Bull. Mater. Sci., Vol. 39, No. 6, October 2016, pp. 1531–1536. © Indian Academy of Sciences.
DOI 10.1007/s12034-016-1297-5

Cavity cutting efficiency of a Bioglass™ and alumina powder combination utilized in an air abrasion system

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MS received 20 August 2015; accepted 25 April 2016

Abstract. This study investigated the attempt to replace alumina in the air abrasion system with an alternative material that is effective at cutting and also has remineralization potential. The powder samples were randomized into three groups: group 1—alumina (composed of aluminium and oxygen), group 2—45S5 (composed of 45% silica, 24.5% calcium oxide, 24.5% sodium oxide and 6% phosphorus pentoxide in weight percentage) and group 3—alumina + 45S5. Thirty human enamel blocks and microscope glass slides of 0.5 mm thickness were randomly divided into these three groups. The time taken to cut a hole through the glass slide and for the cutting of human enamel blocks was recorded, the cutting time was fixed at 15 s. The depths of the cavities were measured using a periodontal probe and the enamel blocks were then analysed by scanning electron microscope (SEM). The mean time taken to cut a hole through the microscope glass slide was 2.96, 23.01 and 3.02 s for groups 1, 2 and 3, respectively. After cutting the human enamel blocks, the mean cavity depths produced were measured to be 2.5, 1.0 and 2.0 mm for groups 1, 2 and 3, respectively. The SEM micrographs revealed that the cavities formed by 45S5 were more conical in shape, whereas cavities produced by alumina and alumina + 45S5 were more cylindrical. The combined use of alumina and 45S5 has demonstrated a promising cutting efficiency and it has the potential to achieve effective cutting with the possibility of the remineralization.

Keywords. Air abrasion; alumina; bioactive glass; 45S5; remineralization.

1. Introduction

The dental air abrasion technique was introduced in 1940s by Black RB [1]. This technique lost its battle against the traditional dental drill, as it was more time consuming and it also lacked the ability to accurately prepare cavity margins for amalgam (which was the only available restorative material at that time) [2]. With the introduction of minimally invasive dentistry concepts and adhesive restorative dental materials, air abrasion has experienced a rebirth [3]. Air abrasion utilizes alumina particles to abrade the surface and works on the principle of kinetic energy [4]. This technique has several advantages, which include no vibration, less heat generation and a reduced need to give local anaesthesia [5]. Therefore, this technique is particularly useful for children and patients who have a fear of dental procedures. Alongside various advantages of air abrasion, alumina particles used in the air abrasion technique could be toxic if inhaled, and prolonged exposure of alumina particles could lead to Shaver's disease, which initially appears as alveolitis and can later get converted into pneumothorax (collapsed lung) [6]. For this reason, the replacement of alumina in the air abrasion system by any other material having good cutting properties is highly anticipated.

A material is said to be bioactive if it gives an appropriate biological response and results in the formation of a bond between the material and the tissue [7]. Bioactive glasses (BGs) are being used for both medical and dental applications. It is composed of 45% silica (SiO_2), 24.5% calcium oxide (CaO), 24.5% sodium oxide (Na_2O) and 6% phosphorus pentoxide (P_2O_5) in weight percentage, and its most common type is called Bioglass™ (45S5), which is mostly used as a bone graft [8]. BG particles are able to dissolve in physiologic environment and they activate the genes that control osteogenesis [8]. BG aids the repair of hard tissues, and various compositions are being used nowadays for the preparation of scaffolds [9], as a coating material for dental implants [10], and for cutting cavities in teeth by air abrasion [11]. BG reacts with the body fluids to form hydroxycarbonated apatite [12], which is closely related to the mineral phase of the tooth. It can, therefore, aid in the remineralization of dental hard tissues.

Numerous researchers are now interested in the potential benefits of the air abrasion technique. However, the alumina particles do not alter the tooth structure to improve its resistance against diseases nor do they aid its remineralization. Therefore, this study was carried out to attempt the replacement (partial or complete) of alumina with an alternative material that is effective in cutting and also has a remineralization potential. With alumina as a control (29 μm particle size; Velopex, London, UK), the cavity cutting efficiency of

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Bioglass™ (45S5), which has earlier demonstrated an ability to have positive effects on the remineralization process, was investigated (separately and in combination with alumina) using microscope glass slides and human enamel.

