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TEMPERATURE EFFECTS ON THE DIMENSIONS OF CoCr ALLOYS: DILATOMETRIC STUDY

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ABSTRACT

Cobalt-chromium (Co-Cr) alloys are widely employed in biomedical and dental applications due to their favourable mechanical properties, corrosion resistance, and thermal stability. This study investigates the effect of silicon (Si) addition on the chemical composition and dimensional behavior of Co-Cr alloys, with an emphasis on their suitability for removable partial denture frameworks. A series of Co-Cr alloys with variable Si content (0.5–7.05 wt.%) were analysed using optical emission spectrometry and dilatometry to establish correlations between composition and thermal expansion.

The experimental approach provides new insights into how silicon content modifies the thermal behavior and dimensional stability of Co-Cr alloys during heating up to 1200 °C. The novelty of this research lies in the systematic evaluation of Si addition as a compositional variable in Co-Cr dental alloys, which has not been extensively explored in relation to dilatometric behavior. The study demonstrates that controlled silicon enrichment not only reduces the linear thermal expansion coefficient but also enhances structural stability during thermal cycling, minimizing the risk of deformation or mismatch with low-fusing dental ceramics. These findings bridge the gap between alloy chemistry and thermal compatibility, offering a scientific basis for optimizing alloy formulations used in precision dental restorations.

The outcomes provide valuable guidelines for the development of advanced Co-Cr-Si alloys with improved dimensional accuracy and thermal performance, contributing to the reliability and longevity of metal-ceramic prosthetic components.

KEYWORDS: Co-Cr-Mo alloys, thermal expansion, silicon, dilatometry

1. Introduction

Cobalt-based alloys, especially those in the Co-Cr system, are widely used in biomedical and technical applications due to their optimal mechanical properties, corrosion resistance, and high temperature stability. In the field of dental technology, these materials represent a viable solution for the production of removable partial denture (RPD) frameworks, where resistance to mechanical stress and dimensional compatibility with ceramic veneers are essential factors [1-3]. The dimensional behavior of alloys under temperature variations plays a critical role, since differences between the thermal expansion coefficients of the alloy and the restorative material can lead to internal stresses, cracks, or micro-leakage at the interface. Therefore, dilatometric analysis becomes an indispensable method for understanding the phase transformations and dimensional changes that occur during the thermal cycles specific to casting and sintering [4].

The dilatometric method allows for the determination of both the linear coefficient of thermal expansion and any discontinuities associated with solid-state structural transformations. In the case of Co-Cr alloys, dimensional stability and the absence of phase transformations within the temperature range ensure their clinical performance. At the same time, the chemical composition directly influences the

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thermal behavior, with silicon being a particularly important alloying element for optimizing physical properties [5-7].

The purpose of this study is to analyse the dimensional changes via dilatometry of select alloys from the Co-Cr system with variable silicon additions, correlating dilatometric behavior with chemical composition and highlighting the practical implications for their use in the manufacture of partial denture frameworks [8-10].

2. Determinations of Chemical Composition by Optical Emission Spectrometry

The determination of the chemical composition via optical emission spectrometry was performed on samples collected after the solidification of the alloy, which was obtained by vacuum induction melting. Sample preparation for optical emission spectrometry was carried out by grinding with coarse-grit abrasive paper [11].

The chemical analysis of the cobalt-based alloys by optical emission spectrometry was conducted in the Laboratory of Optical Emission and X-Ray Fluorescence Spectrochemical Testing, using a SpectromaXx spark spectrometer [12-15].

The electrical discharge releases a significant amount of energy, resulting in the formation of plasma and the emission of characteristic light. The light spectrum is resolved by an optical diffraction grating, and the results are analysed using specialized software [16]. Since the discharge occurs only on the surface of the sample and does not penetrate the bulk, surface contamination must be carefully controlled. The mass concentrations of the elements in the cobalt-based alloys are listed in Table 1.

