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DESIGN OF A FLUID ABRASION SYSTEM PROTOTYPE FOR DENTAL TREATMENT

Vitor Ferreira Romano
Federal University of Rio de Janeiro, Mechanical Engineering Department
romano@mecanica.ufrj.br

Izio Mazur
Superdont Indústria e Comércio Ltda.
sac@superdont.com.br

Cesar Gomes Ferreira
Digital Dinâmica Automação Ltda.
cesarlog@gmail.com

Abstract. *This paper presents the development of a fluid abrasion system designed to provide a minimal invasive technique for tooth structure intervention in dental field, mainly restorative treatment (caries and old restoration removal) and preparation for prosthodontics (cavity preparation for cementation and roughening surface). Instead of metal rotary cutting instruments, the dentist holds a hand piece with a disposable nozzle to maneuver and direct the abrasion jet to the desired work location. The cutting media consists of micron aluminum-oxide particles under controlled air pressure and a water curtain around the abrasive medium to avoid powder ambient diffusion. The main design constrains were ANVISA mandatory safety and health standards, parts design, components, material and manufacturing technology, and available resources at dentist work place. Experiments were made in a prototype at a laboratory test facility to obtain the desired performance for different operational conditions of fluid abrasion jet, such as aluminum-oxide quantity, pressure level, water and air flow, and instantaneous jet interruption.*

Keywords: *Tooth intervention, dental treatment, abrasion device, product design*

1. INTRODUCTION

1.1 General aspects

Operative tooth intervention procedures such as caries removal and removal of small existing restorations need the preparation of tooth structure for cutting or etching for the placement of composites, porcelain and ceramics.

The most popular tooth intervention technique is based on air turbine handpiece with rotary drills. The mechanical contact between the drill and tooth structure generates heat, vibration and bone-conducted noise due to friction, resulting in pain and discomfort for the patient. Anesthesia is a recurrent solution to minimize these effects.

Air abrasion is a minimal invasive technique for tooth structure intervention with a mature technology used in numerous dentist apparatus commercially available since the 90's (Banerjee, *et al*., 2000) . This technique removes tooth structure using a stream of aluminum oxide particles generated from compressed air or bottled carbon dioxide or nitrogen gas. The abrasive particles strike the tooth with high velocity and remove small amounts of tooth structure. Efficiency of removal is relative to the hardness of the tissue or material being removed and the operating parameters of the air abrasion device.

Alumina air abrasion is a non-traumatic treatment with a minimum heat generation. No anesthesia is necessary (in several cases). Air abrasion also has the advantage of decreased noise and vibration as compared to conventional rotary instruments. Studies have shown that the bonding of enamel and dentin surfaces prepared with air abrasion is much better than that with conventional carbide burs or acid etching (Paolinelis, *et al*., 2009).

A number of parameters such as the amount of air pressure, particle size, quantity of particles passing through the nozzle, handpiece nozzle diameter, angulation of the handpiece, distance from surface, and time of exposure to the object vary the quantity of tooth removal and depth of penetration (Hedge and Khatavkar, 2010).

A very critical operational aspect is related to nozzle wear. This component is continuously exposed to the erosive action of the abrasion jet and needs to be replaced frequently.

Some disadvantages of air-abrasion system are the lack of tactile sensation when using the air abrasion handpiece, because the nozzle of air abrasion instrument does not come in contact with the tooth, and damage to dental mirrors, optical devices like magnifying loupes, intraoral camera lenses or photographic equipment (Rao, *et al*., 2011).

The fluid abrasion technology is also used in industrial application such as abrasive jet micromachining (AJM), considered as one of the most appropriate micromachining technologies for hard and brittle materials, such as ceramics and semiconductors (Achtsnick, *et al*., 2005). Owing to its various distinct advantages, such as negligible heat affected zone, small cutting forces, high machining versatility and high flexibility, AJM has been used in fabricating electronic devices and micro-fluidic channels in recent years, where damage-free micro-part features are required (Fan, *et al.*, 2011) .

1.2. Abrasive proprieties

Aluminum oxide (alumina) is the main component of bauxite, the principal ore of aluminum. It is widely used as an abrasive due to its hardness, strength and low cost production. Alumina is insoluble to water.

The most common particle sizes are either 27 or 50 µm in diameter. The larger particles allow the clinician to work faster but will result in comparatively larger-sized cavity preparations than those with the 27 µm particles. Higher particle flow rate will allow more particles to abrade the working surface faster. The particle size used in the experimental facilities is 30 µm in diameter.

