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# The Digitalisation in Cobalt-Chromium Framework Fabrication. Surface Roughness Analysis: A Pilot Study

(Pendigitan dalam Fabrikasi Kerangka Kobalt-Kromium. Analisis Kekasaran Permukaan: Suatu Kajian Rintis)

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ABSTRACT

*Selective laser melting (SLM) is a new technique in fabricating cobalt-chromium denture framework. However, the surface properties of cobalt-chromium denture framework fabricated using the aforementioned technique have not been widely investigated. The aim of this paper was to investigate the surface roughness of cobalt-chromium alloy in removable partial denture fabricated with SLM technique. Cobalt-chromium denture frameworks were fabricated with two techniques (n = 10); the conventional lost-wax casting (conventional group) and SLM techniques (SLM group). Specimens from the conventional group were subjected to the standard cobalt-chromium denture polishing protocols. No treatment was employed for specimens from the SLM group. All specimens were subjected to surface roughness measurement on polished and fitting surfaces using non-contact optical three-dimensional metrology and surface roughness analysis machine (Infinite Focus Real 3D Alicona). Statistical analysis showed no significant difference in surface roughness between the specimens from conventional and SLM groups (*$p > 0.05$*). There was no statistically significant difference in surface roughness between the polished and fitting surfaces of SLM specimens (*$p > 0.05$*). Surface roughness quality of the cobalt-chromium denture framework fabricated with the SLM technique is comparable to that fabricated with the conventional lost-wax casting technique. The surface roughness of SLM fabricated cobalt-chromium denture frameworks carries the same surface roughness quality between the polished and fitting surfaces.*

*Keywords: Cobalt chromium; denture; selective laser melting; surface roughness*

ABSTRAK

*Lebur laser terpilih (SLM) adalah teknik terkini yang digunakan dalam menghasilkan dentur kobalt-kromium. Walau bagaimanapun, masih kurang kajian yang dihasilkan berkaitan permukaaan dentur yang dihasilkan melalui teknik ini. Tujuan penyelidikan ini ialah untuk mengkaji kekasaran permukaan dentur yang dihasilkan melalui teknik SLM. Dentur kobalt-kromium dihasilkan menggunakan teknik konvensional dan teknik SLM (n = 10). Permukaan spesimen konvensional dirawat menggunakan protokol asas penggilapan dentur kobalt-kromium. Tiada rawatan dilakukan untuk spesimen daripada kumpulan SLM. Semua spesimen diimbas dengan mesin optikal pembacaan kekasaran permukaan (Infinite Focus Real 3D Alicona). Tiada perbezaan nyata statistik didapati antara spesimen konvensional dan SLM (*$p > 0.05$*). Tiada perbezaan nyata statistik antara permukaan licin dan permukaan adaptasi tisu untuk spesimen SLM (*$p > 0.05$*). Kualiti permukaan untuk dentur kobalt-kromium yang dihasilkan melalui proses SLM adalah sama dengan dentur yang dihasilkan melalui proses konvensional. Kualiti permukaan dentur kobalt-kromium yang dihasilkan melalui proses SLM adalah sama antara permukaan licin dan permukaan adaptasi tisu.*

*Kata kunci: Dentur; kekasaran permukaan; kobalt-kromium; lebur laser terpilih*

## INTRODUCTION

Prosthodontics is a branch in dentistry concerning prosthetic restoration and substitution of missing intra oral and to some extent extra oral facial structures in order to achieve masticatory function, comfort, and aesthetic. Denture has been a viable option for these purposes for decades and has been on the list for prosthodontics treatment options apart from fixed bridge, crown, and implant treatment. Since 1839, modern denture base materials were developed from materials such as acrylic resin and cast metallic material such as cobalt-chromium, nickel chromium based alloys, pure titanium, and titanium alloys (Anusavice 2003).

From the conventional method of fabricating cobalt-chromium (Co-Cr) denture base where lost-wax casting technique is utilised, advancement in the engineering field has allowed for computerised and digitised fabrication of Co-Cr denture framework using selective laser melting (SLM) technique (Budak et al. 2012). This has helped to overcome the drawbacks of conventional technique, some of which are labour-intensive and time-consuming (Koutsoukis et al. 2015). As denture framework is an entity with close adaptation and interaction to the human body and biological tissue, it is only wise that Co-Cr denture framework fabricated using the SLM technique is thoroughly investigated in all aspects SLM this application is fully adopted in dental fraternity.

