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RESEARCH ARTICLE

Effect of Co-Cr alloy *recasting* on the fracture toughness

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ABSTRACT

Frame denture generally uses Co-Cr alloy. However, alloy is expensive, so dental laboratories use residual sprue casting for recasting. The purpose of this study was to determine the effect of Co-Cr alloy recasting on fracture toughness. This was a laboratory experiment, with five sample groups, namely R0: 100% of new alloys; R1: 50% one-time recasting procedure and 50% new alloys, R2: 50% two-time recasting procedure and 50% new alloys, R3: 50% three-time recasting procedure and 50% new alloys, R4: 50% four-time recasting procedure and 50% new alloys. Fracture toughness was tested using a universal testing machine; the data were analyzed by One-Way Anova test and LSD ($p>0.05$). The results showed that the fracture toughness was 233.103 MPa-m$^{1/2}$ in R4, and the highest was 242.435 MPa-m$^{1/2}$ in R0. The results of the analysis by the LSD test on fracture toughness showed that there were no significant differences in R0 with R1 and R2, but there were significant differences between R0 with R3 and R4. There was a decrease after recasting in each group because of the missing elements of the Co-Cr alloy. The percentage of each element decreased due to oxidation and evaporation during heating. There was a change in the composition of the Co-Cr alloy in R3 and R4. There was a decrease in the fracture toughness. Variation in recasting frequency of Co-Cr alloy affected the fracture toughness. In each sample groups, the fracture toughness of Co-Cr alloy decreased after recasting.

Keywords: CoCr alloy; fracture toughness; recasting

INTRODUCTION

Frame denture must have high strength and durability, which functions as the main connector.[1] Frame denture can meet physical and mechanical requirements, i.e., having a quite high transition temperature value and good dimensional stability, being radiopaque,[2] having resistance to fracture, being free from porosity, not absorbing liquid, having accurate adaptation to soft tissue and smooth surface.[3] Besides, frame denture should also meet the requirements of mechanical properties, such as having adequate flexural strength to be able to withstand fractures.[2]

The mechanical properties of dentistry are related to the resistance of the material through deformation, cracks, and fractures, due to any pressure applied to the material.[4] Fracture toughness is the ability of a material to resist a fracture, which can be influenced by the thickness of a material, which determines the amount of loading in the form of strain or tension and pressure.[5] The manufacture of frame denture requires a material that has good mechanical properties.[4]

Frame denture generally uses Co-Cr alloy.[6] The characteristics of Co-Cr alloy include tarnish and corrosion resistance, good electrochemistry, high strength, hardness, high modulus elasticity, elongation, castability, and polishing capacity that can produce an ideal restoration material.[7] Using Co-Cr alloy for casting has become a routine procedure in dental laboratories.[4,8] Dental laboratories often reuse the residual alloy casting (casting surplus) such as sprue and alloy left in crucible former for recasting for economic reasons.[9,10] Several studies have examined that recasting is done by mixing the residual alloys from sprue and crucible when casting by adding 50% new alloys.[10] Recasting can affect the release of some elements of the alloy through evaporation or

Table 1. Sample groups

Groups	Recasting frequency	Procedure
R0	0 time	100% of new CoCr alloy
R1	1 time	50% residual CoCr alloy casting + 50% new CoCr alloy
R2	2 times	50% + 50% new CoCr alloy
R3	3 times	50% residual CoCr alloy casting + 50% new CoCr alloy
R4	4 times	50% residual CoCr alloy casting + 50% new CoCr alloy

Table 2. Mean and standard deviation (SD) of fracture toughness of CoCr alloy recasting

Groups	Procedure	Mean ± standard deviation (MPa-m$^{1/2}$)
R0	no recasting	242.435 ± 2.784
R1	one-time recasting	240.153 ± 2.194
R2	tow-time recasting	238.647 ± 3.525
R3	three-time recasting	234.613 ± 4.488
R4	four-time recasting	233.103 ± 2.253

oxidation, such as Ni, Co, Cu, Zn, Cr, Sn, and Fe and the amount of the released Ni, Cr, Co, and Fe ions increases during recasting.[9] Alloy recasting in dentistry, without the addition of new alloys, can affect the mechanical properties and affect the microstructure of the alloy.[11]

Fracture toughness is important in frame denture and recasting is also needed to obtain frame denture that can be applied in dentistry. Based on the abovementioned description, this study examined whether there is an effect of Co-Cr alloy recasting on fracture toughness.

