Comparison of Wear Resistance, Surface Hardness and Surface Roughness of Dentoform Tooth and Silane-treated Alumina Reinforced Epoxy Resin

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Abstract

Dentoform teeth are extensively used in the preclinical laboratory practice by dental students. Nowadays, the price of the dentoform teeth has been increased continuously. Therefore, the substitute materials were developed in order to reduce the imported teeth thus reducing the education expenses for dental students. The purpose of this study were to compare wear resistance, surface hardness and surface roughness of dentoform teeth (Frasaco, German; Nissin, Japan) and epoxy composite (70 wt% untreated alumina and 50, 60, 70 wt% silane-treated alumina reinforced epoxy resin) while unfilled epoxy resin served as control. Fifteen specimens of each group (n=15) were examined for pin-on-disk wear resistance, Vickers surface hardness and contact stylus profilometer surface roughness. One-Way ANOVA statistic was used to analyze the data (α = 0.05). It was found that wear resistance of 70 wt% and 60 wt% silane-treated alumina reinforced epoxy resin groups (tx 70% and tx 60% groups) were significantly higher than those of the others including dentoform groups. The surface hardness of dentoform groups was significant higher than all remaining groups (Frasaco: 38.321$\pm$1.278 HV, Nissin: 39.245$\pm$2.060 HV). However, when comparing within the epoxy composite groups, tx 70% group (29.924$\pm$0.921) had been shown the significantly highest value. In surface roughness, tx 60% group had been revealed the lowest value but it was not significantly different with tx 50% and tx 70% groups. Although tx 70% group had been shown less surface hardness when compared with that of dentoform groups, its wear resistance and surface roughness had been superior than those of dentoform groups. Therefore, tx 70% should be considered as a promising and cost-effective substitute material for production of dentoform teeth.

***Keywords**: Epoxy resin/ Silane-treated alumina/ Dentoform tooth*

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Introduction

Dentoform teeth or plastic teeth are frequently used in the preclinical laboratory practice by dental students in several subjects such as prosthodontic and operative practices until they have skill enough to treat their patients. Dentoform teeth have many advantages for example uniform anatomy, unlimited availability, and ease of placement into a simulated dental arch. However, they have some limits such as their tactility is not similar to that of natural teeth, their dento-enamel junction (DEJ) is absent and their bonding ability to resin-based materials is limited. Therefore, it is necessary to practice on the natural teeth in some procedures. However, natural teeth are needed to be disinfected prior to use and limited available. In addition, arranging natural teeth in the dentoform arch is difficult to get proper occlusion.[1] Therefore, dentoform teeth are the favorable choice for education of dental students. Since, a large number of dentoform teeth are used each year and the price of the dentoform teeth increased continuously. Therefore, the effort in this study was to find the substitute material of dentoform teeth.

According to Chamchong's study,[2] the analysis of dentoform teeth components by nuclear magnetic resonance (NMR) technique found that Frasaco dentoform teeth (Frasaco, Germany) comprised melamine as an essential component whereas Nissin dentoform teeth (Nissin, Japan) was epoxy resin. Moreover, themogravimetric analysis

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(TGA) revealed that Frasaco dentoform teeth were composed of polymer approximately 40 wt% and fillers approximately 60 wt%. However, by means of X-ray diffraction, the types of fillers could not be identified because these components were too complicated to analyze. Alumina reinforced epoxy resin without silanization was chosen as substitute material. The result had been shown that surface hardness of Frasaco dentoform teeth was the highest and surface hardness of alumina reinforced epoxy resin increased with increasing alumina content. For the surface roughness, alumina reinforced epoxy resin groups had significantly higher surface roughness than that of dentoform teeth. The reason might during tooth preparation; some of the fillers might be detached.[2]

The facts that main component of Nissin dentoform teeth is epoxy resin and 60 wt% fillers of Frasaco dentoform teeth are still an interesting issue. Epoxy resin had many required qualities including low shrinkage, easy mold ability, chemical erosion resistance, good affinity to homogeneous materials, and thermal stability.[3,4] Meanwhile, melamine had many good properties such as high hardness, good strength, good wear resistance.[5] However, the molding process of melamine is more difficult than that of epoxy resin, because of the production process was to be through heat and pressure with compression molding method.[6] Thus, epoxy resin was chosen to be the experimental material in this study.