The mechanical properties of Co-Cr denture framework fabricated using the SLM technique have been investigated in many previous studies. For instance, Alageel et al. (2018) has demonstrated that Co-Cr denture frameworks fabricated using the SLM technique had more precise fit and exhibited better fracture resistance than those fabricated using conventional cast technique. This corresponds to earlier studies on the mechanical aspects, where it has been demonstrated that Co-Cr alloy fabricated with SLM method exhibited high strength and better brittleness properties (Jevremovic et al. 2012; Kajima et al. 2016).

Besides mechanical property, other aspects that require investigation are microstructure and surface properties. Surface integrity plays an important role, as the deficiency in surface integrity could become the initiation point for fatigue cracking, wear, tension, corrosion (Blunt & Jiang 2003), as well as microbial retention that could lead to oral pathology (Budtz-Jörgensen 1974), especially with dentures. Literature confirms the abundance of studies that have well demonstrated the association between surface roughness and plaque and microbial accumulation (Bollen et al. 1996; Liu et al. 2018; Quirynen et al. 1990; Taylor et al. 1998; Verran et al. 1991).

In other studies, the surface properties of SLM-fabricated Co-Cr were investigated (Hong et al. 2016; Koutsoukis et al. 2015; Pupo et al. 2015; Takaichi et al. 2013). With optimum process parameters, it has been confirmed that SLM fabricated Co-Cr had similar or better properties than the casted counterpart (Koutsoukis et al. 2015). Takaichi et al. (2013) demonstrated its uniform and fine microstructure, while Hong et al. (2016) confirmed similar roughness of the surfaces, as demonstrated by Aydin (1991) and Taylor et al. (1998). However, in all these studies the parameters used for surface roughness measurement were in Ra unit.

As optical technology grew and areal surface analysis became more popular (Leach 2011), a reference for surface roughness for Co-Cr fabricated with SLM technique in Sa measurement was deemed required in the literature. This study investigates the surface roughness of Co-Cr denture frameworks fabricated with SLM technique in Sa unit measurement.

The objectives of this study were to determine and compare the surface roughness of Co-Cr specimens fabricated using SLM and conventional lost-wax casting techniques, as well as to compare the surface roughness between the fitting and polished surfaces of Co-Cr frameworks fabricated using SLM technique. The clinical significance of this study is to compare the surface roughness of the end products of dentures fabricated by both conventional and SLM techniques following the fabrication and post fabrication processing to clinical standards.

## Materials and Methods

The materials used for the construction of removable partial denture frameworks consisted of Co-Cr alloys that were specific for their purpose.

Co-Cr metal alloy ingots from Wironit® (Bego, Bremen, Germany) was used in conventional lost-wax casting group and Co-Cr metal alloy powder from SLM MedDent (SLM Solutions Group, AG, Germany) (Breman et al. 2012) was used for SLM group, both carrying a slightly different composition, as shown in Table 1.

TABLE 1. The composition of cobalt chromium alloys in percentage

| Type \ Component | Cobalt | Chromium | Molybdenum | Silicone | Manganese | Carbon | Tungsten |
|---|---|---|---|---|---|---|---|
| Ingot | 64.0 | 28.5 | 5.0 | 1 | 1.0 | < 1 | 0 |
| Powder | 66.8 | 22.7 | 4.0 | 2 | 0.1 | < 1 | 4.4 |

### PREPARATION OF Co-CR DENTURE FRAMEWORK USING SLM TECHNIQUE

A stainless-steel master die (Figure 1(a)) was fabricated using CAD-CAM with the dimensions as indicated in Figure 1(b), and it was scanned using a desktop 3D scanner (Geomagic Capture®, South Carolina, USA).

The sample design was based on the work by Alageel et al. (2018) and Swelem et al. (2014), in which the experimental specimens that were studied for surface characteristics were constructed to be in removable partial denture design. This would simulate the clinical application of Co-Cr alloy used in a clinical dental setting, as opposed to flat specimens used *in vitro*.