Continuous exposure to alumina powder may be considered a hazard to patients with known respiratory diseases, including asthma. Proper evacuation with a high volume suction device to remove dry particles or the adoption of an air abrasion system with water spray curtain will help to minimize inhalation of particles by the patient. Anyway, the particles inhaled are more than 10 µm in size and cannot enter the alveoli; they are readily swept away by normal cilialy action (Rao, *et al*., 2011).

1.3. Historical background

The study of the use of air abrasion technology for dental applications was initiated by Dr Robert Black in the 1940's and successfully introduced in 1951 with the Airdent air abrasion unit, developed by S.S. White Company as an alternative to the slow-speed, belt-driven handpieces used at that time (Hedge and Khatavkar, 2010). The technology enjoyed a brief period of popularity but did not become a pattern due to the following major factors. Firstly, air abrasion was not able to prepare cavities with well-defined walls and margins, and the materials during that time (mostly amalgam and direct or indirect gold) demanded such preparations. Secondly, the introduction of the air turbine handpiece in the late 1950s made conventional cavity preparations less time consuming. Thirdly, solutions to minimize the effect of powder generated in the process had not been developed, such as water curtain and high-velocity suction systems.

Air-abrasive technology has experienced a rebirth in the 90’s in synergy with rapid evolution of adhesive dentistry, which has changed tooth preparation requirements and eliminated the need for mechanical retention (Rao, *et al*., 2011).

Since its recent re-emergence, air-abrasive technology again offers an alternative to conventional air turbine handpieces.

Acquacut Quattro (Velopex, 2010), Air-Flow Prep K1 Max (EMS, 2008), PrepStart H2O Hydro (Danville, 2005). are some of the available air abrasion systems in market.

Superdont developed in 2003 the product Allumina Jet, selling nearly a hundred units in Brazil. Superdont decided to stop production due to problems with suppliers and the absence of an oxide-aluminum powder evacuation device. In 2012 the company received a financing support from FAPERJ to develop a new product to overcame the technological gaps and increase its operational functionalities.

Figure 1. PrepStart H2O Hydro air abrasion system (Danville, 2005)

2. EXPERIMENTAL PROTOTYPE

2.1. Design requirements

The design team developed a prototype to provide operational functionalities and characteristics such as:

- maintain a stable, consistent and precise air abrasive jet.
- water curtain to be included in the air abrasion jet.
- only pneumatic components commercially available in Brazil.
- equipment actuation by pedal.
- by-pass function (extra air supply for air abrasive mixture).
- no air abrasive reflux to the compressor.
- set up controls located at the console.
- air abrasion fast interruption device to be included.
- use of disposable nozzles.
- test unit to perform air abrasive jet and nozzle materials experiments.

2.2. Prototype and test facility

The prototype components disposition in a test facility is presented in Fig. 2. This arrangement was extensively tested to fulfill the design requirements. Its pneumatic circuit can be subdivided in 6 parts:

A - air inlet.
B - air-abrasive mixture inlet.
C - abrasive reservoir.
D - by-pass.
E - fast interruption device - FID.
F - water spray.

