Revista Brasileira de Engenharia Biomédica,
v. 24, n. 1, p. 17-22, abril 2008

ISSN 1517-3151
http://dx.doi.org/10.4322/rbeb.2012.045

Artigo Original
Recebido em 25/01/2006, aceito em 03/04/2007

Abrasive wear of conventional glass ionomer cements

Desgaste abrasivo de cimentos de ionômero de vidro convencionais

Marx Bernardi Cintra
Eduardo Carlos Bianchi*
Departamento de Engenharia Mecânica / UNESP Bauru
Av. Eng. Luiz Edmundo Carrijo Coube, s/nº
Caixa Postal 473
17033-360 Bauru, SP
E-mail: bianchi@feb.unesp.br

Márcia Furtado Antunes de Freitas
César Antunes de Freitas
Departamento de Materiais Dentários / USP Bauru

Paulo Roberto de Aguiar
Departamento de Engenharia Elétrica / UNESP Bauru

Michele Paoline de Marins Ulhoa
Departamento de Engenharia Mecânica / UNESP Bauru

*Corresponding author

Abstract
An evaluation was made of the abrasive strength of three different brands of conventional glass ionomer cement (GIC) for dental restoration available on the Brazilian market. The evaluation was based on an aggressiveness assay in which, under pre established conditions, a disk coated with porcelain wears down a static disk coated with the restorative material under study. According to this method, low aggressiveness values indicate high abrasive wear resistance. Eight test specimens were prepared for each brand, making a total of 24 specimens. The GIC brands evaluated here were Vidrion R (manufactured by the Brazilian enterprise SSWhite), Ketac Fil Plus (manufactured by the American enterprise 3M ESPE) and Fuji IX GP (manufactured by the Japanese enterprise GC), lately replaced by Vitro Fill (manufactured by the Brazilian enterprise DFL Indústria e Comércio Ltda.). The materials were prepared following the instructions of their respective producer. The assays were carried out in two stages: in the first, the exposure time of the materials was not controlled, and the data analysis revealed the strong influence of this exposure on the property of abrasive wear resistance of those materials. In the second stage, the exposure time, air humidity and ambient temperature were strictly controlled from the preparation of the test specimens up to the conclusion of the assays. Thus, in addition to classifying each GIC brand according to its abrasive wear resistance, it was also shown that their exposure time to ambient air should receive special attention in studies of the mechanical properties of glass ionomer cements.

Keywords: Abrasive wear, Glass ionomer cement, Dental restorations, Dental materials.

Resumo
Este trabalho tem por finalidade avaliar a resistência abrasiva de 3 diferentes marcas de cimento de ionômero de vidro (CIV) restauradores, do tipo convencional, disponíveis no mercado nacional. Para isso foi utilizado o teste de agressividade, onde um disco dinâmico revestido com porcelana desgasta, em condições adequadamente estabelecidas, um disco estático revestido com o material restaurador estudado. Neste método valores menores de agressividade indicam maior resistência ao desgaste abrasivo. Foram confeccionados 24 corpos de provas, sendo 8 para cada marca. As marcas de CIV avaliadas foram: Vidrion R (fabricado pela empresa brasileira SSWhite), Ketac Fil Plus (fabricado pela empresa americana 3M ESPE) e Fuji IX GP (fabricado pela empresa japonesa GC), que posteriormente foi substituído pela marca Vitro Fill (fabricado pela empresa brasileira DFL Indústria e Comércio Ltda.). Os materiais foram confeccionados de acordo com as instruções dos respectivos fabricantes. Os testes foram executados em duas etapas: na primeira não houve controle do tempo de exposição ao ambiente, e as análises dos dados revelaram grande influência desta exposição na propriedade de resistência ao desgaste abrasivo. Em uma segunda etapa, o tempo de exposição foi rigidamente controlado, assim como a umidade do ar e a temperatura ambiente, desde a confecção dos corpos de prova até a finalização dos ensaios, obtendo-se assim os resultados desejados. Deste modo, além da classificação de cada marca de acordo com a resistência ao desgaste abrasivo, também foi mostrado que o tempo de exposição deste material ao ar ambiente deve receber atenção especial em trabalhos que versem sobre propriedades mecânicas do cimento de ionômero de vidro.
Palavras-chave: *Cimento ionômero de vidro, Resistência à abrasão, Restauração dentária, Materiais dentários.*

Introduction

Glass ionomer cement (GIC) offers an excellent alternative for dental restorations because it releases fluoride ions, giving this material an anticariogenic property, and also because of its esthetic appearance, for its color resembles that of teeth, and its excellent adherence to teeth (Kent *et al*., 1973; Wilson and Kent, 1972).