2. Materials and methods

This study was approved by the Institutional Review Board of the institute, and all the ethical protocols were strictly followed. An air abrasion machine (Aquacut Quattro, Velopex, London, UK) was utilized for performing the air abrasion experiments.

2.1 *Study groups*

The powder samples to be used in the air abrasion experiments were divided into three groups: group 1—alumina (control), group 2—45S5 and group 3—alumina + 45S5 (25 g each). Thirty noncarious extracted teeth belonging to healthy patients were collected from the Oral and Maxillofacial surgery clinic of the College of Dentistry, University of Dammam, and kept in 10% formalin at room temperature for no longer than a month before use (stored between February and March 2015). These teeth were randomly divided into the above three groups ($n = 10$ per group). In addition to the natural teeth, cutting experiments were performed initially on commercial soda-lime silicate microscope glass slides of 0.5 mm thickness ($n = 10$ per group).

2.2 *Particle size fractions*

The powder samples of alumina and 45S5 were sieved on separate days to acquire a particle size of >25 and <45 μm utilizing mesh analytical sieves (Endecotts Ltd, London, UK). The reason for selecting a powder size between 25 and 45 μm was to make the size of the powder samples closer to that of the 29 μm alumina, the most commonly used material for cutting in an air abrasion machine. Between sieving each powder, the sieves were thoroughly washed with deionized water and left overnight to dry in order to avoid the mixing of the powder samples during sieving.

2.3 *Mixing of powder samples for group 3*

Each 25 g of alumina powder and 45S5 was first weighed and then placed together in an orbital shaker at an agitation rate of 100 r.p.m. for 1 day to obtain a thorough mixing of the powder samples for group 3 (alumina + 45S5).

2.4 *Particle morphology analysis through scanning electron microscope*

Scanning electron microscope (SEM) was used to analyse the morphology of the particles. Powder samples from each group were mounted on stubs, coated with a thin layer of gold, and viewed in an SEM (FEI, Inspect F50, The Netherlands) using an electron mode of 20 kV. Micrographs were taken at 300× and 1000× magnifications.

2.5 *Human enamel block preparation*

Thirty enamel blocks of 3.0 mm (±0.2 mm) length and 3.5 mm (±0.2 mm) width were prepared. The teeth were initially cut mesiodistally after measuring the required distance from the cusp tip followed by cutting the teeth longitudinally to obtain the required width of the enamel block using a water-cooled diamond saw (Isomet® 5000 Linear Precision Saw, Buehler Ltd, IL, USA) at a blade speed of 3500 r.p.m. and feed rate of 8 mm min^{-1}. The blocks were then washed with distilled water for 2 min and were left overnight to obtain complete drying prior to air abrasion experiments.

2.6 *Parameters used for air abrasion experiments*

All air abrasion experiments were conducted using the maximum air pressure (6–7 bars), maximum feed rate (70 litre min^{-1}) and maximum speed/velocity (speed: C, available for this machine), and the powder samples were placed in the cutting powder chamber of the air abrasion machine. All the experiments were performed using a 0.6-mm diameter tip of the hand piece. The distance between the tip of the hand piece and the sample (microscope glass slides and teeth) was kept constant at 1 mm by fixing the hand piece in a burette stand. After using each powder sample, an empty tub was placed and the machine was run for 1 min to remove any residual powder. A quantity of 50 g of the powder samples from each group was placed in the tub for cutting microscope glass slides. The time taken to cut a hole through the glass slide was recorded with the help of a stop watch. The microscope glass slides were used to test the cutting efficiency of different materials because they are inexpensive, homogenous and can be easily replaced. A quantity of 50 g of the powder samples from each group was also used for cutting the glass slides. The time to cut human enamel blocks was fixed at 15 s. The depth of the resultant cavities was then measured with the help of a periodontal probe. After measuring the depth of the cavities, the enamel blocks were sent for SEM analysis (using an electron mode of 20 kV and 70× magnification) in order to observe the retention of the particles inside their respective resultant cavities.