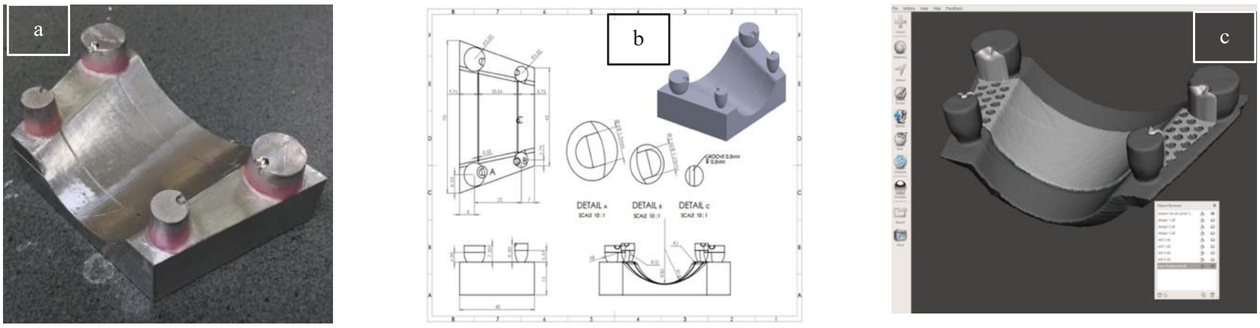


FIGURE 1. (a) Stainless-steel master die, (b) schematic design of master die, and (c) STL design of master die

The scanned data was obtained using an application software (Geomagic Design X, 2016.1.0, United States) and converted into an STL file and transported into a CAD software (Autodesk MeshMixer software; version 3.2.37, California). A virtual block out of undercuts was subsequently performed on the master die in the CAD software. The framework design included virtual relieving of both left and right saddle areas by 0.5 mm. Meshwork of 0.6 mm thickness was designed on each side of the saddles, followed by proximal plates on the proximal areas of the abutments. Occlusal rests were created on abutments, and finally, the major connector in the form of a palatal strap of 0.6 mm thickness was designed on the palatal area. The finalised design was exported to another CAD software Magics, 3-matic® (Materialise, Belgium), and support structures were designed along the lateral margins of the polished surface of the framework at an angle of 30°.

The resulting STL file of the framework design was then sent to an SLM machine (SLM 280 HL, SLM Solutions GmbH) for additive manufacturing of the framework. Laser power of 170 W and scanning rate of 760 mm/min were employed. Five removable partial denture frameworks were fabricated. The support structures were not removed from the samples due to no interference with the areas of surface roughness analysis was observed.

### PREPARATION OF CO-CR DENTURE FRAMEWORK WITH CONVENTIONAL LOST-WAX CASTING TECHNIQUE

Stainless steel master die was prepared for duplication by first blocking out the undercut areas and relieving the saddle areas (Figure 1(a)). Duplication was done with agar, and upon setting, refractory investment material (Wirovest®, Bego, Germany) was poured to produce a refractory cast. The refractory cast was removed from the agar after 45 min, then preheated to 250 °C for 30 min, soaked in hardening agent, and air-dried to increase the surface integrity. Five refractory casts were prepared by the same operator.

The wax-up of the denture frameworks was performed on individual casts (Figure 2). Wax patterns of 0.6 mm thick were laid on the palatal area for the major connector, followed by the rests and minor connectors to connect the major connector to the rests. Meshwork wax was then applied on both saddles and chip-blowed to achieve a smooth surface. Three sprues of 2.5 mm diameter were attached to the wax-up.

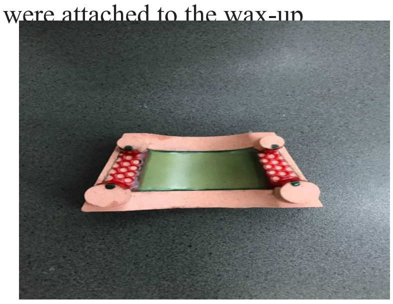

FIGURE 2. framework wax-up

The refractory casts with wax patterns were then flasked in mould rings and investment material (Wirowest®, Bego, Germany) was poured into the ring. They were left to set for more than 30 min. Prior to casting, the moulds and crucibles were placed in the furnace (Bego Fornax 35 EM, Bremer, Germany) for preheating at 250 °C between 30 and 60 min. The temperature of the furnace was then raised to a final temperature of 1000 °C and held for another 30-60 min. The Co-Cr ingots were then placed in the crucibles and transferred to the induction casting machine until the ingots were partially melted. Subsequently, the mould rings were transferred from the furnace into the casting machine and the casting process started. Once casting was completed, the mould rings were removed from the machine and left to bench cool for 2 h. The frameworks were then devested and subjected to sprue cutting with the carborundum bur, sandblasting with 110 µ silica particles, electropolishing for 5 min with 12 V of electric current, followed by polishing with rubber points, final polishing with bristle brush and polishing lathe, and finally, buffed with cotton brush. Five polished denture frameworks were obtained.