Mechanical properties and tribological behavior of epoxy resin can be improved in many ways such as glass or carbon fiber reinforcement.[7,8] Addition of microparticle or nanoparticle, such as Al_2O_3, SiO_2, TiO_2, and $CaSiO_3$, also improve mechanical properties and tribological behavior of epoxy composite. Its strength, modulus, toughness, hardness and wear resistance were higher than pure epoxy.[2,3,9-13] However, fiber reinforcement was a cause of reduction in flowability of the composite. Hence, using particle was a better choice to improve mechanical and tribological properties of epoxy resin.[4] When considering types of particle added, alumina was more appropriate for improving mechanical particle than any others because of its high surface hardness.[7,9] Moreover, substitute materials made from alumina reinforced epoxy composite had advantages which were their availability, and low price. Thus, alumina was chosen to be the filler in this study.

Silane coupling agent (SCA) is a substance being able to attach organic polymer to inorganic substrate such as glass, mineral filler, metal and metallic oxide. It creates stable bond between organic and inorganic substrate which is significantly improve properties of the composite.[14] In addition, surface silanization on alumina particle provides lower surface energy and also reduced the tendency for agglomerate formation. Hence, surface modification of alumina particles is found to be effective in the improvement of flowability through the reduction of particle cohesion.[15] Selection of SCA was also important because efficiency of silanization depended on types of filler and organic polymer used.[16] 3-aminopropyl triethoxysilane (APTES) is amino functional silane. It was used in previous studies, and the result showed that mechanical properties of the composite such as tensile modulus, flexural modulus, flexural strength and fracture toughness, and wear resistance were increased.[17-19] In this study, APTES was used for silanization on alumina particle. Then, the wear resistance, surface hardness, and surface roughness of silane-treated and un-treated alumina reinforced epoxy resin were investigated and compared with the dentoform teeth. Therefore, the null hypotheses of this study were that there was no significant differences in terms of the wear resistance, surface hardness, and surface roughness among test groups.

Materials and Methods

1. Silicone mold preparation

Dentoform teeth were cut by low speed diamond saw (Isomet 40003™, Buehler, USA) and polished by polishing machine (Ecomet 3™, Buehler, USA) to achieve a rectangular prism shape, 5 ± 0.05 mm in width on both sides and 13-14 mm in length. Then, the rectangular prisms were attached on a tile at the distance of 1 cm between one another. The tile was boxed around by pink wax. Afterwards, silicone and its hardener were mixed in the vacuum mixer (Combination unit, Whip-Mix corporation, USA) for 1 min. Silicone mixture was poured in the box and left for 2 days until it solidified. Then rectangular prisms were removed out of the silicone mold. (Figure 1)

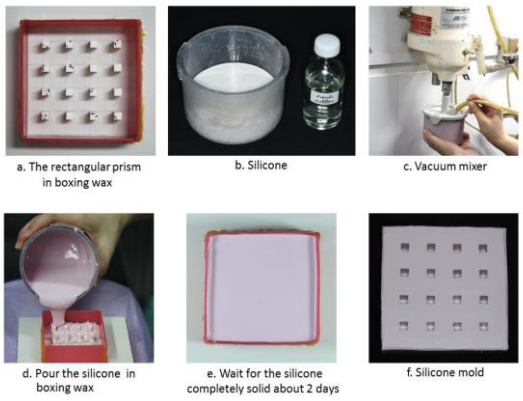

Figure1 Silicone mold fabrication

2. Substitute material preparation

2.1 Silanization of alumina powder Spherical-shaped alumina with mean particles size of 4.5 µm (IndalCalined Alumina, HTM30, Loxley, Thailand) was selected as a filler. APTES (Sigma-Aldrich®, USA) was used for silanization of the alumina particle. The amount of APTES used was calculated from Arkle's equation to create monolayer of silane coating on its filler surface.

$$\text{Amount of silane (g)} = \frac{\text{Amount of filler (g)} \times \text{Surface area } (m^2/g)}{\text{Minimum coating area of silane coupling agent } (m^2/g)}$$

Where: Surface area = 1 m^2/g

Minimum coating area of APTES = 353 m^2/g

0.3 ml (d = 0.95 g/cm^3) of APTES was added and stirred in 70 vol% ethanol 100 ml. These solutions were stored in a polyethylene cup with a cover and allowed to hydrolyze for 5 min. After that, 100 g of alumina powder was added into APTES solution. The mixture was stirred until the solvent was evaporated entirely, dried at room temperature for 14 days. Finally, silanization of the alumina powder was verified by energy dispersive spectroscopy (EDS: EMAX x-act, Horiba, Japan) and Fourier transform infrared spectroscopy (FTIR: Perkin Elmer, Spectrum One, USA).

