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Hardness and Surface Roughness of Cobalt-Chromium Alloy Produced by Selective Laser Melting and Casting Techniques (An *in vitro* study)

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ABSTRACT

Aim: Investigate the differences of hardness and surface roughness between specimens produced by two techniques, the conventional casting technique and selective laser melting technique.

Materials and Methods: Co-Cr alloy specimens are manufactured by two different techniques; Conventional casting of resin pattern, selective laser melting techniques. Each technique was used to manufacture twelve specimens for each test, making a total of forty-eight. Each group was used for testing hardness and surface roughness. Differences in hardness and roughness were statistically analyzed by using the Independent sample T-test.

Results: Hardness of the selective laser melting specimens had a significantly higher value compared to casting specimens. While, surface roughness of casting show rougher surface than selective laser melting.

Conclusion: As casting has a lower hardness than laser, but it has a rougher surface than laser.

Key words: Cobalt chromium alloy, Hardness, Surface roughness, SLM

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INTRODUCTION

Cobalt-chromium (Co-Cr) dental alloys are base metals. Double-crown, precision-attachment, conventional-clasp – held, and combination, removable partial dentures are mostly made of Co-Cr alloys [1,2]. Their popularity stems from their high strength, corrosion and wear resistance, biocompatibility, and low cost [3,4]. According to ANSI/ADA regulation No. 14, the weight alloy for removable partial dentures should be no less than 20%, and the overall weight of chromium, cobalt, and nickel should be no less than 85%.The alloys pass the toxicity, hypersensitivity, and corrosion tests with flying colors. These alloys have a density of 7.6 to 8.3 g/cm3 [2,5]. PFM alloys should have the ability to attach to dental porcelain, which necessitates adhering oxides on the surface and thermal contraction coefficients that are equivalent to those of dental porcelain [6].

The traditional way of manipulating co-cr is known as conventional casting. Wax and resin are utilized in the manufacturing process; resins are more durable and have less flow than pattern waxes, and they burnout cleanly. Co-Cr alloys are difficult to melt because their fusion temperatures range from 1150°C to 1500°C. The induction method provides better temperature control, resulting in a uniform mass of all alloy components and a reduced risk of oxidation and contamination of the molten alloy [7-10]. 3-D printing is a type of additive manufacturing method that involves depositing successive layers of material to build a 3-D item. This technology is currently routinely utilized to create dental restorations and prostheses using metal powders [11,12]. Joe Beaman and Carl Deckard invented and patented selected laser sintering (SLS) technology in 1989[13]. Digital dental technology is becoming more common as manufacturing processes become more automated. This method is a direct descendant of 3D printing and fast prototyping technologies, which are widely used in the industry [14,15].

The powder is focused on the laser beam, which has enough energy to melt it. By adjusting the wavelength, laser source, and power, the melting process may be fine-tuned. Thermal gradients created during the manufacturing process cause internal stresses in materials. More heat treatment is required to release these stresses [16-18].

Hardness refers to the restoration's resistance to scratching and abrasion by the opposing tooth or restoration, as well as its ability to maintain smoothness in the oral environment. A harder restoration surface, on the other hand, can result in excessive wear of softer opposing dentition or restorations. Mechanical property requirements for yield strength, percentage elongation, and Vickers hardness. The relevant current standard is International Organization for Standardization (ISO) 22674:2016.Using a standard force or weight to indent a test specimen is used to determine hardness. The depth, area, and width of the symmetrically shaped depression are measured under a microscope. The indentation dimensions are then compared to previously calculated hardness values. The indentation's dimensions are inversely proportional to the resistance to penetration. For softer materials, smaller loads are used [2,5].

A device for determining the texture or roughness of a material's surface. The measured roughness depth (Rz) as well as the mean roughness value is displayed on a roughness tester. Surface roughness (Ra) is a unit of measurement for the irregularity of a finished and polished surface is micrometers (μm) [9].

MATERIALS AND METHODS

Preparation of resin samples

In this *in-vitro* study, Co-Cr alloy specimens were manufactured by two different techniques; Conventional casting of resin pattern, selective laser melting techniques. Twenty-four specimens for each test (n=12 of each fabrication technique) hardness and surface roughness .The specimen was rectangular in shape with 20mm in length, 10 mm in width, and 0.6mm in thickness. The specimen size is according to ADA specification NO.14, and the test was done using a portable roughness tester and a digital micro-hardness tester.