2.7 *Statistical analysis*

The results were analysed using the Statistical Package for the Social Sciences software (SPSS version 19.0; SPSS Inc., Chicago, IL, USA). A t-test (statistical test which gives calculated average mean and standard deviation values of two groups by calculating chance deviation from the real mean and standard deviation) was used to compare the time taken to cut a hole through the microscope glass slides as well as the depth of the cavity created in the teeth after 15 s by different powder samples. The level of significance was set at $p < 0.05$.

3. Results

3.1 *Scanning electron microscope analysis*

The SEM micrographs from group 1 revealed coarse angular particles with sharp edges and an absence of smaller sized particles (figures 1 and 2). Images from group 2 presented a similar morphology to that of the alumina (figure 3); however, the presence of smaller particles were also observed (figure 4). After mixing the powder samples from group 3, SEM analysis confirmed the thorough mixing of alumina with 45S5 (figure 5). Furthermore, the distinction between the alumina and 45S5 particles was very difficult, although a fraction of smaller particles was clearly observed in this powder group, which probably entered the sample along with the 45S5 powder (figure 6).

3.2 *Air abrasion experiments*

The mean time taken by the powder samples to cut a hole through the microscope glass slides was 2.96, 23.01 and 3.02 s for groups 1 (alumina), 2 (45S5) and 3 (alumina + 45S5), respectively (table 1). No significant difference was observed between the means of groups 1 and 3 (p-value = 0.069), but significant difference was observed between means of groups 1 and 2 (p-value = 0.008). When cutting human enamel blocks, the mean cavity depths produced by the powder samples were measured to be 2.5, 1.0 and 2.0 mm

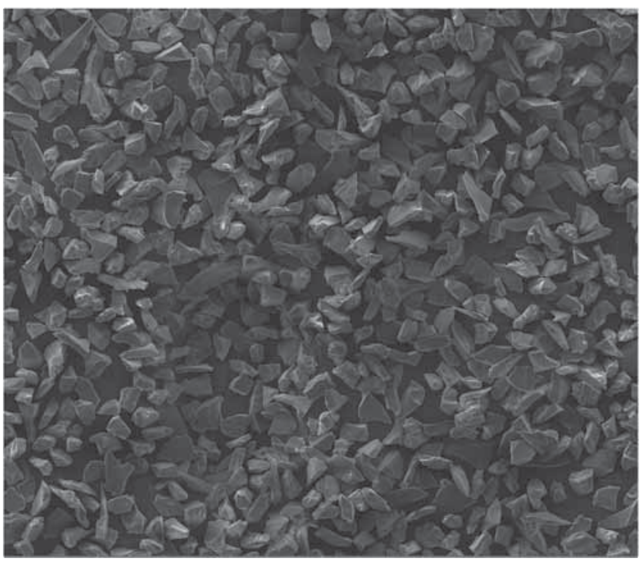

Figure 1. SEM micrograph of group 1 (alumina particles) at 300× magnification, scale bar 400 μm).

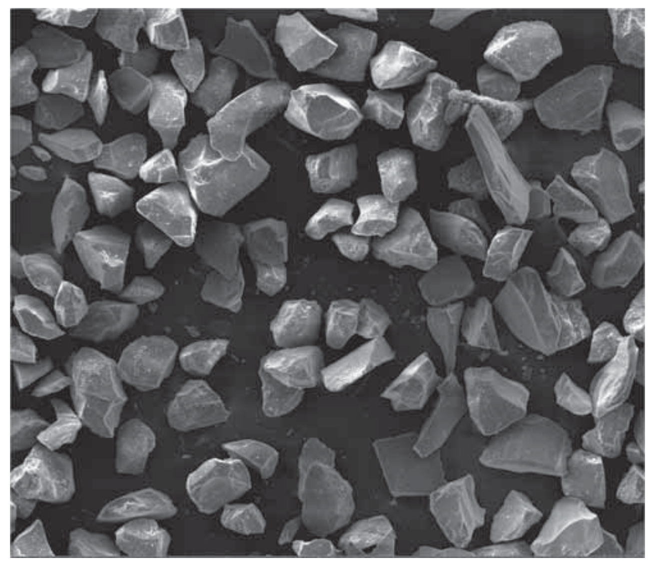

Figure 3. SEM micrograph of group 2 (45S5 particles) at 300× magnification, scale bar 400 μm).