2.2 Fabrication of alumina reinforced epoxy resin 105 specimens will be divided into seven groups (n = 15/group). The specimens of each group were prepared by its compositions (Figure 2). For the epoxy composite groups, epoxy resin was heated up to 70°C for reduce viscosity. Then, the alumina powder was gradually added into epoxy resin and stirred until it was homogeneous. After that, the mixture was left to cool (40°C). Hardener was added at an epoxy to hardener ratio of 2:1 and mixed all ingredients with vacuum mixer machine for 2 min. The mixture was poured into the silicone mold and left for 6 hr at room temperature and another 18 hr at 80°C for complete curing. Finally, the substitute materials were removed from the silicone mold and inspected (Figure 3).

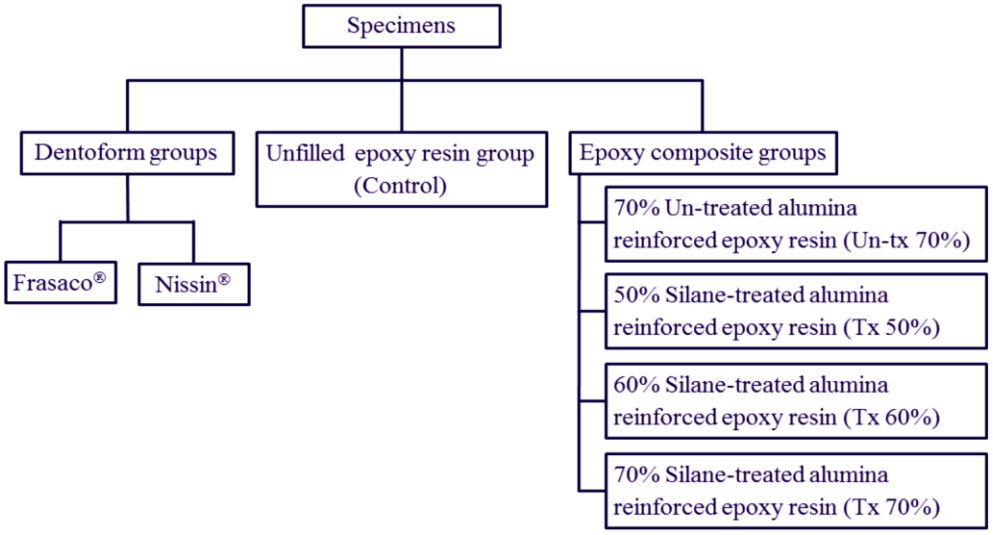

Figure 2 Specimen groups in this study

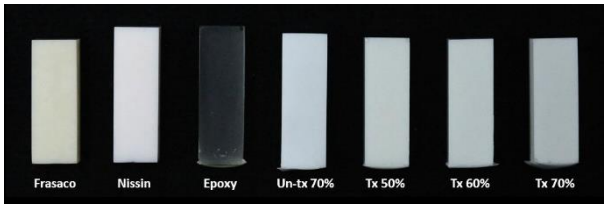

Figure 3 The specimens of dentoform groups prepared from dentoform teeth; the specimens of epoxy composite groups fabricated from the silicone mold

3. Test procedure

3.1 Wear resistance test Pin-on-disc technique (modified from ASTM G99-95a) was used by pressing the specimens against a rotating counterpart which was sandpaper 280-grit (Buehler, USA) on the polishing machine (Ecomet 3^{TM}, Buehler, USA) at room temperature (Figure 4). In each test, load of 1 kg was applied and a rotation velocity of 0.12 m/s and testing time of 2 min were employed. Wear resistance was determined by calculating the volume loss of the specimens by measuring the reduction in length of the specimens after test and calculating the volume loss.

Figure 4 Specimen holder with polishing machine that used for wear resistance test.