### SPECIMEN ANALYSIS AND DATA COLLECTION

Frameworks were then subjected to surface roughness analysis using a non-contact optical three-dimensional metrology and surface roughness analysis machine (Infinite Focus Real 3D Alicona). Surface roughness was determined on four different points on the major connector on each of the fitting (Figure 3(a)) and polished surfaces (Figure 3(b)) of the denture frameworks. These areas were selected to be as widely apart from each other for better representation of the whole denture surface. They were positioned towards the saddle areas, as it was critical for these areas to exhibit smooth surface, being close to hard tissue, which accumulates plaque more so than the mucosal surface.

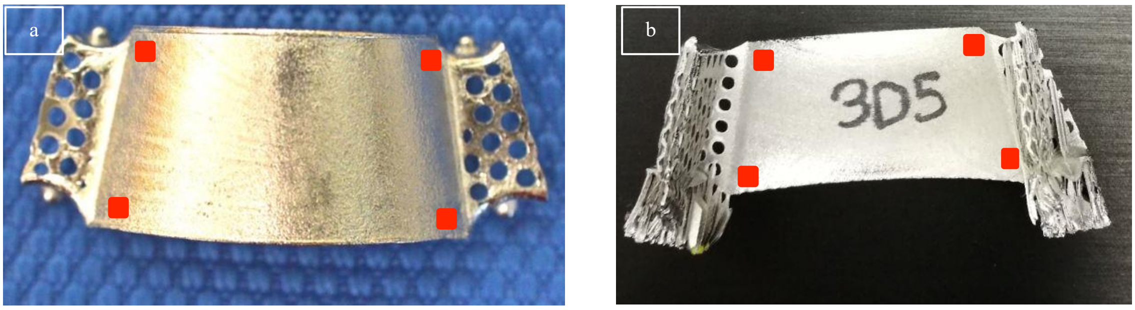


FIGURE 3. Red squares indicate points chosen for surface roughness measurement (a) Fitting surface, and (b) Polished surface

The measurements were repeated three times for each point. A data set was produced for every surface texture analysis and the Sa value representing surface roughness was taken and recorded in SPSS (SPSS Statistics V21; IBM Corp, US). Statistical analysis was done in SPSS and independent t-test was used to compare the surface roughness. The statistical significance value was set at $p < 0.05$.

## RESULTS AND DISCUSSION

The results of the independent t- test are summarised in Table 2, which showed no significant difference ($p > 0.05$) in the roughness of the polished and fitting surfaces between the conventional casting and SLM specimens.

TABLE 2. Mean surface roughness (Sa) values of the fitting and polished surfaces of specimens fabricated by conventional casting and SLM methods (n=5)

| SURFACE | n | Surface roughness, Sa (µm) Mean (SD) | | |
|---|---|---|---|---|
| | | Conventional | SLM | **p-value* |
| Polished | 5 | 31.06 (16.32) | 30.24 (12.19) | 0.217 |
| Fitting | 5 | 28.90 (10.57) | 29.14 (11.68) | 0.659 |
| | | 0.17 | 0.45 | |

SD = standard deviation; underlined are *p-values*; *significance level was set at 0.05 using t-test

In addition, independent sample t-test was employed to analyse the difference in surface roughness between all specimens fabricated by both methods of conventional casting and SLM regardless of the surface. No significant difference ($p > 0.05$) was found and the results are demonstrated in Table 3.

