 and 2000 mesh sandpaper followed by alumina polishing with 1 and 0.3mm. This procedure aimed at obtaining a flat and polished surface. After that, samples were chemically etched using a 2:1 HCl and HNO3 solution for approximately 10 seconds. The etching was controlled to produce a correct observation of phases and morphologies present in the microstructure.

Finally, they were submitted to metallographic examination using Scanning Electron Microscopy (SEM) in a JEOL-JSM microscope (T-330) coupled to a x-ray dispersive energy analyzer (XDE) and a camera with similar origin. The tensile and elongation tests were performed using a Material Test System (MTS 810) equipment and data analysis was made using a specialized computer software (Test Star II) coupled to the system. Load cells of 100kN with 1.0mm/mim speed were used. Hardness measurements were obtained using a Micromet – 2003 – Buehler device under 500gf or 4903 mN strength4,8-10.

Two-way analysis of variance (ANOVA) was used to detected significant differences among the conditions studied.

**Results**

Table 2 shows the chemical analysis results under the three studied conditions for the NiCr alloy (NC= no cast; T1= temperature recommended by the manufacturer (1420°C) and T2= temperature above the recommended (1520°C)).

Figure 2 shows the SEM analysis of the NiCr alloy in the no cast condition (NC).

Figure 3 shows the SEM analysis of the NiCr alloy under the T1 condition. We verified a clumsier dendritic microstructure and less quantity of particles than in the NC condition.

Figure 4 shows the SEM analysis of the NiCr alloy under the T2 condition. We verified a clumsier dendritic brute fusion microstructure with fewer amounts of precipitates than under the NC and T1 conditions.

The results obtained in the tensile strength test and respective statistical data can be observed in Figures 5, 6 and 7. The results obtained with the Vicker’s hardness test and respective statistical analysis can be verified in Figure 8.

<table>
<thead>
<tr>
<th>Elements</th>
<th>NC</th>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0,0127 ± 0,0005</td>
<td>0,0161 ± 0,002</td>
<td>0,0100 ± 0,0003</td>
</tr>
<tr>
<td>Cr</td>
<td>24,4 ± 0,07</td>
<td>22,5 ± 0,15</td>
<td>22,3 ± 0,42</td>
</tr>
<tr>
<td>Mo</td>
<td>9,08 ± 0,02</td>
<td>8,99 ± 0,10</td>
<td>9,29 ± 0,25</td>
</tr>
<tr>
<td>Si</td>
<td>0,482 ± 0,08</td>
<td>0,232 ± 0,007</td>
<td>0,222 ± 0,02</td>
</tr>
<tr>
<td>Nb</td>
<td>0,742 ± 0,05</td>
<td>0,606 ± 0,01</td>
<td>0,603 ± 0,05</td>
</tr>
<tr>
<td>Ce</td>
<td>0,347 ± 0,03</td>
<td>&lt;0,012</td>
<td>&lt;0,012</td>
</tr>
<tr>
<td>Fe</td>
<td>0,10 ± 0,03</td>
<td>0,13 ± 0,03</td>
<td>0,17 ± 0,01</td>
</tr>
<tr>
<td>Ni</td>
<td>BALANCE</td>
<td>BALANCE</td>
<td>BALANCE</td>
</tr>
</tbody>
</table>

**Fig. 2** – Micrography of the NiCr alloy in the NC condition, Attack: água régia, 1000X.

**Fig. 3** – Micrography of the NiCr alloy in the T1 condition, Attack: água régia, 1000X.

**Fig. 4** – Micrography of the NiCr alloy in the T2 condition, Attack: água régia, 1000X.
Discussion

By observing the chemical analysis of the alloy in an no cast condition, we verified that Table 2 is coherent with the composition supplied by the manufacturer. The chemical composition of Ni, Cr, Mo, C, Nb and Fe remained practically constant under the three studied conditions. For Si and Ce there was a slight reduction under the T1 and T2 conditions when compared to the NC condition. This reduction may be due to an inefficient protection provided by the argon atmosphere during casting procedures, as long as these elements are more reactive with oxygen under high temperatures.