3.2 Surface hardness test Vickers microhardness test of all specimens was assessed by digital microhardness testing machine (FM-800, Future-Tech®, Japan). The diamond indenter was pressed into the specimens under a load of 300 gf for 15 s.[2] Each specimen was tested 3 times at the distance of 2 mm between each point (Figure 5). Then, diagonal lengths were measured and used to calculate Vickers hardness as follows:

$HV = 1854.4 \times P/d^2$

Where:

HV = Vickers hardness number (gf/μm2)

P = Force (gf)

d = Mean diagonal length of indentations (d1 and d2) (μm)

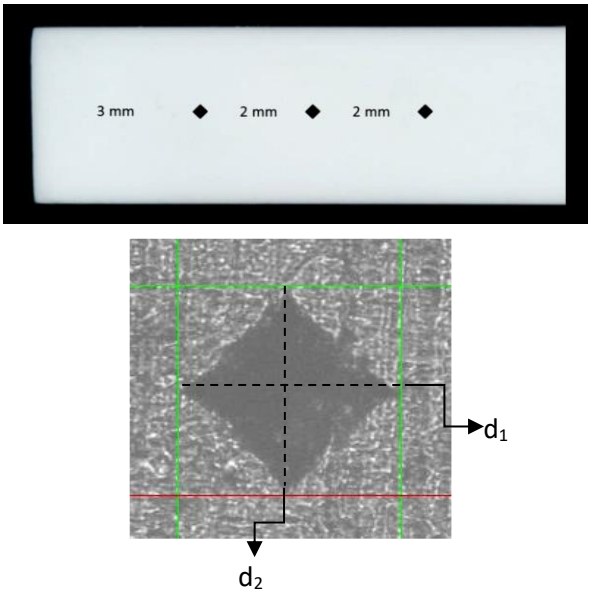

Figure 5 Vickers microhardness test; d_1 and d_2 = diagonal length of indentation.

3.3 Surface roughness test Surface roughness of all specimens was measured with contact stylus tracing profilometer (Surftest SV-3000, Mitutoyo, England). Tip of needle had to keep distance from the edge of the specimen around 1 mm. The measured distance was 3 mm, measure twice and these two times had to be 2 mm far from each other. The arithmetic average of the roughness profile (Ra), the maximum profile peak height (Rp) and the maximum profile valley depth (Rv) was recorded. Ra had been representative value for surface roughness of this study.

3.4 Scanning electron microscope (SEM) After all investigations, 5 specimens of each group were cut to 5 mm in thick by low speed diamond saw (ISOMET 40003TM, Buehler, USA) and clean with ultrasonic cleanser (Vitasonic II, Vita Zahnfabrik, Germany) for 5 min. Then, cut surface was coated with gold and examined by SEM (S-3000N, Hitashi, Japan)

4. Statistical analysis

Data of wear resistance, surface hardness and surface roughness test were statistically analyzed. For test of normality, Shapiro-Wilk test was used and the results showed normal distributions. The homogeneity of variance was test by Levene statistic and the result showed that there were no significant differences. Then, the parametric ANOVA test was used and multiple comparisons were performed by Bonferroni test ($p>0.05$).

Results

1. Energy dispersive spectroscopy (EDS) and Fourier transform infrared spectroscopy (FTIR)

Silicon was found in silane-treated group, but not in un-treated group by using EDS. Mean percentage of Al and Si composition in silane-treated alumina particles were 98.47-98.65 and 1.35-1.53 respectively. For FTIR spectral analysis was made to evaluate the chemical reaction on the surface of alumina particle due to the silane treatment. For un-treated alumina particle (Figure 6), the peaks at 3304 cm^{-1} and 1066 cm^{-1} were caused by hydroxyl groups (Al-OH) on the surface of alumina powder due to the presence of atmospheric moisture on the surface of aluminum powder. For the silane-treated alumina particle (Figure 7), the characteristic absorption peak at 1042 cm^{-1} was attributed to Si-O stretching vibration originated from the bond between the –OH bond, which was obtained from ethanol as a diluents to the Si atom on the alumina surface or the OH bond to Si atom of the silane molecule. Moreover, the small peak at 1392 cm^{-1} corresponded to the methyl symmetrical C-H bending in the silane chain. These results had been the suggestions of the existence of an organic layer on the alumina surface. Furthermore, the other peak which indicated the existence of silane group on the alumina surface was small peak at 1555 cm^{-1} , where the peak was assigned to symmetric bending vibration of $–NH_2$ indicating the existence of amine group. Therefore, this confirms the reaction of APTES on aluminum particle surface.