MATERIAL AND METHODS

This was a laboratory experiment. There were five sample groups with different casting variations which can be seen in Table 1. Each group consisted of four samples.

The sampling was carried out in the material and dental technology laboratory at Faculty of Dentistry Institut Ilmu Kesehatan Bhakti Wiyata Kediri. The alloy used was CoCr alloy Remanium GM-380 + alloy. The samples were made in blocks according to the ASTM standard: E399-90, specification (25 mm × 4 mm × 4 mm). Two rectangular metal molds were prepared with a size of 25 mm × 4 mm × 4 mm and a notch was made with a width of 0.12 mm and a length of 1.6 mm. An inlay wax was made and then invested in a casting ring and cast according to the sample groups in Table 1.

The fracture toughness was tested using a universal testing machine (Tokyo Testing Machine MP-160, Kyoto Japan) on the materials and industry laboratory, Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada. An ethical clearance letter was obtained from the research ethics committee Faculty of Dentistry, Universitas Gadjah Mada No.00117 / KKEP / FKG-UGM / EC / 2019. The mean differences of the data were analyzed statistically using a One-Way Anova, followed by LSD test to see the value of the mean difference between each group. SEM EDX was used to determine the composition of the alloy after recasting was carried out in each group.

RESULTS

The highest average fracture toughness results were found in R0 with 0 recasting procedure and the lowest in R4 with four-time recasting procedure as seen in Table 2 which shows the standard deviation (SD) of the fracture toughness of CoCr alloy recasting. The results showed that the fracture toughness was 233.103 MPa-m$^{1/2}$ in R4, and the highest was 242.435 MPa-m$^{1/2}$ in R0.

The ANOVA test results obtained F = 5.969, showing a significant difference ($p<0.05$) between the mean fracture toughness of the CoCr alloy recasting. Therefore, it can be concluded that CoCr alloy recasting affected the fracture toughness.

DISCUSSION

For economic reasons, recasting has become one of the routine procedures carried out at a dental laboratory because Co-Cr alloy is expensive. This

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Table 3. Composition of CoCr alloy with recasting variation

Elements	no recasting (Wt%)	one-time recasting (Wt%)	two-time recasting (Wt%)	three-time recasting (Wt%)	four-time recasting (Wt%)
Si	1.02	1.12	1.45	1.18	1.51
Mo	5.59	5.37	5.32	4.87	4.84
Cr	30.70	31.00	30.40	30.22	29.95
Mn	0.66	0.63	0.73	0.90	0.79
Co	62.79	62.30	62.11	62.03	62.70

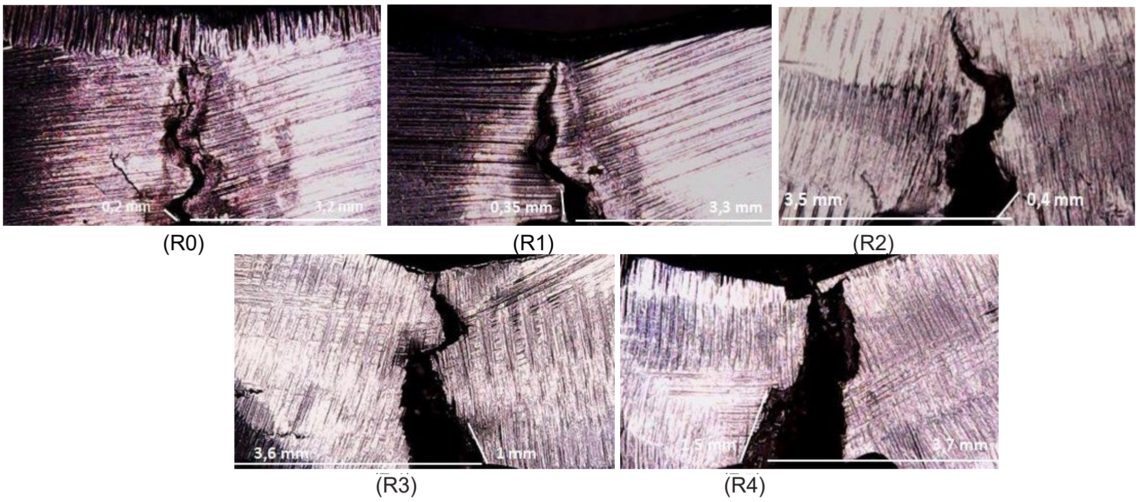

Figure 1. Digital microscope results of crack propagation from the fracture toughness of the sample groups with a magnification of 10X. The samples with no recasting (R0) one-time recasting (R1) two-time recasting (R2) three-time recasting (R3) four-time recasting (R4).

research was carried out to find the impact of Co-Cr alloy casting on fracture toughness. The SEM EDX showed the percentage of the components in each treatment group which had the same value. Adding new alloy to each recasting procedure ensures the existence of the main elements by replacing any elements lost, thus ensuring that the material can function normally. Therefore, this study found no significant differences in the fracture toughness between R0 with R1 and R2.