Table 1. *Chemical composition of alloys in the Co-Cr system*

Alloying element	**Co-Cr**	**Co-Cr-Si5**	**Co-Cr-Si6**	**Co-Cr-Si7**
	(Mass %)			
Co	70	60	57.70	56.88
Cr	19.28	27	26.53	26.40
Si	**0.50**	**5.06**	**6.10**	**7.05**
Mo	6	5	5.29	5.20
Ni	2.90	1.52	2.84	2.87
Mn	0.31	0.43	0.39	0.38
Fe	0.33	0.31	0.58	0.43
Other	0.68	0.68	0.57	0.79

Chemical composition studies have revealed that the primary elements present in these cobalt-based alloys are Co, Cr, and Mo, alongside the specific elements added to the commercial formulation. With the incremental increase of silicon, the proportions of the other elements showed proportionally lower values, with a notable change occurring in the base element, cobalt. While it was initially present at 70 wt.% in the commercial Co-Cr alloy, in the Co-Cr-Si7 alloy, its concentration decreased to 56.88 wt.%.

3. Thermal Effects on the Dimensional Stability of Co-Cr Alloys

Dilatometry was performed using a Linseis L75H/1400 differential dilatometer. The cobalt alloys subjected to dilatometric analysis featured flat parallel ends and a square cross-section with a width of 5 mm and a sample length of 30 mm, adhering to dilatometer standards [17].

Dilatometric analysis is used to establish the solid-state phase transformation points of materials and to determine the coefficient of linear thermal expansion. The theoretical basis of the coefficient of linear thermal expansion is rooted in the principle that atoms in equilibrium occupy the lowest energy level within the crystal lattice [18-22].

The melting range of alloys in the Co-Cr system must be at least 150-200 °C higher than the firing temperature of the associated ceramic materials. The ceramic veneers used fall into the category of low-sintering-temperature materials (850-1100 °C). To ensure efficient processing, it is recommended that the melting temperature of the alloys remain below 1400 °C, a range in which the studied alloys fit well [23].

The Co-Cr samples were placed on the sample holder, where they were heated linearly. Dimensional changes were transmitted through a quartz pushrod to a displacement sensor, while sample temperature was monitored using a thermocouple [6]. Specimen heating was conducted in an electric tubular furnace,

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up to the maximum temperature of 1200 °C, with a heating rate of 10 °C/min. The furnace cooling rate was regulated by the water-cooling system with a flow rate of 5 m^3/h [24-26].

Fig. 1. *Linseis L75H/1400 Dilatometer* [4]

Fig. 2. *Sample subjected to experimental investigations* [3]