TABLE 3. Mean surface roughness (Sa) values of specimens fabricated by conventional casting and SLM methods regardless of surfaces

| Surface roughness, Sa (µm) Mean (SD) | | |
|---|---|---|
| Conventional | SLM | **p-value* |
| 29.97 (13.61) | 29.69 (12.15) | <u>0.50</u> |

*n=10; significance level was set at 0.05 using independent t-test

Additive manufacturing, particularly the SLM technique, has been introduced in the fabrication of metal partial denture framework after rapid prototyping and stereolithography have brought forth the manufacturing of non-metallic parts from acrylic, resin, and plastic materials (Dickens 1995).

Being a relatively recent application and realising the fact that a dental prosthesis interacts with biological environment and tissue, the requirement for denture framework fabricated with this new technique to be investigated is undeniable. A number of research is available in the literature on the investigation of titanium and nickel-chromium based denture framework and dental prostheses (Bartolomeu et al. 2019; Hong et al. 2016; Revilla-León et al. 2018). However, the specific focus on surface characteristics of Co-Cr denture framework fabricated using SLM technique calls for more investigation and publication.

This work investigates the surface roughness of the Co-Cr denture framework fabricated with conventional lost-wax casting technique and the recently introduced SLM technique in Sa measurement. There was no statistical difference ($p > 0.05$) obtained of the roughness between these two types of specimens of the conventional lost-wax casting and SLM groups.

Previous studies have shown the surface roughness measurement of conventionally fabricated Co-Cr denture frameworks in Ra measurement to be as low as 0.14 µm (Aydin 1991) in polished samples and 0.15 µm (Taylor et al. 1998) to as high as 2.13 µm (Taylor et al. 1998), 3.50 µm (Aydin 1991), and 13.39 µm (Jang et al. 2001). As for Co-Cr specimens fabricated with SLM, Pupo et al. (2015) demonstrated Ra value of surface roughness ranging between 4 and 15 µm with different laser power and scanning space settings. Hong et al. (2016) reported Ra values of 1.3 to 21.5 µm with variable scan line spacing parameters. These values are, however, not suitable for direct comparison with the findings of this study for the reason that Ra measurement employs a different procedure of measurement compared to Sa type of measurement used in this study. The areal method of measurement deals with the average roughness value obtained from a determined area as compared to a line drawn on a surface in a linear measurement approach.

According to Whitehouse (2004), due to the optical nature of optical measurement in which the angle, resolution, and depth of focus are not adjustable without affecting each other, surface roughness readings might be affected for very fine surfaces. The optical method might give a larger value for surface roughness than that by the stylus method. Nevertheless, these two measurement modalities should not be treated as correct or wrong because they behave according to their own physical laws and should be regarded as complementary to each other.

In a study by Vorburger et al. (2007) attempting to investigate the differences between the optical and stylus methods of measuring surface texture, it was found that the average differences between the Ra and Sa measurements were less than or equal to 6 µm. However, the largest discrepancy was up to 75% of the Ra value. Taking this paper as a reference and comparing the mean Sa measurement obtained from this study to the Ra measurement of surface roughness from other studies (Aydin 1991; Jang et al. 2001; Taylor et al. 1998), it could be inferred that the mean Sa readings of 29.97 µm (conventional) and 29.69 (SLM) carry the converted Ra readings between 23.97-35.97 µm and 23.69-35.69 µm, respectively. These figures are comparably higher than

Ra values of surface roughness obtained from other previous studies (Aydin 1991; Jang et al. 2001; Swelem et al. 2014; Taylor et al. 1998).

This work adopted Sa measurement for surface roughness analysis instead of the Ra measurement which is more prominent in the literature. Sa measurement is considered a more recent parameter and came into existence with the development of optical devices that are used for surface analysis Vorburger et al. (2007) and standardisation of areal surface texture measurement that has been developed by ISO for geometrical product specification.

Analysing the difference in surface roughness between the same type of surface of denture framework between specimens fabricated using conventional and SLM techniques showed that there was no significant difference obtained ($p > 0.05$). No pertinent study was found available in the literature relating the direct comparison of conventionally fabricated Co-Cr denture framework to those fabricated with SLM technique with specific regard to the surface roughness subject. Therefore, it can be concluded that both techniques yield comparable surface roughness quality.