Lewis\textsuperscript{11} found a composition of 69.30\% Ni, 16.00\% Cr; 5.40\% Mo, 3.90\% Mg; 2.89\% Al, among other metals in less quantity, in a chemical analysis using X-ray emission spectrometry microscopy of a NiCr alloy. Baran\textsuperscript{12} states that the binary phase diagram for the NiCr system shows extensive solid solubility of chromium in nickel, and as a result binary alloys are hardened by means of precipitation. Approximately 37\% of Cr in weight can remain dissolved at room temperature in the gamma matrix. This author found the following composition for the Wiron S and Wiron 77 alloys: Wiron S: 69\% Ni, 17\% Cr, 5\% Mo, 0.37\% Fe, 0.42\% Co, 0.04 C, 3\% Mn and Wiron 77: 67\% Ni, 20\% Cr, 65 Mo, 1.5\% Nb, 4\% Si, 0.04\% C. Mondelli\textsuperscript{5} also reported the chemical composition of some NiCr alloys: Nicron G (70.0\% Ni, 99.1\% Cr; 4.20\% Mo); Kromalit (62.5\% Ni, 20.4\% Cr, 6.58\% Mo) and Resistal P (62.5\% Ni; 18.5\% Cr e 9.85\% Mo). These results are similar to those obtained in this study. We can verify in a Figure 2 a dendritic brute fusion microstructure with precipitates dispersed in the entire matrix\textsuperscript{13-14}. The SEM of the NiCr alloy in this study shows a dendritic...
brute fusion microstructure with porosities similar to those found by Lewis. When the alloy was cast above the recommended temperature this microstructure was less refined and presented more porosity. Lewis observed an interdendritic phase with a lamellar structure and areas of micro porosity in an original ingot of NiCr alloy. According to this author, the lamellar - shaped morphology is considered as the normal shape produced with the euhetic solidification. In a first casting he observed lamellar structures with interdendritic distribution. The overheated microstructure presented three characteristics:

a) Absence of acicular phase;
b) Absence of interdendritic euhetic phase;
c) Absence of fine linear interdendritic phase.

Lewis studied fusion patterns (ADA nº 14) obtained from a Ni-based alloy submitted to a tensile strength test and observed under SEM. The Ni-based alloys exhibited a strong tendency towards a dendritic crystallization, as it was also evidenced in this study.

Lewis showed that the solidification produced using NiCr alloys initially involves the formation of a dendritic skeleton followed by the filling of the process that occurs interdendritically. The first formed solid is essentially the NiCr solution, and in each case the two elements are presented in strictly corresponding proportions to those determined for alloys. It would be expected that this composition was maintained during the subsequent solidification, and the study demonstrated that this is normally the situation that occurs inside the alloy. The optical microscopy of the NiCr alloy shows a transitional zone between the matrix and the interdendritic euhetic formations, as it was evidenced in the present study.

The rupture tensile strength and creeping limit values for the T1 and T2 conditions of the NiCr alloy are statistically similar. The elongation presents higher values under the T2 than the T1 condition. This can be explained by the more homogeneous microstructure observed under the T2 condition.

The elongation values obtained under the T1 and T2 conditions are similar to those found for Ultratek, Microbond NP/2 and Litecast alloys (24%, 27% and 28%, respectively), as according to Baran. The Vicker’s hardness values for the NiCr alloy under T1 and T2 conditions are statistically similar, but higher than those found under the NC condition. These results are in agreement with Phillips and Baran for the Wiron alloy submitted to the temperature recommended by the manufacturer.

Moffa et al. compared two NiCr alloys with a conventional gold-based alloy and concluded that the Vicker’s hardness is 174 for the gold alloy and 270-310 for the non-gold alloys. These values obtained for non-gold alloys are superior to those found in this study.

Conclusion

This study evaluated the metallurgical and clinical aspects of the different casting temperatures on a NiCr alloy. Within the limitations of this work, it can conclude:

- All the castings that were performed using manufactures recommendations showed the best results.
- Clinically, it may predict that when elevated temperatures was used, above manufacture’s recommendations (more than 200°C), there will be failures in the prosthesis, like porosities, fissures or cracks.

Acknowledgements

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