Component losses in a small percentage do not affect the toughness of a material.[12] The addition of 50% new metal during recasting is done to replace any lost elements due to evaporation and oxidation during casting.[13]

Baron et al (2015) reported CoCr alloy ASTM F1537 has a fracture toughness of 100 MPa-m$^{1/2}$, which is lower than the results of this study. The difference in these results is likely because of different compositions of the CoCr alloy, in which this previous study used lower composition of CoCr alloy than this present study. The study by Baron used a composition of Cr 27.8%, Si 0.25%, Mo 5.5%, Mn 0.68%, but the percentage of the main component such as Co is not stated. On the other hand, the percentage of Co in the present study was the highest.

Digital microscope showed an image of shorter and narrower initial crack propagation. The tips of the crack propagation in R0, R1 and R2 were smaller and tapered, then ended in the direction of loading. The material still had good bonding so the crack width gradually decreased and got narrower, showing that the crack propagation decreased and the crack tip could end. In other words, the crack propagation could be inhibited, so the material showed good toughness.

There were significant differences in the fracture toughness between R0 with R3 and R4. A recasting procedure decreases fracture toughness. SEM EDX shows that the percentage of some elements decreases when recasting. This study showed that the main elements such as Co and Cr decreased in each recasting and In addition, R3 and R4 experienced a decrease in the percentage of Mo elements because the main components in this study were Co and Cr which contribute to toughness, strength, and tarnish resistance as well as Mo which also contributes to toughness, improves the characteristics of alloy during a casting process, and decreases the purifyed grain structure. Therefore, these elements affected the decrease in the fracture toughness in each sample group, especially in R3 and R4 which were used a material with three-time and four-time recasting.

R3 and R4 were seen to have longer and wider initial cracks leading to the direction of loading. Those sample groups obtained lower fracture toughness values. The wider and longer cracks, the lower the material fracture toughness. A material loses function because some of its elements are lost when recasting, so the material will be brittle and easily traversing due to crack propagation because there is no element that can block the tip of the crack propagation.

Co-Cr alloy has advantages as a dentistry material with mechanical characters. The addition of molybdenum (Mo) to Co-Cr alloy, which has high strength, is generally used for frame denture and in this study the Mo element was seen to decrease in R3 and R4 where Mo was hardening, improving the properties of the alloy during the casting process and refining the grain structure.

Co-Cr alloy which has been recast four times mechanically still has good fracture toughness, but in this study, the composition of Co-Cr alloy which had been recast three times and four times changed, i.e., the alloy element decreased. These results are in accordance with the findings of Vailant-Corroy et al.[9] Excessive recasting of alloys changes the composition, physical, and mechanical properties of the material.

In addition, small-sized metal elements in alloys can be lost through evaporation or oxidation during a heating process. Alloy recasting can disrupt the stability of the alloy composition.[14] Recast alloys do not have the same strength compared to between new alloys. The physical characteristics of recast alloys and new alloys are not always the same.[10] In addition, recasting can increase the microporosity of the alloy and change the mechanical characteristics of the material.[15] In this study, to obtain fracture toughness in Co-Cr alloy recasting, recasting can be done up to two times. It is necessary to conduct further research with different recast and new alloy ratios, that is 25% - 50% recast alloy and 50% - 75% new alloy, followed by fractography with observations using the scanning electron microscope (SEM) to see the fracture surface character of Co-Cr alloy specimens in more details.

CONCLUSION

Variation in recasting frequency (0-4 time recasting of Co-Cr alloy) affects fracture toughness. The fracture toughness of Co-Cr alloy in each sample group decreased after recasting. There was no significant difference between no recasting with one-time and two-time recasting, but there was a significant difference between no recasting with three-time and four-time recasting in terms of a decrease in the fracture toughness.

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