

A Literature Review of Ni-Cr Metallic Alloys: Biomedical Applications and Material Properties

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March 2025

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Abstract

Biomedical applications of metallic alloys are a wide area where different metals can be combined to achieve the desired properties. Nickel and Chromium are two widely used metals for dental applications, hard alloys such as dental crowns and bridges and dental frameworks. This study will review previous literature that studied this alloy and will summarize the findings. It was found that Ni-Cr is a crucial metallic alloy for its high corrosion resistance and high hardness and affordable prices. It has also been shown that Ni-Cr is better than other alloys that were used in terms of the easy casting and molding with ceramic teeth. This alloy can withstand an average yield strength of 417 MPa with high fatigue strength rate of 245 MPa to 380 MPa at 10^7 cycles. Furthermore, Ni-Cr was found to have several hardening and strengthening mechanisms that could contribute to better mechanical properties. This alloy was found essential for dental applications given that it can withstand required forces and stresses and can also resist corrosive environment under specific conditions.

1. Introduction

Biomedical applications of metals are a popular sector of material engineering. For most applications, Titanium based alloys are used, yet specific dental applications require corrosion free metal with high strength levels which is general to any implant that needs to be placed in a human body [1]. One of the most used alloys in such fields is the Nickel - Chromium (Ni-Cr) alloy with some additives to enhance specific mechanical properties [2]. In this study, the reviewed literature about Ni-Cr alloys will be discussed, and its alloy structure, material properties and strengthening mechanisms will be reviewed, along with its advantages and limitations.

2. Alloy Composition

Nickel is found in nature as a face centered cubic (FCC) crystalline structure with lattice parameter $a = 0.352 \text{ nm}$ and atomic radius $r = 0.124 \text{ nm}$. [3] Chromium is found as body centered cubic (BCC) structure with lattice parameter $a = 0.288 \text{ nm}$ and atomic radius $r = 0.130 \text{ nm}$ [4]. When diffused together, the atomic radius difference

can be computed using the following equation:

$$\% \Delta r = \frac{r_1 - r_2}{r_1} \times 100 \quad (1)$$

Where r_1 is the atomic radius of the host (main) element; in this case, it is nickel. For this alloy, $\% \Delta r = 4.839\%$ which is less than 15%. Also, the two elements have similar electronegativity, triggering - under convenient conditions- substitutional solid impurities. This shows that, at room temperature, and for low concentration of Cr (that will be more obvious in the phase diagram), the alloy exhibits an FCC crystal structure similar to the Ni structure. Figure (1) shows the phase diagram of the Ni-Cr where it verifies the theoretical work for low concentrations of additive atoms.

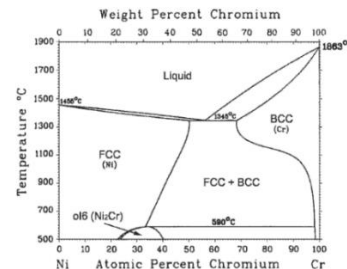


Figure 1: Ni-Cr phase diagram [4]

For the desired purpose, specific ranges of concentrations are used, namely, 50-80% Ni, 10-30% Cr, and some additional impurities like Mo, Co, Ti, Be, Si, Nb, and Fe [1] can be used to enhance some specific mechanical properties. Figure (2) shows an image of the grains of different concentrated alloys of Ni-Cr showing grain sizes.

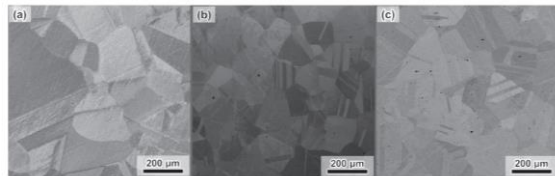


Figure 2: Electron scanning microscope image of different concentrations (a) pure Ni, (b) Ni-20Cr, and (c) Ni-44Cr [5]

3. Material Properties

To assess some mechanical properties, studies used several setups for measuring different properties. One study [6] evaluated the hardness of Ni-Cr prepared at 1000 °C based on a Rockwell Hardness Test and it found a hardness of 42.6 HR as well as a hardness of 51.2 HR for that prepared at 1200 °C. This increase in hardness will be discussed in section 4. Moreover, several studies conducted tensile tests to measure the stress-strain behavior of this alloy. One study found that Ni-Cr has an average yield strength of 417 MPa and an ultimate tensile strength of 550 MPa [7]

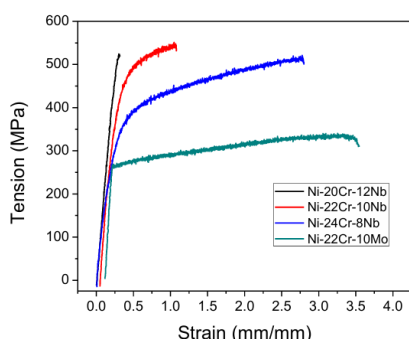


Figure 3: Stress-strain curve of different alloy composition of Ni-Cr based alloys [7]

The same study also observed the influence of different impurities in the alloy such as Mo and Nb where it found the maximum strength for the Ni-20Cr-12Nb. It has been also found that the alloy exerts a fatigue strength of 245 MPa to 380 MPa at 10^7 cycles. This high fatigue strength is very compatible with the desired application since human teeth exert negligible forces of around 350 N [f8]. Hence, no matter

how small the area that it is exerted on is, the resulting stress will not exceed the fatigue limit, nor will it exceed any cycle limits.