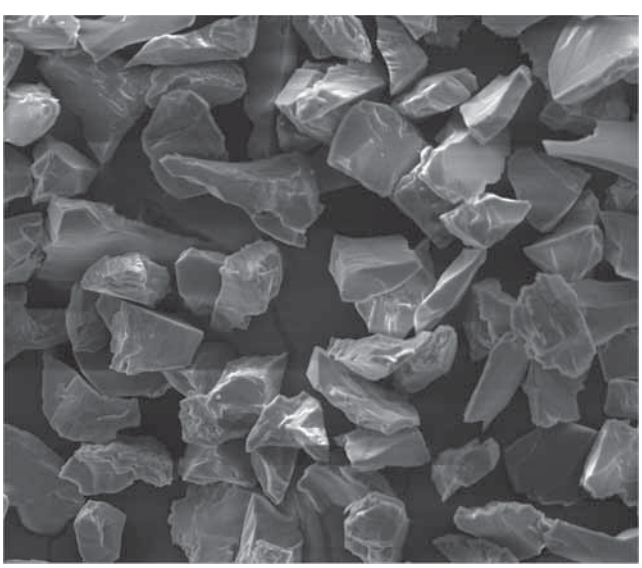

Figure 2. SEM micrograph of group 1 (alumina particles) at 1000× magnification, scale bar 100 μm).

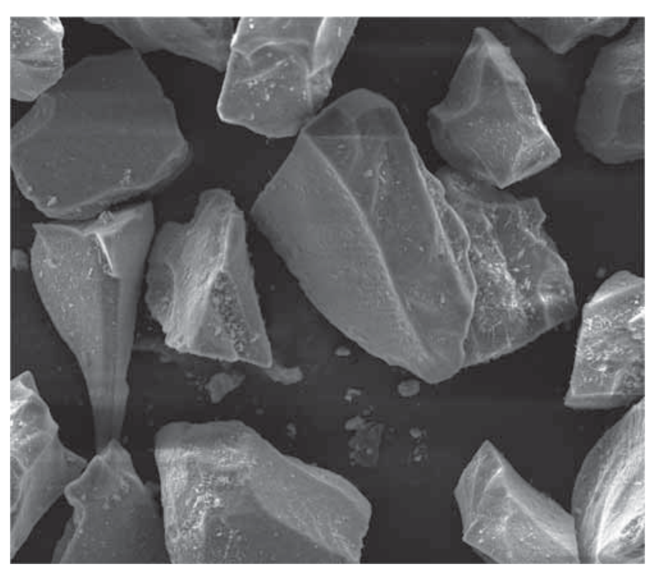

Figure 4. SEM micrograph of group 2 (45S5 particles) at 1000× magnification, scale bar 100 μm).

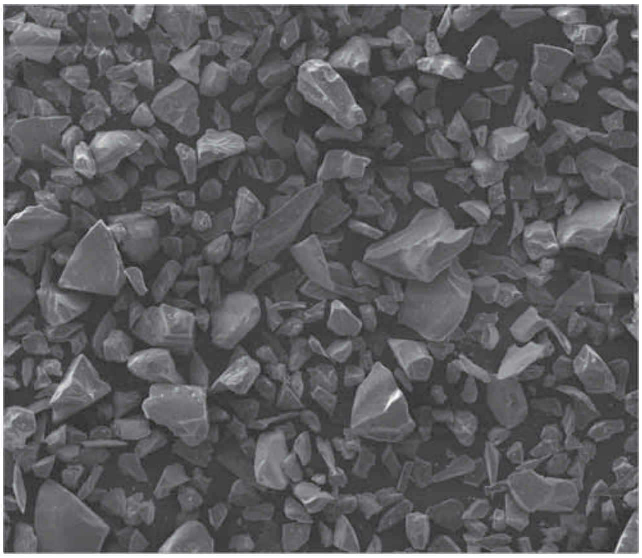

Figure 5. SEM micrograph of group 3 (alumina + 45S5 particles) at 300× magnification, scale bar 400 μm).