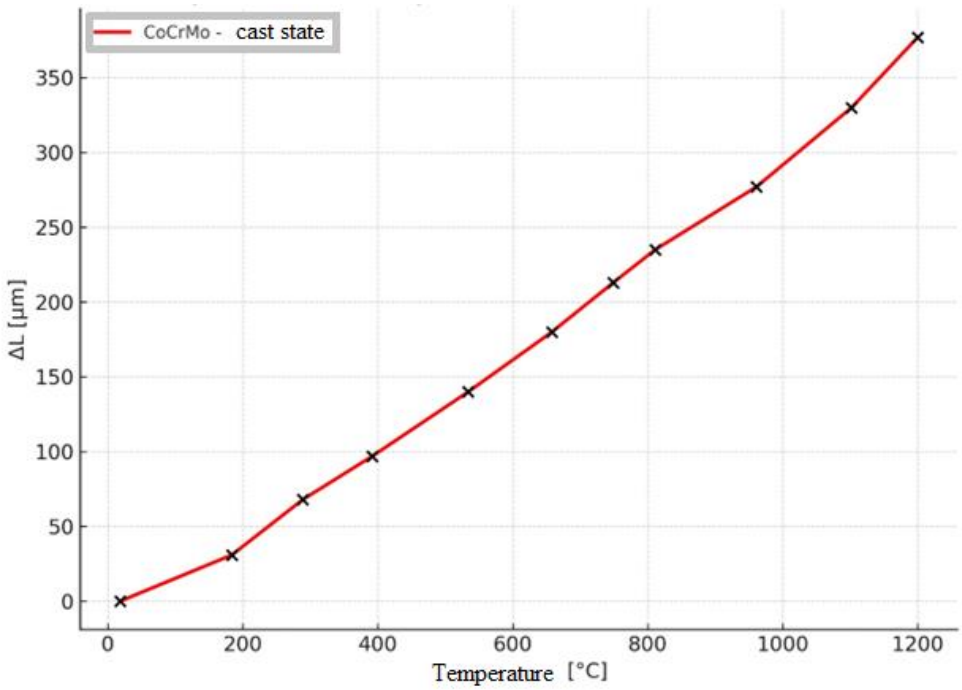

Fig. 3. *Variation of thermal expansion with temperature, for the Co-Cr alloy*

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During mechanical processing of cobalt alloys, dimensional variations may occur at high temperatures, leading to partially irreversible thermal expansion in the affected areas. Under these conditions, we analysed the behavior of Co-Cr system alloys under heating, considering both their clinical applications and the high temperatures reached during manufacturing (machining, melting, and investment casting).

Understanding the high-temperature behavior of these materials provides critical data on how physical, mechanical, and technological properties are established. The use of small samples usually ensures better precision in temperature control and increases the repeatability of results, while large samples facilitate superior precision in determining linear elongation [8].

The images below illustrate elongation as a function of temperature for the Co-Cr and Co-Cr-Si alloy systems. Figure 3 illustrates the thermal expansion of a Co-Cr alloy specimen, commonly used for removable partial dentures. The maximum thermal expansion that the specimen reaches at a temperature of 1200 °C is 377 µm.

Table 2 presents the variation of elongation as a function of heating temperature for the Co-Cr alloy.

Table 2. *Elongation values for Co-Cr alloy*

Temperature [ºC]		18	184	289	392	534	658	749	811	961	1102	1200
Thermal expansion [µm]	**Co-Cr**	0	31	68	97	140	180	213	235	277	330	377

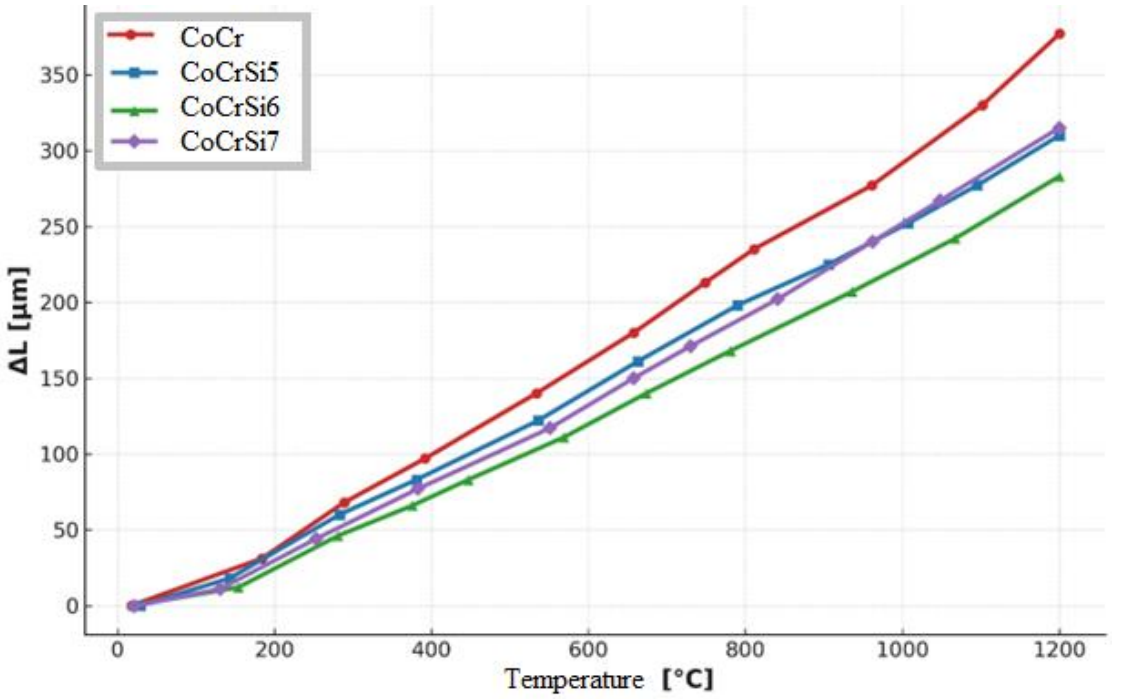

Fig. 4. *Variation of thermal expansion with temperature, for the Co-Cr-Si 5,6,7 alloy, cast state*