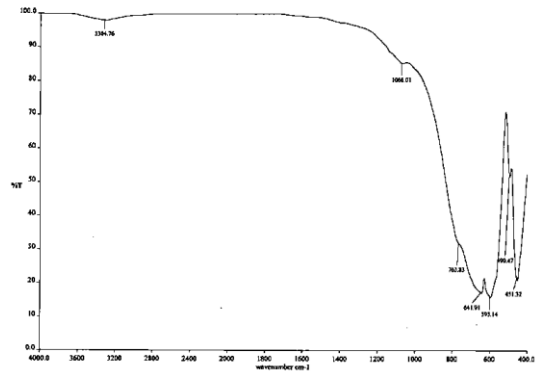

Figure 6 FTIR spectrums of un-treated alumina particle

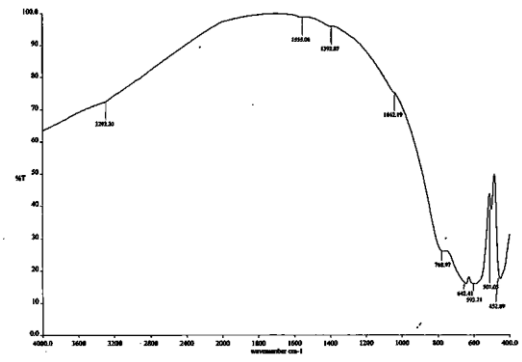

Figure 7 FTIR spectrums of silane-treated alumina particle

2. Wear resistance

Figure 8 shows mean and standard deviation of volume loss of the specimens after wear resistance test; Materials with low volume loss mean that they have high wear resistance. Unfilled epoxy resin specimens which were served as control group had been disclosed significantly largest volume loss among study groups indicating its lowest wear resistance, while Tx 70% group had the highest wear resistance. Tx 70% group was significantly higher wear resistance than that of un-tx 70% group and also significantly higher than those of dentoform groups.

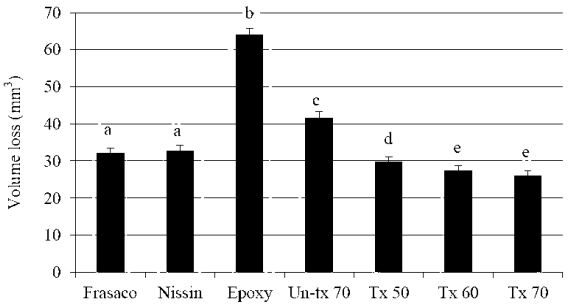

Figure 8 Mean and standard deviation of volume loss after wear resistance test (the same letters were not significantly different at $p>0.05$).

3. Surface hardness

Significantly highest surface hardness was found for Nissin group (39.245 HV), whereas unfilled epoxy resin group (14.759 HV) had the significantly lowest surface hardness. Moreover, the surface hardness values of both dentoform groups were significantly higher than the other experimental groups. However, within the epoxy composite groups, the surface hardness of tx 70% group (29.925 HV) was significantly highest. (Fig.9)

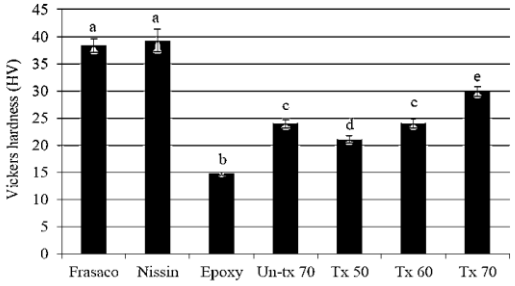

Figure 9 Mean and standard deviation of Vickers hardness (the same letters were not significantly different at p>0.05)

4. Surface roughness

In surface roughness (Ra), tx 60% group had the lowest surface roughness where as unfilled epoxy resin group had the significant highest surface roughness. However, the results had been shown that no significant different in surface roughness among the silane-treated alumina reinforced epoxy resin groups. About un-tx 70% group, it was no significant different with dentofrom groups. (Figure10)

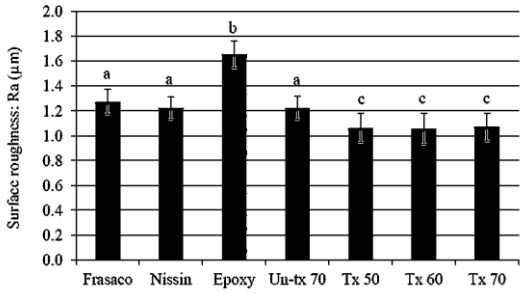

Figure 10 Mean and standard deviation of surface roughness (Ra) (the same letters were not significantly different at p>0.05)

5. Scanning electron microscopy

The material surfaces images by SEM after wear resistance testing at 1000 magnification had been observed (Figure11). Frasaco specimen had been obtained typical wear mechanisms such as matrix cracking and exforlation of matrix. For the Nissin group, it had been revealed appearance similar to that of Frasaco group but presented less matrix degradation and more exposure of air bubble. For unfilled epoxy resin group, the ploughing deformation and parallel scratching on the worn surface had been manifested. In all epoxy composite groups, the definite separation of the resin-filler interface could be detected and small craters had been seen throughout entire surface due to loss of alumina particle. However, the alumina particle of un-tx 70% group were dislodged more than tx 70% group and fracture alumina particle was found only in tx 70% group.