Nonetheless, it has to be respected that different process parameters produce different results with respect to laser power, scan rate, and scan line spacing (Koutsoukis et al. 2015; Takaichi et al. 2013). It was discovered that the optimal laser power, scan rate, and scan line spacing for smooth surface formation were 200 W, 128.6 mm/s, and 100 µm, respectively, for Co-Cr alloy by Hong et al. (2016), and 400 W laser power and 450 µm scan spacing by Pupo et al. (2015). In another study, parameters that had been determined for SLM fabricated nickel chromium alloy were 200 W for laser power, 98.8 mm/s for scan speed, and 60 µm for scan spacing (Hong et al. 2018).

The analysis between the polished and fitting surfaces of the SLM specimens was conducted with independent sample t-test analysis. It is known that cast Co-Cr exhibits many microstructural variations (Koutsoukis et al. 2015; Takaichi et al. 2013), therefore, it is important to determine if any variation in the surface quality was present within the SLM specimens. It was found that there is no statistical difference ($p > 0.05$) in the surface roughness between the polished (30.24 µm–$\bar{X}$) and fitting surfaces (29.14 µm–$\bar{X}$) of the SLM specimens. This observation corresponds to another study by Takaichi et al. (2013) with regard to the uniformity of surface quality for Co-Cr specimens fabricated with SLM technique. It has been demonstrated by optical microscopy images that in SLM Co-Cr specimens observed in transverse cross section from build direction, fine lamellar elongated to the build direction was observed. This phenomenon is related to the previously mentioned process parameters, as differences in input energy results in differential melted and densified zones will affect the porosity or density of the microstructure (Takaichi et al. 2013).

## Conclusion

Within the limitation of this study, it is concluded that the surface roughness quality of the Co-Cr denture framework fabricated with the SLM technique is comparable to that fabricated with the conventional lost-wax casting technique. The surface roughness of SLM fabricated Co-Cr denture frameworks carry the same surface roughness quality between the polished and fitting surfaces.

## REFERENCES


Alageel, O., Abdallah, M.N., Alsheghri, A., Song, J., Caron, E. & Tamimi, F. 2018. Removable partial denture alloys processed by laser-sintering technique. *Journal of Biomedical Materials Research Part B: Applied Biomaterials* 106(3): 1174-1185.

Anusavice, K.J. 2003. *Philip's Science of Dental Materials.* 11th ed. St. Louis: Elsevier Science. p. 96.

Aydin, A.K. 1991. Evaluation of finishing and polishing techniques on surface roughness of chromium-cobalt castings. *The Journal of Prosthetic Dentistry* 65(6): 763-767.

Bartolomeu, F., Costa, M., Gomes, J., Alves, N., Abreu, C., Silva, F. & Miranda, G. 2019. Implant surface design for improved implant stability - A study on Ti6Al4V dense and cellular structures produced by selective laser melting. *Tribology International* 129: 272-282.

Blunt, L. & Jiang, X. 2003. *Advanced Techniques for Assessment Surface Topography: Development of a Basis for 3D Surface Texture Standards SURFSTAND*. Oxford: Butterworth-Heinemann.

Bollen, C.M., Papaioanno, W., Van Eldere, J., Schepers, E., Quirynen, M. & Van Steenberghe, D. 1996. The influence of abutment surface roughness on plaque accumulation and peri-implant mucositis. *Clinical Oral Implants Research* 7(3): 201-211.

Bremen, S., Meiners, W. & Diatlov, A. 2012. Selective laser melting: A manufacturing technology for the future? *Laser Technik Journal* 9(2): 33-38.

Budak, I., Kosec, B. & Sokovic, M. 2012. Application of contemporary engineering techniques and technologies in the field of dental prosthetics. *Journal of Achievements in Materials and Manufacturing Engineering* 54(2): 233-241.

Budtz-Jörgensen, E. 1974. The significance of *Candida albicans* in denture stomatitis. *European Journal of Oral Sciences* 82(2): 151-190.