4. Strengthening Mechanisms

Sometimes, it is required to harden the alloy, and this could be done by several means. For example, one paper [6] suggested that preparing the alloy at elevated temperatures influences the hardness of the alloy. As mentioned above, the hardness increased from 42.6 HR to 51.2 HR when the preparation temperature increased from 1000 °C to 1200 °C. The same study suggested that introducing impurities to the alloy may also increase its hardness. For instance, among the studied alloys, an addition of MoS₂ to the alloy would strengthen it, and for high temperatures that are necessary for reinforcement and homogenizing of the mixture, it showed that the addition of MoS₂, Ag, and CaF₂ is the best addition to enhance its hardness. Yet this addition may be limited to dental use, where some metals like Fluorine may induce allergy or toxic inhalation and it accelerates the rate of corrosion [9]. Another suggests that annealing for longer times could enhance the strength of the Ni-Cr due to Hall-Petch strengthening [10], where increased annealing time results in smaller grain sizes which allow a better stress distribution among the grains. These size increased grains function as barriers for dislocation movements. This study also suggests that strain hardening had a significant contribution in strengthening the material. An older paper studied the strength of the Ni-Cr alloy annealed at different temperatures, showing (figure 4) that annealing at elevated temperatures (maximum at 350 °C) can increase the yield and ultimate strength of the alloy [11].

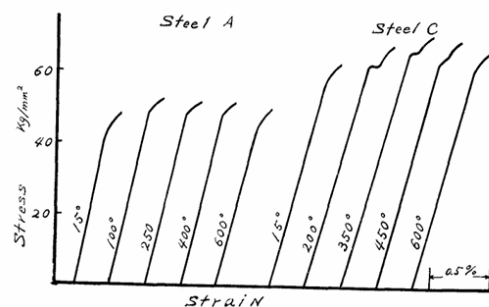


Figure 4: Stress-strain curve for Ni-Cr alloys annealed at different temperatures [11]

5. Application Specific Properties

Along with other mechanical properties, some application-specific properties are considered when choosing Ni-Cr as a dental implant metal. Corrosion is the main property to investigate the alloy's resistance to it. For Ni-Cr, a paper suggested that Cr is the element responsible for preventing any corrosion that may evolve over the nickel atoms given that chromium helps the surface become more passive by inducing a layer of Cr_2O_3 molecule, protecting the metal from any corrosion [1]. In addition, bonding with porcelain is a key property for this alloy since it is required to stick to the surface of some porcelain in the mouth. One study shows that it possesses similar thermal expansion as ceramics which allows effective casting and molding in dental applications [12]. In addition, one research highlights that bond between Ni-Cr and porcelain with firing techniques at the right temperature (990 °C) results in diffusion at the surface of the two materials where several molecules such as SnO_2 , AlNi_3 , $\text{SnCr}_{0-14}\text{O}_x$, and KAlSi_2O_6 crystalize. Upon firing for 2.5 minutes, shear and bond strength reach up to 43.8 MPa [13]. This achieves good adhesion with porcelain and results in a trusted implant to place for dental use.

6. Advantages

Ni-Cr alloys have been popular dental-used alloys for their perfect replacement of gold-based alloys that are more expensive especially for developing countries [14,15] and were thus in use since 1930s. Moreover, the addition of Cr in this alloy enhances anti-corrosion properties which are essential for dental applications [1]. Regardless of the concerns raised from the allergy, a study stated that there is no significant danger for using this alloy in dental applications [16].

7. Limitations

Nickel raises a lot of concern regarding allergic symptoms in patients [17] where the EU has posed strict laws on its use. [18] Moreover, although this alloy exhibits high corrosion resistance, the acidity of its medium may alter this property especially for high acidic medium [19]. In addition, this alloy requires precisely controlled elevated

temperatures which induces a challenge when casting and molding [1].

8. Conclusion

Nickel-Chromium alloy is a widely used alloy in dental industries as it has shown high mechanical properties and advanced usage advantages that made it viral in the market. The literature suggests that nickel and chromium can be used widely in implants but with little caution for it may cause allergies to some people. Despite these valuable results, the results include some limitations that include not studying all possible combinations. Also, the reviewed literature can be misinterpreted if the conditions were not matching the exact parameters in laboratory-produced alloys. And with respect to biocompatibility, the papers mainly discussed short range effects and interactions of the alloy with oral environment. Hence, future papers should focus on specific alloy properties such as hardness and strength, and adjust the composition of the alloy to achieve the best quality of the metallic alloy.

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