The main reason, among others, for replacing GIC restorations is its abrasive wear, which can be caused by brushing and mastication. This phenomenon must be studied in order to foresee the replacement of the restorative material in time due to its wear, especially in the case of posterior teeth restorations, which are subjected to constant friction during mastication. Knowledge of the characteristics of the material is crucial, particularly insofar as its wear resistance is concerned.

According to Pugh (1973), wear can be defined as the ultimate consequence of the interaction between surfaces, which is manifested by the gradual removal of material. The various determining factors of abrasive wear include, generically, the characteristics of the GIC itself and the cavitary preparation, as well as the restoration and the aggressive conditions to which it is subjected. The complex set of individual factors involved and which interact here (some of them of a strictly mechanical, chemical or biological nature, or a combination of these) include: the size, quality and homogeneity of the particles, the respective types of organic matrixes, the filler/matrix proportion and the quality of their consolidation, the dimensions of the restoration itself, its quality of consolidation (and/or adhesion) to the dental tissues, and its surface characteristics and overall strength.

The difficulty of *in vitro* assays lies in simulating oral moisture. This factor is extremely relevant in the case of GIC, which readily loses water to the environment, resulting in a loss of its wear resistance.

Among the methods that have been proposed to evaluate the abrasive wear of GIC, analysis of aggressiveness (the capacity of a material to wear down another) has proved to be a rapid, practical and reliable method.

Materials and Methods

The method consists of an aggressiveness analysis proposed by Coelho (1991) and later adapted by Bianchi *et al*. (1996) for use in the analysis of wear resistance of dental materials.

In this method, a static disk (a circular plate) containing the material to be analyzed (in this case GIC) is pressed against a rotating disk, called a dynamic disk, whose material is porcelain. The static disk does not rotate, but moves only vertically. The GIC is placed on the outside circumference of the static disk and this disk is then ground with a conventional aluminum oxide grinding wheel until its diameter is reduced to 24 mm and its entire surface is even. The dynamic disk is similarly ground, but with a diamond grinding wheel.

The porcelain disks (made of a mixture of quartz, kaolin and feldspar) were manufactured by the Department of Materials Engineering at the Federal University of São Carlos, SP - Brazil. The porcelain disks (actually cylinders) had a diameter of 26 mm and a thickness (length) of 18 mm. A cavity was then drilled and ground in each disk using a CBN (cubic boron nitride) grinding wheel attached to the shaft of the head of the test bench, thus ensuring the total concentricity of the disk. The final diameter of the dynamic disk was 24 mm, identical to that of the static disk, thanks to the use method's mathematical imposition.

Because the thickness of the dynamic disk was about 18 mm and that of the static disk was 1.5 mm, 6 assays were carried out on 6 different regions (or bands) of the dynamic disk before it was ground again.

The effective assay began at the moment when the ionomer started to become worn by the porcelain, i.e., when the dynamic disk began to wear the static disk. As both disks became worn, the static disk showed a vertical displacement (δ) corresponding to wear in real time.

The displacement value (δ) was recorded point by point as a function of time, using an electronic probe (TESA model 32.10904) positioned under the shaft of the guide set, as illustrated in Figure 1. The probe was connected to an electronic displacement-measuring device (TESATRONIC model TT60), which, in turn, was coupled to an A/D data acquisition board connected to a computer located near the test bench. The displacement values acquired by the probe were recorded on a micrometric scale.

A computational routine was created using the MATLAB® package to convert each tension signal generated by the acquisition board into a real displacement value, plotting the respective displacement graph as a function of time. By increasing the time value of this graph by 2/3, a straight line was obtained, called a straight linear regression line, whose tangent was the linear regression coefficient (a_1).