Dickens, P. 1995. Research developments in rapid prototyping. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 209(4): 261-

266.
Hong, M.H., Son, J.S. & Kwon, T.Y. 2018. Surface roughness of a 3D-printed Ni–Cr alloy produced by selective laser melting: Effect of process parameters. *Journal of Nanoscience and Nanotechnology* 18(3): 2037-2040.
Hong, M.H., Min, B.K. & Kwon, T.Y. 2016. The influence of process parameters on the surface roughness of a 3D-printed Co–Cr dental alloy produced via selective laser melting. *Applied Sciences* 6(12): 401.
Jang, K.S., Youn, S.J. & Kim, Y.S. 2001. Comparison of castability and surface roughness of commercially pure titanium and cobalt-chromium denture frameworks. *The Journal of Prosthetic Dentistry* 86(1): 93-98.
Jevremovic, D., Puskar, T., Kosec, B., Vukelic, Đ., Budak, I., Aleksandrovic, S., Egbeer, D. & Williams, R. 2012. The analysis of the mechanical properties of F75 Co-Cr alloy for use in selective laser melting (SLM) manufacturing of removable partial dentures (RPD). *Metalurgija-Zagreb* 51(2): 171.
Kajima, Y., Takaichi, A., Nakamoto, T., Kimura, T., Yogo, Y., Ashida, M., Doi, H., Nomura, N., Takahashi, H., Hanawa, T. & Wakabayashi, N. 2016. Fatigue strength of Co–Cr–Mo alloy clasps prepared by selective laser melting. *Journal of the Mechanical Behavior of Biomedical Materials* 59: 446-458.
Koutsoukis, T., Zinelis, S., Eliades, G., Al-Wazzan, K., Al Rifaiy, M. & Al Jabbari, Y.S. 2015. Selective laser melting technique of Co-Cr dental alloys: A review of structure and properties and comparative analysis with other available techniques. *Journal of Prosthodontics* 24(4): 303-312.
Leach, R. 2011. *Optical Measurement of Surface Topography* (Vol. 14). Berlin, Heidelberg: Springer.
Liu, B., Kuai, Z., Li, Z., Tong, J., Bai, P., Li, B. & Nie, Y. 2018. Performance consistency of AlSi10Mg alloy manufactured by simulating multi laser beam selective laser melting (SLM): Microstructures and mechanical properties. *Materials* 11(12): 2354.
Pupo, Y., Monroy, K.P. & Ciurana, J. 2015. Influence of process parameters on surface quality of cocrmo produced by selective laser melting. *The International Journal of Advanced Manufacturing Technology* 80(5-8): 985-995.
Quirynen, M., Marechal, M., Busscher, H., Weerkamp, A., Darius, P. & Van Steenberghe, D. 1990. The influence of surface free energy and surface roughness on early plaque formation: An *in vivo* study in man. *Journal of Clinical Periodontology* 17(3): 138-144.
Revilla-León, M., Ceballos, L., Martínez-Klemm, I. & Özcan, M. 2018. Discrepancy of complete-arch titanium frameworks manufactured using selective laser melting and electron beam melting additive manufacturing technologies. *The Journal of Prosthetic Dentistry* 120(6): 942-947.
Swelem, A.A., Abdelnabi, M.H., Al-Dharrab, A.A. & Abdelmaguid, H.F. 2014. Surface roughness and internal porosity of partial removable dental prosthesis frameworks fabricated from conventional wax and light-polymerized patterns: A comparative study. *The Journal of Prosthetic Dentistry* 111(4): 335-341.
Takaichi, A., Suyalatu, Nakamoto, T., Joko, N., Nomura, N., Tsutsumi, Y., Migita, S., Doi, H., Kurosu, S., Chiba, A., Wakabayashi, N., Igarashi, Y. & Hanawa, T. 2013. Microstructures and mechanical properties of Co–29Cr–6Mo alloy fabricated by selective laser melting process for dental applications. *Journal of the Mechanical Behavior of Biomedical Materials* 21: 67-76.
Taylor, R., Maryan, C. & Verran, J. 1998. Retention of oral microorganisms on cobalt-chromium alloy and dental acrylic resin with different surface finishes. *The Journal of Prosthetic Dentistry* 80(5): 592-597.
Verran, J., Lees, G. & Shakespeare, A.P. 1991. The effect of surface roughness on the adhesion of *Candida albicans* to acrylic. *Biofouling* 3(3): 183-191.
Vorburger, T.V., Rhee, H.G., Renegar, T.B., Song, J.F. & Zheng, A. 2007. Comparison of optical and stylus methods for measurement of surface texture. *The International Journal of Advanced Manufacturing Technology* 33(1-2): 110-118.
Whitehouse, D.J. 2004. *Surfaces and Their Measurement.* Oxford: Butterworth-Heinemann.

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