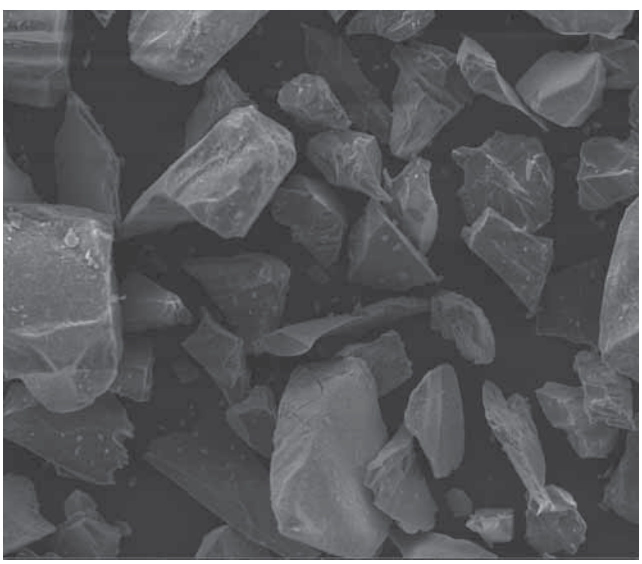

Figure 6. SEM micrograph of group 3 (alumina + 45S5 particles) at 1000× magnification, scale bar 400 μm).

for groups 1, 2 and 3, respectively (table 2). Significant differences were observed between means of groups 1, 2 and 3 (groups 1 and 2: p-value = 0.008, groups 1 and 3: p-value = 0.008). The SEM micrographs of the cavities revealed that the cavities formed by the 45S5 powder were more conical in shape (figure 7), whereas the cavities produced by the alumina and alumina + 45S5 were more cylindrical in shape (figures 8 and 9). These images also revealed that the particles from all the powder groups remained on the surface of the tooth, both inside and outside the cavities.

4. Discussion

The first BG was composed by Hench LL in 1969 [13] and was termed Bioglass™ (45S5), having a mol% composition of 46.1 SiO_2, 2.6 P_2O_5, 24.4 Na_2O and 26.9 CaO [14]. It has been previously reported by Banerjee *et al* [11], that BGs have the potential to be used in air abrasion machines as they are capable of selectively removing demineralized enamel as compared to conventional alumina [11]. After a study, Paolinelis *et al* [15] also observed that BGs were embedded in the surface of the tooth after a dental procedure like alumina and proposed that the resultant changes in the composition of the BG could prove beneficial for the tooth structure after a dental procedure. The greatest advantage that BG

Table 1. Mean time taken by powder samples to cut a hole through microscope glass slide.

Group 1 (alumina)	Group 2 (45S5)	Group 3 (alumina + 45S5)
2.96 ± 0.243	23.01 ± 0.159	3.02 ± 0.148

Values expressed as cutting time (s) are reported as mean ± standard deviation.
T-test was significant at $p < 0.05$, no significant difference was observed between the means of groups 1 and 3 (p-value = 0.069) but significant difference was observed between the means of groups 1 and 2 (p-value = 0.008).

Table 2. Mean depth of cavities produced by powder samples after 15 s.

Group 1 (alumina)	Group 2 (45S5)	Group 3 (alumina + 45S5)
2.5 ± 0.164	2.0 ± 0.207	1.0 ± 0.164

Values expressed as cutting depth (mm) are reported as mean ± standard deviation.
Significant differences were observed between means of groups 1, 2 and 3 (groups 1 and 2: p-value = 0.008, groups 1 and 3: p-value = 0.008).