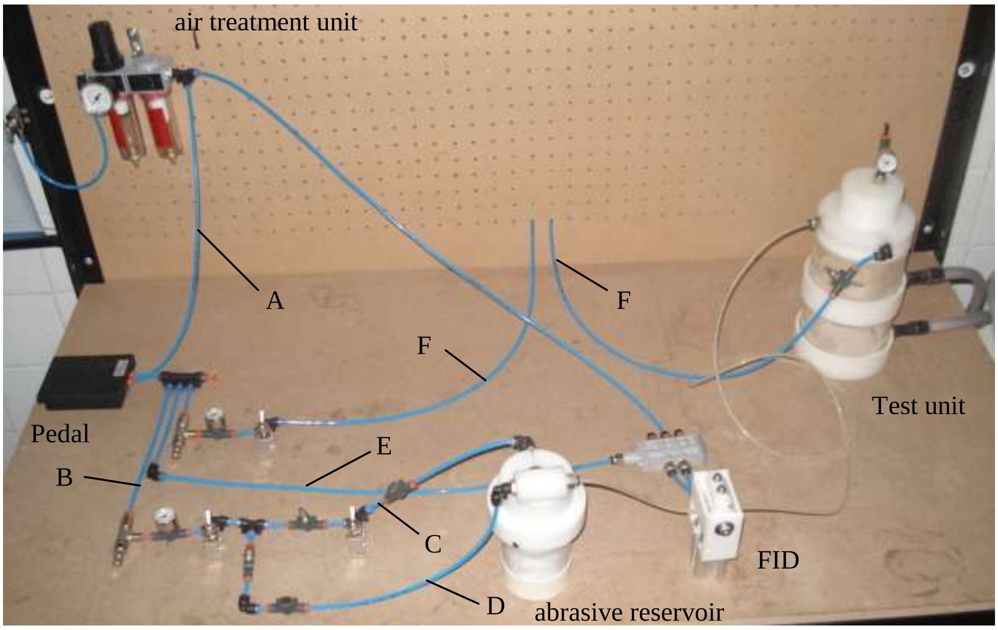


Figure 2. Prototype main components and test facility

The equipment is connected to a compressor which pressured air is regulated to specific pressure and flow. The air abrasion system has an air treatment unit to filter particles in suspension and eliminate air humidity. A control panel consisting on a pressure regulator, flux regulators and manometers, provides pressure and flow set up and fine adjustment to pneumatic circuits. A pedal is used to control the passage or blockage of pressured air from compressor.

The air and aluminum oxide particles mixture is formed in the air-abrasive pneumatic circuit, when pressurized air enters the abrasive reservoir and a turbulent flow is created inside a camera mixer. The resultant air-abrasive flow needs to receive an additional air flow, so that the dentist will to be able to control the right amount of abrasive he or she intends to use for a specific operational requirement.

Finally the air-abrasive mixture flows through the air-abrasive duct where is located the handpiece (not shown in Fig. 2). The handpiece contains a nozzle where effectively is generated the abrasive jet.

Water spray is obtained whenever a pressured air is injected at the water reservoir and the resultant air-water flux flows through the air-water duct to find the sprinkler connected to the air-abrasive duct at the handpiece. The air-water is induced to form a water curtain around the air-abrasive jet due to its high velocity and pressure variation at the nozzle.

The handpiece has two main parts: a grip where air-abrasive and air-water ducts converge and a head with its nozzle and water sprinkler.

3. EXPERIMENTAL ANALYSIS

The experiments performed at the test facility presented in Fig. 2 are mainly concerned to nozzle material feasibility analysis and the operational performance of the air abrasive jet.

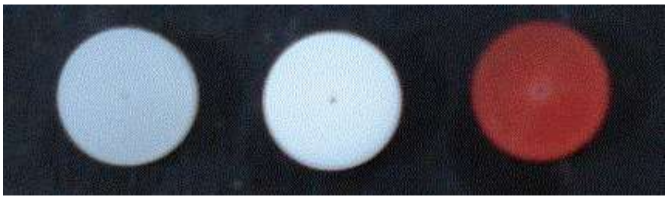
3.1. Study of nozzle materials

The dentist has to sterilize the handpiece and install a new nozzle each time a different patient is submitted to a tooth intervention with the fluid abrasion system equipment. Therefore, the use of disposable nozzles is one of the design team goals. A disposable nozzle should work properly for a 30 minutes period, estimated as an average time for tooth intervention.

A very critical operational aspect is related to nozzle wear. This component is continuously exposed to the erosive action of the abrasion jet and needs to be frequently replaced, so, disposable nozzles should be made of polymer material to reduce costs.

Some tested samples were manufactured by milling process and some others by thermoset-molding process.

In this article the samples will be denominated by Polymer 1 to 5, to preserve industrial proprietary information. In Fig. 3 are presented some of the polymer samples tested.



(a) (b) (c)

Figure 3. Polymer nozzles. (a) Polymer 1, (b) Polymer 2, (c) Polymer 3

3.1.1. Experimental conditions

Tests were performed for the following operational conditions indicated in Tab. 1.

Table 1. Test operational conditions

Parameter	**Operational condition**
Pressure	4 bar
Test duration	30 minutes
Abrasive flow	Medium to high
Nozzle initial inlet diameter, d_{in}	0.5 mm
Nozzle initial outlet diameter, d_{out}	0.5 mm
Number of samples/material	4 samples

The test unit (Fig. 2) consists on an acrylic pressured vessel designed to avoid aluminum powder contamination in the environment. Each nozzle sample was installed at the nozzle support of the test unit and submitted to operational conditions.

A tungsten nozzle sample was used at the test unit in order to define a pattern for the performance of different nozzle materials and also to validate the air abrasion system operational parameters. All tested nozzles had the same initial geometrical dimensions.