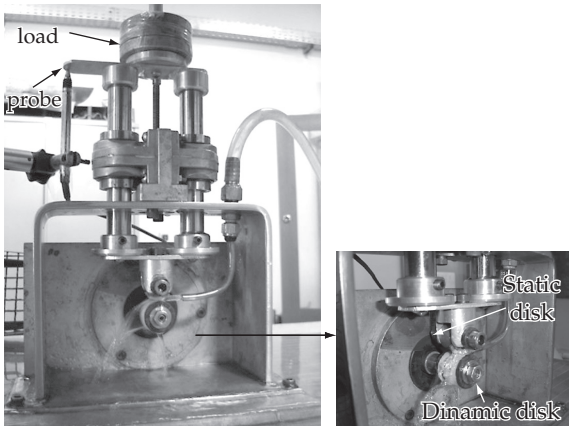

Figure 1. Test bench setup.

Based on equation (1) developed by Coelho (1991) and the linear regression data, it was concluded that the aggressiveness imposed on the ionomer by another material k [mm^3/N·s] is:

$$k = \frac{2b\sqrt{4r}}{3F_n}(a_1)^{3/2} \quad (1)$$

where Fn [N] is the normal force needed to remove material over a given period of time, b [mm] is the width of the static disk, r [mm] is the radius of the disks, and a_1 is the angular coefficient of the straight linear regression line.

Thus, it was possible to calculate the aggressiveness using all the points acquired in the experiment, rendering the result more significant.

For the first stage of the assays, 24 test specimens were prepared with conventional GIC, 8 specimens of each brand. The brands evaluated were Vidrion R, Fuji IX GP, and Ketac Fil Plus. The test specimens were prepared according to the recommendations of each manufacturer and were placed in the cavities ground into the static disks, as indicated in Figure 2, making a total of 6 disks with 4 test specimens each. This step of the experiment was carried out in the Laboratory of Dental Materials at the School of Dentistry, University of São Paulo, Bauru, SP - Brazil, where the temperature and air relative humidity were controlled constantly from 24 to 26 °C and from 58 to 62%, respectively.

After complete curing, the material was protected with a layer of varnish (Cavitine, manufactured by the Brazilian enterprise SSWhite) and immediately thereafter placed in distilled water for a minimum of 24 hours, after which it was removed for grinding to a final diameter of 24 mm and its curved surface evened in preparation for testing. The assay began since the dynamic disk began to wear the ionomer, ending when the graph stabilized.

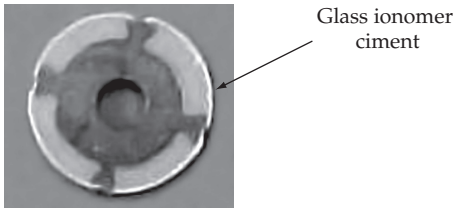

Figure 2. First stage static disk (before grinding).

After all the test specimens, dynamic disk and data acquisition and recording equipment were prepared, the first disk containing GIC was removed from the holder and attached to the test bench support screw located at the end of the set of linear guides, so that the tooth containing the material (the test specimen) was positioned at its geometric center, vertically aligned with the point of contact between the disks. Figure 1 illustrates the position of the static disk upon the dynamic disk at the moment when the test began. This positioning was done carefully to prevent impacting and cracking of the test specimen.

When the static disk was properly positioned, the probe was adjusted and the measuring device reset to zero. The data acquisition program was then initiated and the test bench motor turned on, supplying the dynamic disk with 3,300 rpm. Once the displacement of the static disk stabilized, the data acquisition program was stopped and the test bench motor switched off. To prepare for a new test, the test bench was uncoupled from the head, the static disk turned until a new tooth (test specimen) as yet untested reached the testing position, and this disk was moved, in relation to the fixation device, to a new region of the dynamic disk, after which the assay was repeated. The regions were separated correctly by 3 pairs of washers with different thicknesses. Thus, whenever a new position of the static disk was required, the order of the washers or a pair of washers was changed. After the 5 regions of the dynamic disk were used up, the disk was ground again simply to "clean" it surface, thereby letting 6 new regions ready for 6 new assays.