Discussion

The mechanical properties of epoxy composite groups had been improved by additional alumina particles with silane treatment (APTES). Consequently, wear resistance, surface hardness and surface roughness of the silane-treated alumina reinforced epoxy composite groups could be comparable to the dentoform teeth groups. Significant differences among the groups in wear resistance, surface hardness and surface roughness investigations had been shown. Therefore, the null hypotheses had been rejected.

From silanization point of view, there are various types of silane coupling agents available in the interphase region, the area between an inorganic substrate (such as glass, metal, and minerals) and an organic substrate (such as an organic polymer, coatings, and adhesives), act as a bonding or bridging agent to improve the adhesion between the two dissimilar materials. However, APTES was selected based on its functional group and application. APTES reaction had been accomplished by its silanol groups with the hydroxyl groups on the alumina surface, which thus formed covalent bonds. Moreover, APTES can chemically react via its amino groups with the epoxy groups of the epoxy resin.[20] The silanization process in this study had been followed the protocol of previous studies.[21] This wet technique was chosen because of easy manipulation and uniform coverage of filler particles. Amounts of APTES were selected based on the Arkle's equation, which were the minimum amount to create monolayer of APTES on alumina particle. The mechanical properties of composite can be improved by the silane-treated alumina when used the amount of SCA according to Arkle's equation.[21]

Pin-on-disc wear testing had been performed in this study. The advantage of this technique are easy to perform and measurement. The result had been revealed that when increasing amount of alumina particle, there was tendency for increased wear resistance. According to the prior study which was a linear relationship of filler volume on wear resistance. The wear rates were decreased with high filler volumes due to the area of resin unprotected by filler particles were decreased as well.[22]

Wear resistance of tx 70% group was 37% higher than that of un-tx 70% group. Furthermore, within epoxy composite groups, the wear resistance of tx 70% group was significantly the greatest and also significantly higher than that of the dentoform teeth groups. Therefore, silanization could improve wear resistance effectively. This corresponds to previous studies which revealed that wear resistance of silane-treated alumina reinforced epoxy resin was greater than that of un-treated alumina reinforced epoxy resin.[17,20,23]

Considering the use of dentoform tooth for laboratory practice, a clear outline of tooth preparation could be indicative of material's surface roughness. The unfilled epoxy resin group had been revealed the highest surface roughness. It is possible that unfilled epoxy resin was the softest materials in this study, resulting in the deepest wear trace. This conforms to SEM that showed deep ploughing deformation of its surface (Figure11; C). About void in materials, the specimen of un-tx 70% group exhibited dislodgement of alumina filler (Figure11; D). Moreover, all silane-treated alumina reinforced epoxy resin groups had been shown less surface roughness when compared with that of other groups. This plausibility of both alumina filler and silianization could improve surface roughness property.[2]