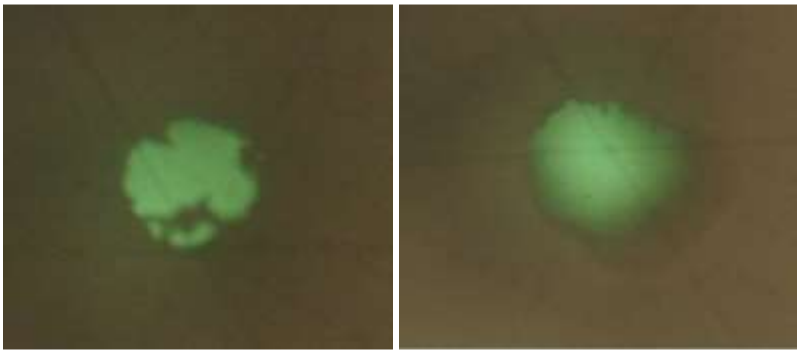
3.1.2. Experimental results

The most important sample measured parameters are related to nozzle inlet and outlet diameters. Table 2 presents the results for each polymer, where Δdin is the inlet and Δdout is the outlet diameter percentage variation. An optical microscope with ±0.001 mm accuracy was used to obtain the measurements.

Table 2. Test results on nozzle inlet and outlet diameters for different polymers

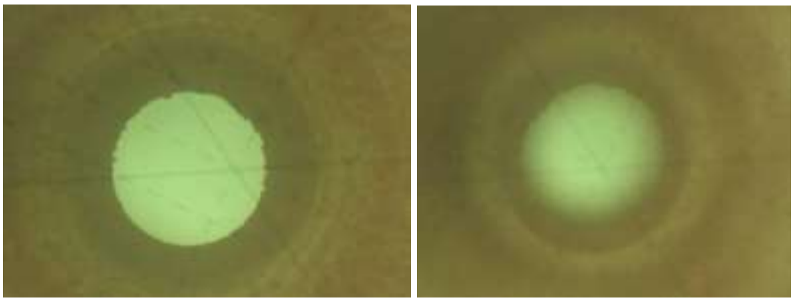
Test	Material	**Δdin [%]**	**Δdout [%]**	Results
a	Polymer 1 (milling)	30.12	76.65	Not approved
b	Polymer 2 (thermoset)	66.75	117.2	Not approved
c	Polymer 2 (milling)	92.68	53.56	Not approved
d	Polymer 3 (milling)	-1.75	174.63	Not approved
e	Polymer 4 (thermoset)	30	69	Not approved
f	Polymer 5 Sh60 (thermoset)	3.25	2.87	Approved. Best performance.
g	Polymer 5 Sh100 (thermoset)	2.5	19.25	Approved

Figures 4 and 5 are related to observed behavior of polymer 2 and polymer 5 Sh60 samples, respectively. All samples presented a conical shape.



(a) (b)

Figure 4. Polymer 2. (a) inlet nozzle diameter, (b) exit nozzle diameter



(a) (b)

Figure 5. Polymer 5 Sh60. (a) inlet nozzle diameter, (b) exit nozzle diameter

3.2. Prototype performance analisys

The defined experiments to investigate the air-abrasive jet operational performance and prototype components behavior are listed in Tab. 3.

Table 3. Air-abrasive jet and prototype components evaluated items

Experiment	Evaluated item
a	Air-abrasive mixture without water spray
b	Air-abrasive mixture with water spray
c	Pedal flux control of air, abrasive and water spray.
d	Pedal flux interruption of air, abrasive and water spray.

A handpiece designed to support disposable nozzles substituted the test unit in the original test facility and a tungsten nozzle was used in all tests to preserve the same outlet jet characteristics.