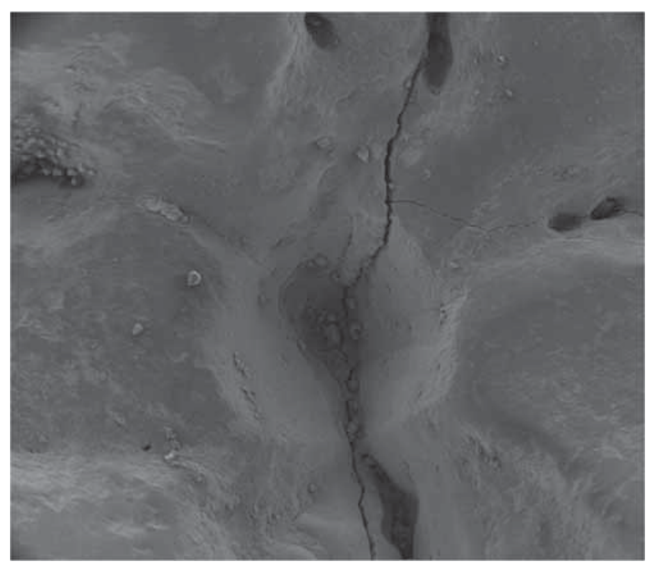

Figure 7. SEM micrograph showing cavity cut with 45S5 at 70× magnification, scale bar 1 mm.

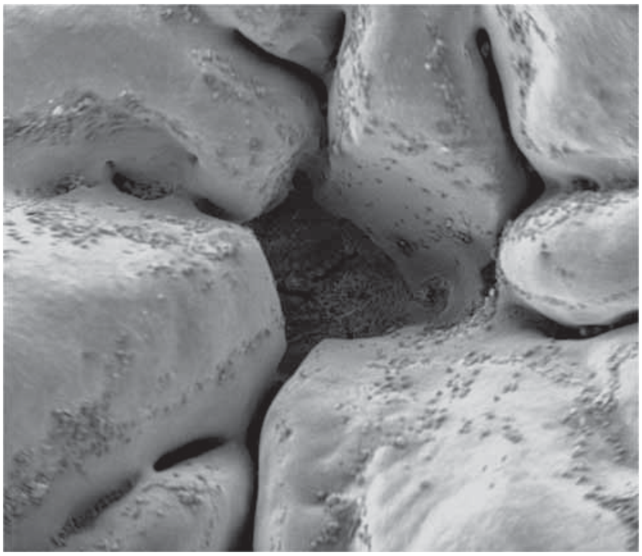

Figure 8. SEM micrograph showing cavity cut with alumina at 70× magnification, scale bar 1 mm.

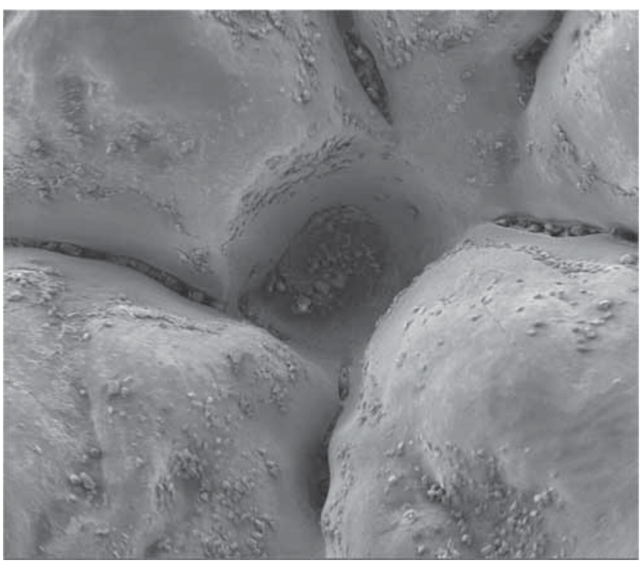

Figure 9. SEM micrograph showing cavity cut with alumina + 45S5 at 70× magnification, scale bar 1 mm.

offers is the formation of apatite when it is present in an aqueous solution like saliva [16]. This implies that the utilization of BG is favourable in caries prevention and the management of dentin hypersensitivity [17].

A dental air abrasion machine utilizes abrasive particles (such as alumina) aimed at the removal of decayed tooth tissue and works on the principal of kinetic energy. The formula for kinetic energy is $1/2\ mv^2$, where m is the mass and v the velocity, indicating that greater mass and velocity will result in increased kinetic energy and vice versa [18]. In the current study, cutting experiments with different powder groups were initially performed on commercial soda-lime silicate microscope glass slides and then on human enamel blocks. The hardness value of enamel is estimated to be 4 GPa [19], while for glass slides, it has been reported to be 6.1 GPa [20]. This similarity in the hardness value was the reason why the present study initially conducted cutting experiments on glass slides, followed by human enamel blocks.