This procedure involved a considerable time interval between the assay of the first and the last test specimen of the same static disk. Since each specimen took about 10 minutes to assay and there were 4 test specimens per disk, there was a time difference of 30 minutes between them during which the material was exposed, i.e., outside the container with distilled water.

To correct this problem, a second stage of assays was conducted, but this time, instead of containing 4 cavities filled with GIC, the static disk contained only one. Thus,

it was possible to control the time each test specimen was exposed to the air in the laboratory (without the protection afforded by distilled water), a procedure that standardized all the assays. This time was dubbed *exposure time*, which corresponds to the time spent between the removal of the test specimen from the distilled water and the beginning of the assay. To ensure this standardization, the test bench motor was switched on only after 10 minutes had elapsed after the test specimen was removed from the water. Care was also taken with the relative air humidity and ambient temperature, which were kept at 60% and 25 ºC, respectively, during the assays. According to the literature review conducted prior to the experiments, these factors affect the mechanical properties of this material.

Another alteration adopted in the second stage of the assays was to replace the Fuji IX brand produced by the Japanese enterprise GP with a Brazilian brand, Virto Fil, manufactured by DFL Indústria e Comércio Ltda.. According to our suppliers, the Fuji IX brand is no longer sold by the Japanese manufacturer GP, which now sells a GIC that is not the conventional type but one modified with resin, which is outside the interests of this study. Since the Vitro Fil brand is already in use by professionals of this area, this replacement had a positive aspect, which was to bring the assay closer to the reality of the domestic market.

Results

The arithmetic average of the aggressiveness values, as well as those of the standard deviations of the assays in the first stage, are shown in Figure 3. Figure 5, in turn, depicts the results of the second stage.

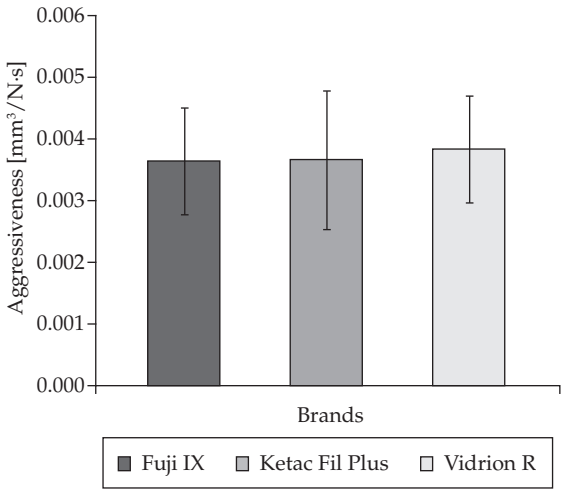

Figure 3. Average aggressiveness value and standard deviation of each brand in the first stage of the assay.

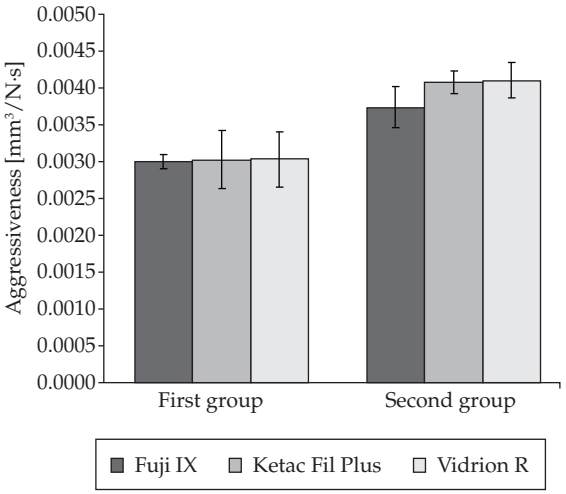

Figure 4. Average aggressiveness value of each brand in the first stage of the assay, grouped according to air exposure time.