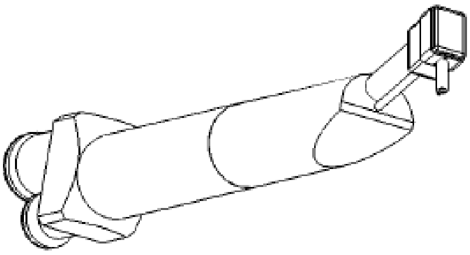


Figure 6. Handpiece for disposable nozzle

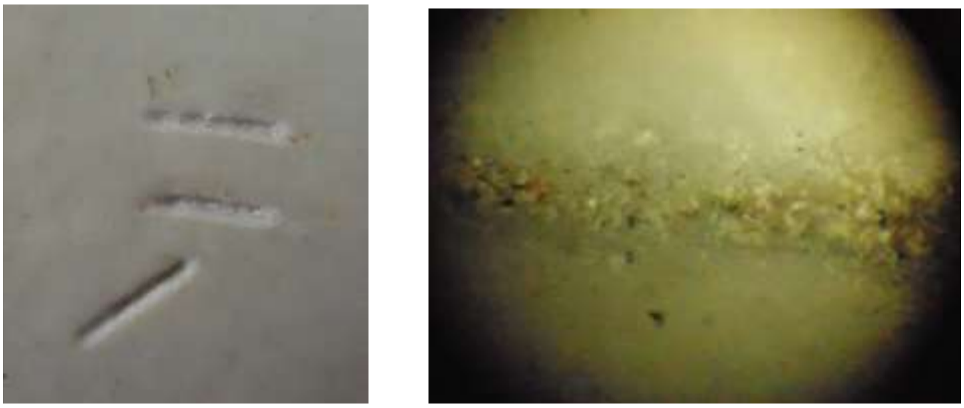
The experiments a and b were made on the surface of a ceramic material with similar hardness to human tooth and an optical microscope with ±0.001 mm accuracy was used to quantify the measurements on tested materials. Both experiments were performed in upward and downward directions.

The first test was associated to the capability of creating punctual erosion, obtained by on/off command. Figure 7 shows a punctual abrasion test giving a diameter measurement of 0.55 mm.

The second test was related to continuous paths, so that the operator ability to maneuver the handpiece could be observed. Figure 8 presents some test results, where the obtained path repeatability is around 0.6 mm.

(a) (b)

Figure 7. Punctual abrasion test. (a) Normal view. (b) Augmented view at microscope



(a) (b)

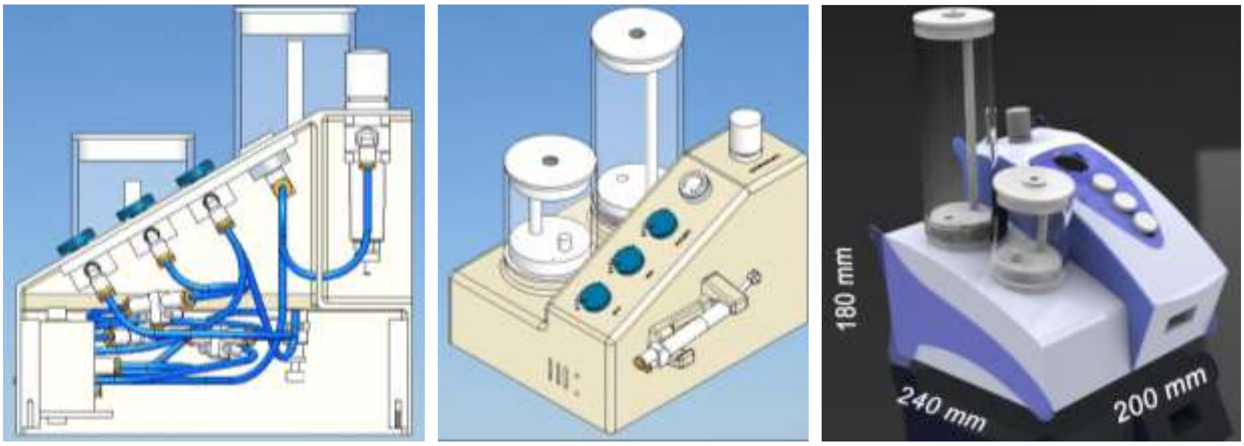
Figure 8. Continuous abrasion tests. (a) Normal view. (b) Augmented view at microscope

The pedal flux performance was evaluated by experiments c and d, were a simple observation of the equipment behavior was enough to verify its acceptable functionality.

4. PROTOTYPE CONCEPTUAL DESIGN

A 3D CAD model of the abrasion system equipment (Fig. 9a and 9b) was conceived to serve as a basic reference for the final product design developer. Based on this study a molded mock-up was made in plastic material (Fig. 9c). Some of the considered aspects were:

- volume optimization to include all components previously tested.
- manufacturing and assembling of structural parts.
- visual harmonization.
- ergonomic design to easy the control of operational parameters.



(a) (b) (c)

Figure 9. Conceptual design. (a) internal assembling. (b) external lay-out. (c) main unit mock-up

5. CONCLUSIONS

Although the equipment operation is very dependent of human operator ability to maneuver the handpiece, control its distance from tooth and define parameters set up, the measured data obtained for punctual and continuous abrasion tests were considered acceptable.

The fluid abrasion system prototype can be easily adjusted for air pressure level, powder quantities passing through the nozzle, water curtain and air flow. Besides, the dentist can instantaneously control jet interruption according to its necessity.

The equipment fulfills ANVISA mandatory safety and health standards. Its availability to market depends on final product construction and performance tests.

6. ACKNOWLEDGEMENTS

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