In our previous study, an attempt was made to completely replace alumina in air abrasion systems with newly synthesized fluoride containing BG of varying sodium oxide (Na_2O) content (0–10 mol%) [20]. The results of that study demonstrated longer cutting times for BG batches while cutting microscope glass slides. However, the recorded times for cutting human enamel were comparable for a BG batch (having 2.5 mol% Na_2O) and alumina.

Cutting efficiency could be defined as the ability of the abrasive particles in terms of time to cut a cavity (in cases of tooth sample) or the time taken by particles to cut a hole (in cases of microscope glass slides), where less time indicates better cutting efficiency and vice versa. It can be observed from the results of the present study that 45S5 took the longest time (23 s) to cut a hole through the microscope glass slides as compared to alumina and the combination of alumina + 45S5. In the study by Farooq *et al* [18], it was also reported that the cutting time of glass slides were directly proportional to the mol% of Na_2O in the glass batch; thus, for glasses with high sodium content, longer cutting times were reported and vice versa [20]. The commercially available 45S5 used in the present study contains 24.4 mol% Na_2O, thus making the silicate network less compact as compared to the glasses with low Na_2O content, which have a stronger and condensed silicate network, resulting in longer cutting times.

Hardness is an important parameter that should be taken into account when cutting efficiency is being evaluated. In the literature, the hardness value of 45S5 has been reported to be 4.5–5.75 GPa [21,22], whereas the hardness value of alumina is reported to be 16–18 GPa [23]. It can therefore be suggested that the harder particles (alumina) were able to cut glass slides quicker and human enamel deeper, as compared to the softer particles (45S5).

Particle size (mass) also influences the cutting effectiveness; larger abrasive particles possess a greater cutting capability than smaller particles. Therefore, in the present study, in order to maximize standardization, all the powders were sieved to a particle size fraction of 25–45 μm. With regard to the shape of the particles, alumina particles were coarse angular with sharp edges, and there was an absence of smaller particles present in the sample, whereas in the BG powder, smaller particles were present along with the large, coarser particles. When smaller particles are present in a powder sample, they have the ability to stick to larger ones and consequently reduce the flow of the abrasive particles. In addition to the differences in the hardness values, this may also explain the inferior cutting performance of 45S5 in comparison with alumina.

In air abrasion machines, 45S5 is currently being used for polishing teeth [24]. To the best of the authors' knowledge, this is the first study to utilize a combination of alumina and 45S5 for cutting purposes. The mean depth of the cavities in enamel blocks and cutting times for glass slides of the combination of 45S5 + alumina were very close to those of the commercially available alumina. This novel finding could pave the way for the partial replacement of alumina in the air abrasion system. The advantage of using a combination of alumina and 45S5 in air abrasion is that the alumina gives hardness to the material, whereas 45S5 can help in the remineralization of tooth structure through the formation of apatite.

These advantages cannot be achieved using alumina alone because although it achieves effective cutting, it does not possess remineralization capabilities. It is therefore recommended that further studies utilizing other parameters of the air abrasion machine (feed rate, air pressure, distance, diameter of the nozzle) should be conducted to observe the cutting efficiency of this powder combination under other settings.

5. Conclusion

The combined use of alumina and 45S5 has revealed promising cutting efficiency, almost similar to that of the commercially available alumina. Their combined use in an air abrasion system is potentially encouraging for better cutting purposes and the remineralization of the tooth structure.

Acknowledgements

We acknowledge the funding from the Deanship of Scientific Research (DSR) of the University of Dammam (Grant no. 2014212). We are also grateful to Bader Al-Saqr for providing assistance with the SEM analysis and would also like to thank Soban Qadir Khan and Faraz Ahmed Farooqi for providing the statistical support.

Conflict of interest

The authors do not have any financial interest in the companies whose materials are included in this study.

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