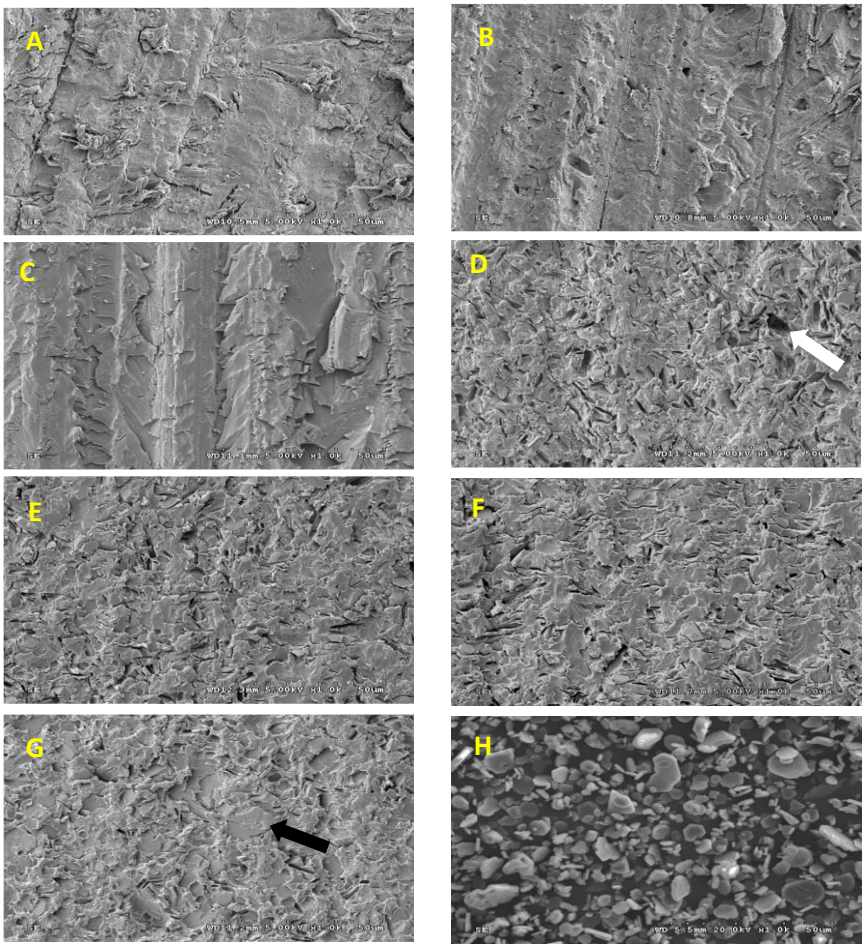

Figure 11 Surface material images of scanning electron microscope (SEM) at 1000 magnification after wear resistance test. A: Frasaco, B: Nissin, C: Unfilled epoxy resin, D: Un-tx 70%, E: Tx 50%, F: Tx 60%, G: Tx 70%, and H: Alumina particle, the white arrow indicated area of alumina dislodgement whereas the black arrow indicated alumina particle.

In aspect of surface hardness, the results in this study agreed well with the results had been shown formerly that un-tx 70 had the surface hardness lower than that of the dentoform teeth.[2] In addition, the proportion of alumina was increased, the surface hardness was comparatively increased as well which are similar to several prior studies.[3,8-10,20] Nevertheless, more than 70 wt% of alumina could not be added even if alumina was treated with SCA, because of the materials were too high viscosity and difficult to fabricate. However, the viscosity of tx 70% was lower than that of un-tx 70% resulting in easier molding. This is supported by Jallo' study, they reported that silanization provides lower surface energy values and the materials were expected to flow better.[15] Moreover, study in dental resin composite showed that surface hardness of resin composites with silane-treated fillers is significantly greater than those of composite with un treated filler.[24] However, surface hardness of dentoform teeth group still significantly higher than that of tx 70% group. It is probable that polymer matrix of those are difference. Furthermore, the SEM figure had been revealed small void in epoxy composite groups, this is possible cause of lower surface hardness.

From the result, the surface hardness of tx 70% group was found to be the highest within the epoxy composite groups. Even if it was still lower than the dentoform teeth, the wear resistance and surface roughness of tx 70% group were significantly superior than those of dentoform groups. Therefore, tx 70% should be considered as a cost-effective substitute material for development of dentoform teeth.

In the future, silane-treated alumina reinforced epoxy resin may be improved in many ways such as modification of resin matrix, temperature of curing cycle of epoxy resin, shape and size of alumina particle and production process may be developed. In further study, developed substitute material should be assessed at the application level for example, material satisfaction evaluated by dental students when the materials are used for laboratory practice.

Conclusion

Silane-treated alumina particle is significantly greater to the improvement of wear resistance, surface hardness and surface roughness of the epoxy composite than the un-treated alumina particle. Wear resistance and surface hardness of epoxy composites were increased with increasing of alumina particle. Wear resistance of tx 70% group was significant highest among all test groups. Surface hardness of dentoform groups was significant higher than those of all epoxy composite groups. Surface roughness of all silane-treated alumina reinforced epoxy resin groups was significant lower than that of dentoform groups. Tx 70% is a promising substituted material for dentoform teeth. Further study of this material at the application level should be evaluated in term of the satisfaction of user.