Temperature [ºC]		29	143	283	381	536	663	790	906	1007	1095	1200
Thermal expansion [µm]	**CoCrSi5**	0	18	60	83	122	161	198	225	252	277	310
	CoCrSi6	0	12	46	66	83	111	140	168	207	242	283
	CoCrSi7	0	11	44	77	117	150	171	202	240	267	315

Dilatometric analysis revealed a steady increase in elongation as temperature increased, which is characteristic of metallic materials. For the commercial Co-Cr alloy, the maximum expansion at 1200 °C was 377 µm, suggesting moderate thermal expansion suitable for low-fusing ceramic veneers. The modified alloys (C-oCr-Si5, Co-Cr-Si6, Co-Cr-Si7) showed maximum expansion values between

283–315 µm. These values are slightly lower than those of the commercial alloy, indicating superior dimensional stability at high temperatures. The melting range of these Co-Cr alloys (below 1400 °C) is sufficiently higher than the firing temperature of the ceramic (850–1100 °C), thus minimizing excessive deformation or expansion during ceramic sintering.

The phase transformation curves for both the Co-Cr and Co-Cr-Si alloys (Figures 3 and 4) display slight deviations from the otherwise linear trend. These irregularities may be associated with minor phase transformations or structural rearrangements occurring during heating, which could influence the thermal expansion behavior and should be further investigated.

This demonstrates the viability of using Co-Cr and Co-Cr-Si alloys for metal-ceramic and removable partial denture (RPD) frameworks without significant risks of thermal incompatibility. The small sample dimensions (5×5×30 mm) facilitated precise monitoring of temperature and elongation, ensuring repeatability across the experiments. The differences found between the Co-Cr-Si versions can be attributed to variations in chemical composition, which directly affects the coefficient of thermal expansion [27-29].

The expansion curves show an almost linear relationship between elongation and temperature, without abrupt discontinuities, suggesting a stable solid structure free of metastable phases within the examined range. The minor differences between Co-Cr-Si5 and Co-Cr-Si7 suggest an opportunity to optimize the composition to reduce thermal expansion, thus increasing the dimensional accuracy of the final prostheses.

4. Conclusions

Chemical analysis confirmed that the primary elements of these cobalt alloys are Co and Cr, with Si included in the experimental versions to adjust their physicochemical characteristics. The increase in silicon concentration caused a proportional reduction in the levels of the other alloying elements, most notably cobalt, the main component. Thus, cobalt, which was initially 70 wt.% in the commercial Co-Cr alloy, decreased to 56.88 wt.% in the modified Co-Cr-Si7 alloy. Dilatometric analysis validated the compatibility of both the base Co-Cr alloy and its Co-Cr-Si variants with dental ceramics, confirming an adequate melting range relative to the firing temperature of the ceramic.

The thermal expansion coefficient of the analysed alloys ensures precise control of dimensional changes during the ceramic sintering and firing processes.

The Co-Cr-Si5, Co-Cr-Si6, and Co-Cr-Si7 variants offer superior dimensional stability at high temperatures compared to the commercial Co-Cr alloy, which is highly beneficial for precision dental applications. The use of standardized small-scale specimens guaranteed superior repeatability and precision in the evaluation of elongation and expansion coefficient.

However, this study presents certain limitations. The dilatometric analysis was performed on cast specimens without subsequent heat treatment or microstructural characterization, which could further clarify the nature of the phase transformations observed as minor deviations in the expansion curves. In addition, the investigation was limited to a maximum temperature of 1200 °C; extending the thermal range and including controlled cooling cycles could provide more comprehensive insight into reversible structural changes.

Future work will focus on correlating the dilatometric behavior with detailed microstructural observations (via optical and electron microscopy) and differential scanning calorimetry to confirm phase transformation phenomena. Further studies will also evaluate the mechanical properties and metal-ceramic bond strength of the optimized Co-Cr–Si alloys to support their practical application in advanced dental prosthetics.

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