Selective laser melting machine (D-150, Riton, China) and Co-Cr powder alloy (cocrmow, Mti, China) were used to make laser specimens, while electric induction casting machine was used to make casting specimens (Dentamatic3000, Tokmet, Bulgaria). The ingot that was used was (cocrwmo, Schefter, Germany). Both groups were sandblasted with 250-mm Al_2O_3 powder (strahltechnik, Renfert, Germany) and then finished using tapered carbide burs and polishing wheels to smooth out the surfaces. Digital calipers were used to verify the final dimensions of all specimens (DCP-300n, PCE, Uk).

Evaluation of hardness and surface roughness

Hardness Test: The total number of all specimens distributed as previously mentioned. The device is calibrated according to manufacturer instructions before the experiment. the test was done by Microhardness Tester (HV-1000Z Digital Micro Vickers Hardness, HST, China). Dwell time 15 sec. Vickers micro indenter 40 objectives, 9.8 N force [19].

For each specimen, five measurements were taken, and the mean value was utilized to define it according to ADA requirements no. 14.

Surface Roughness: As previously stated, the total number of all specimens disseminated. The surface roughness of the specimens was measured with a portable roughness tester utilizing the parameters Ra (TR220, Beijing Time High Technology, and China). The following options are available: 8 mm traverse length; standard critical, 0.1 mm/s velocity A probe with a cutoff length of 0.4 mm and diameter of 2 mm was used to make the measurements, which were taken perpendicular to the polishing direction. The optical lens moves over length 11 mm and records the measurements. The company claims that the device's accuracy is 10%. Each measurement was repeated three times before the mean value of Ra was calculated [20].

Statistical analysis

The following statistics were used to examine the data: (SPSS, version 26). Normality testing was performed on the data collected of hardness and surface roughness respectively. The values followed a normal distribution, according to the Shapiro-Wilk and Kolmogorov-Smirnov tests.

RESULTS

An unbiased sample When the independent t test is used to the two values, it indicates equality in variances because sig >0.05 in Levene's Test for Equality of Variances between two groups. While the Equality of Means t-test reveals sig 0.05, indicating that there is a difference in Hardness between casting and laser. Laser is harder than casting, according to the mean value (Table 1).

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Table 1: The means, SD, and standard errors, in addition the minimum and maximum values of hardness.

Group	N	Minimum	Maximum	Mean	Std. Error	Std. Deviation
Casting	12	409	451	428.6667	3.86776	13.39833
Laser	12	525	655	605.5	10.10288	34.9974
Total	24					

Table 2: The means, SD, and standard errors, in addition the minimum and maximum values of surface roughness.

Group	N	Minimum	Maximum	Mean	Std. Error	Std. Deviation
Casting	12	1.34	2.08	1.7092	0.05935	0.20558
Laser	12	0.77	1.11	0.9125	0.02728	0.0945
Total	24					

Means t-test reveals sig 0.05, indicating that there is a difference in surface roughness between casting and laser. Casting has a rougher surface than laser, according to mean value (Table 2).

DISSCUSSION

The dentist, in consultation with a dental technician, chooses the Co-Cr alloy based on the principal purpose of the prosthesis. Several qualities in the alloy to be used should be available in this regard. Most notably, we concentrate on hardness and surface roughness in this research. Because they are the most relevant to our study's demand. One of the most essential qualities of the Cr-Co alloy is its hardness; it should have a definitive value to resist deformation from mechanical load in the oral cavity. A different test has been used to measure the hardness value, but in this study, we used the microvicker test. The material of interest, the predicted hardness range, and the required degree of localization all influence which hardness test is used. A highly polished and flat test specimen is required [5]. The hardness of the SLM was substantially higher (p 0.05) than that of the casting, implying a shorter tool life [21]. The hardness of laser-sintered microstructures was higher than that of casted samples, according to microhardness studies [22]. SLM specimens were found to have a higher hardness than casting specimens [23]. The microhardness of the cast specimens was found to be considerably higher in the Vickers hardness test. This discovery contradicts the findings of another study, which claimed that Because the laser-sintered surfaces were consistent and homogeneous, they had a higher toughness than cast specimens [24].

The scattered phase has a finer dispersion. It is generally known that materials with finer and scattered phases have higher hardness due to increased impediments to dislocation mobility. The microstructure of the casted samples revealed the presence of this second scattered phase. However, the precipitates were larger in size and came in smaller quantities. This characteristic supports dislocation mobility and a decrease in hardness. Furthermore, due to the slower cooling process, the microstructural grain size acquired by casting was larger than that obtained by laser sintering [25]. Another reason for the increased hardness could be the presence of residual stresses during sintering [26].