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การเปรียบเทียบความต้านทานการขัดสี ความแข็งผิว และความขรุขระผิวของฟันเดนโตฟอร์ม กับอีพอกซีเรซิน ที่เสริมความแข็งแรงด้วยผงอลูมินาที่ผ่านการทำไซเลน

สุคนธ์ทิพย์ อาวัชนาการ นวิยา ธนภูมิพงศ์** จินตมัย สุวรรณประทีป*** แมนสรวง อักษรนุกิจ*****

บทคัดย่อ

ฟันเดนโตฟอร์มถูกนำมาใช้อย่างแพร่หลายในการฝึกหัดในห้องปฏิบัติการของนักศึกษาทันตแพทย์ ในปัจจุบันราคาของฟันเดนโตฟอร์มสูงขึ้นอย่างต่อเนื่อง ดังนั้น วัสดุทดแทนจึงถูกพัฒนาขึ้น เพื่อเป็นการลดการนำเข้าสินค้าจากต่างประเทศและลดต้นทุนการศึกษาของนักศึกษาทันตแพทย์ การศึกษานี้มีวัตถุประสงค์เพื่อเปรียบเทียบความต้านทานการขัดสี ความแข็งผิว และความขรุขระผิวของฟันเดนโตฟอร์ม (ฟราซาโก, เยอรมัน; นิสชิน, ญี่ปุ่น) กับอีพอกซีคอมโพสิต (อีพอกซีเรซินที่เสริมความแข็งแรงด้วยผงอะลูมินาร้อยละ 70 และผงอะลูมินาที่ผ่านการทำไซเลนร้อยละ 50, 60, 70) เมื่ออีพอกซีเรซินที่ไม่มีวัสดุเสริมความแข็งแรงทำหน้าที่เป็นกลุ่มควบคุม ตัวอย่างกลุ่มละ 15ชิ้น ถูกทดสอบความต้านทานการขัดสีด้วยวิธีพินออนดิสก์ ความแข็งผิวแบบวิกเกอร์สและความขรุขระผิวโดยเครื่องวัดความขรุขระผิวชนิดคอนแทคสไตรัสโพรฟิโลมิเตอร์ ใช้สถิติการวิเคราะห์ความแปรปรวนแบบทางเดียวในการวิเคราะห์ข้อมูล กำหนดนัยสำคัญที่ระดับ 0.05 ผลการศึกษาพบว่า ค่าความต้านทานการขัดสีของกลุ่มอีพอกซีเรซินที่เสริมความแข็งแรงด้วยผงอะลูมินาที่ผ่านการทำไซเลนร้อยละ 70 และร้อยละ 60 สูงกว่าค่าของทุกกลุ่มทดลองอย่างมีนัยสำคัญทางสถิติ ค่าความแข็งผิวของกลุ่มเดนโตฟอร์มสูงกว่าค่าความแข็งผิวของกลุ่มที่เหลืออย่างมีนัยสำคัญทางสถิติ (ค่าวิกเกอร์ส์ฟราซาโก: 38.321±1.278, ค่าวิกเกอร์ส์นิสชิน 39.245±2.060) อย่างไรก็ตาม การเปรียบเทียบความแข็งผิวในกลุ่มของอีพอกซีคอมโพสิต พบว่าค่าวิกเกอร์ส์ของกลุ่มผงอะลูมินาที่ผ่านการทำไซเลนร้อยละ70 (29.924±0.921) มีค่าสูงที่สุดอย่างมีนัยสำคัญทางสถิติ ในส่วนค่าความขรุขระผิวของกลุ่มผงอะลูมินาที่ผ่านการทำไซเลนร้อยละ 60 มีค่าต่ำที่สุดแต่ไม่แตกต่างอย่างมีนัยสำคัญทางสถิติกับกลุ่มผงอะลูมินาที่ผ่านการทำไซเลนร้อยละ 50 และร้อยละ 70 แม้ว่ากลุ่มผงอะลูมินาที่ผ่านการทำไซเลนร้อยละ 70 มีค่าความแข็งผิวน้อยกว่ากลุ่มเดนโตฟอร์ม แต่ความต้านทานการขัดสีและความขรุขระผิวมีค่าที่ดีกว่ากลุ่มเดนโตฟอร์ม ดังนั้นควรพิจารณาอีพอกซีเรซินที่เสริมความแข็งแรงด้วยผงอะลูมินาร้อยละ 70 เป็นวัสดุทดแทนที่มีแนวโน้มความเป็นไปได้และคุ้มค่าสำหรับการผลิตฟันเดนโตฟอร์ม

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