The phase transformation and behavior of the precipitates are affected by heat treatment, resulting in complicated changes in mechanical qualities such as hardness [27]. Because of the quick cooling process in SLM Co-Cr alloys, much of the FCC phase is kept at room temperature. As a result, the alloying elements' solid solution limit rises, lowering precipitate and dendritic segregation while preserving oversaturation. This has the effect of solidifying the solution and strengthening the second phase [28]. Because SLM Co-Cr alloys have larger face-centered cubic phase fractions and solid solution limits than cast Co-Cr alloys, they have higher strength and hardness [29]. The SLM group's slightly higher ε -phase peak is linked to better hardness, but its production also results in reduced ductility [30]. Investment casting was used to make the first alloy, while 3D printing was used to make the second. Despite a large variance in the initial microstructure state, SLM proved that the alloy has a similar reaction to annealing at different temperatures in terms of hardness measurement [31]. In our study, we compare between casting and laser, the microhardness vicker test shows that the high value was with laser specimens ,this is agree with [21-23] and disagree with [24].

Because the size of SLM metal powder fine particles is significantly smaller (very fine) and homogeneous than the Casting process, which has a heterogeneous structure, this was the reason of superiority of SLM hardness [32]. The surface roughness of Co-Cr is different, according to methods of production and composition of alloy that has been used, and technique of finishing and polishing, bur types, and direction of polishing all these factors together affect surface roughness, while the critical factor which determine the surface roughness is the purpose of use which either for removable purposes or fixed one. In our study we use to make it smooth surface and well-polished surface. Surface roughness has been extensively studied in the production of biofilms. *In vivo* studies have demonstrated that smooth surfaces attract less biofilm than rough surfaces [5]. The surface of casting should be smooth, although finishing and polishing are still required. Roughness in the casting may suggest a breakdown of the investment due to high burnout temperatures [6].

Any indirect prosthesis should have a Ra value of at least 0.2 m µm [33]. Surface roughness (Ra) increases as the depth of cut and feed rate increase, and reduces as the cutting speed and depth of cut decrease [34]. Due to stress relief and thermal grain development, the porosity and surface roughness of post-thermal treated samples decrease [35]. There are three possible locations: A diametrical line is used as a reference point for testing one in the center and the two other lines 2 mm left and right to it all the lines are parallel to a diametrical line. For polishing and mass loss evaluation, A random number table was used to number the specimens and chose them at random Ra (µm) and mass loss (percent) averages were calculated [36]. Each sample has four zones that were examined. For each sample, ten roughness measurements were taken, with the conclusion that Laser was rougher than casting [22]. Heat treatment; Cast and laser-melted Co–Cr alloys following heat treatment have a rougher surface [37]. LED has a major influence on the roughness of the top surface: little energy applied to the powder bed results in high roughness [38]. Casting has a surface roughness of 1.19 ±0.58, while SLM has a surface roughness of 1.10±0.30 Ra µm [39]. SLM Co-Cr dental alloys have a rougher surface than conventionally cast or 3D-printed patterns alloys [40]. Other in vitro investigations comparing the interior surface roughness of laser-sintered Co–Cr alloys to cast crowns indicated that laser-sintered alloys were rougher than cast crowns [41,42]. The surface roughness quality of the SLM-fabricated Co-Cr denture framework is comparable to that of the traditional lost-wax casting approach [43].

Roughness might cause the opposing tooth enamel to deteriorate faster. When there is surface roughness, mechanical interlocking develops. Additional finishing and polishing are required if the casting's outside surface has excessive roughness or imperfections. Incorrect method can result in a significant increase in roughness and the creation of surface imperfections [2]. The majority of studies reveal that is laser rougher than casting, which contradicts our study, which found that casting is rougher than laser based on an independent T-test with the mean value of casting greater than laser which agree with [39] and disagree with [40-42]. Surface microstructure is directly related to uniform, fine-grained, and less porous microstructure, homogeneity in SLM surface less roughness than heterogeneity in casting [30].

CONCLUSION

Within the limitation of this in-vitro study, the following was concluded.

- ✓ Hardness is harder in SLM than casting which shows less scratch resistance.
- ✓ Casting shows slightly roughness as compared to SLM.

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