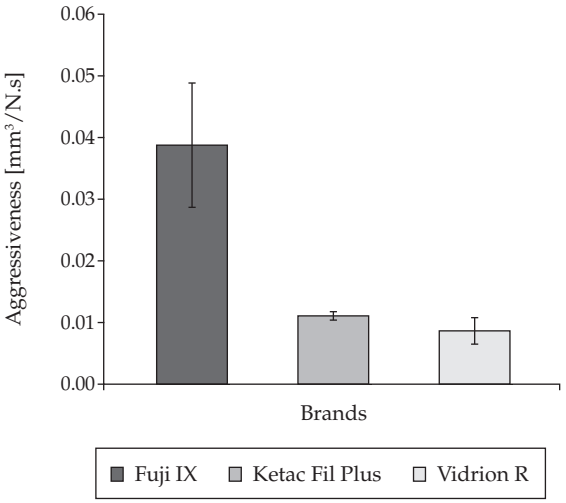

Figure 5. Average aggressiveness value and standard deviation of each brand in the second stage of the assay, in increasing order of resistance (decreasing order of aggressiveness).

Two-factor ANOVA statistical analyses were carried out, followed, when necessary, by Tukey's test with a 5% significance level, according to Montgomery and Runger (2003). The results did not reveal statistically significant differences among the brands in the first stage of the assays.

In the second stage, however, in which the exposure time of each test specimen was controlled and standardized, the analyses revealed a significant difference between Ketac Fil Plus and the other two brands ($p << 0.001$), though not between Vitro Fill and Vidrion R.

Discussion

An analysis of Figure 3 indicates that the results underwent some interference, particularly when one analyses the standard deviations, which showed high values. However, when one associates the aggressiveness values with the sequence of the assay of each static disk, i.e., the values of the first and last test specimens assayed in each disk, it can be noticed that the lowest aggressiveness values (highest resistance) were obtained in the first assays and the highest (lowest resistance) in the last ones. This organization is depicted in the graph in Figure 4, in which the first group comprises the first two test specimens assayed on each disk while the second group shows the last two specimens.

According to the literature, the mechanical properties of GIC are strongly affected by the quantity of water in the material (Musanje *et al*., 2001). This quantity is determined by the atmosphere to which the material is exposed and by the amount of exposure time.

In the first stage test procedure, the exposure time of the test specimens, i.e., when they were not immersed in distilled water, was not taken into account. Between each assay the static disk had to be repositioned and the new test specimen aligned with the dynamic disk. The time spent on this operation varied from one assay to another and took no more than a few minutes, but that time was not measured.

Because each disk held 4 test specimens, the time elapsed from when the disk was removed from the distilled water and the beginning of the last assay of that same disk varied from 20 to 30 minutes. In other words, the difference in time between the assay of the first and last test specimens exposed to the air sometimes reached up to 30 minutes

Musanje *et al*. (2001) analyzed the changes in the properties of glass ionomer cement when exposed to environments with different levels of humidity, and found that this material dehydrates in an atmosphere of low humidity. The test specimens of the present study may have displayed a similar behavior. We were already aware of this property of GIC; however, because the exposure time was relatively short, and also since this was our first experiment with GIC using this method, we were not overly concerned about the exposure.

The statistical analyses were repeated, this time comparing the aggressiveness values of the same brands of the two groups, with the following results.

All the brands compared showed significant variations ($p < 0.05$), with $t = 0.044$, 0.044 and 0.024 for the Fuji IX, Ketac Fil Plus and Vidrion R brands, respectively.

This results highlighted the influence of the exposure time of the test specimens to air. Since this time was not controlled, the high values of standard deviation found in the first stage precluded any conclusion about the performance of the brands evaluated here. However, these results can be explained by the continuous interaction of GIC with its surrounding medium (Braden and Pearson, 1981; Fan *et al*., 1985; Feilzer *et al*., 1995; Hirasawa *et al*., 1983; Musanje *et al*., 2001; Small *et al*., 1998).

The results of the second stage, however, proved to be more stable and reliable thanks to the care taken in handling and controlling the procedure.

The American brand of conventional GIC (Ketac Fil Plus) was found to be markedly less resistant to abrasive wear than the Brazilian brands Vitro Fill and Vidrion R, manufactured by DFL Indústria e Comércio and SSWhite, respectively.

Another fact observed in this stage was that the displacement of the dynamic disk recorded by the data acquisition program followed an order of magnitude compatible with the order of aggressiveness values that each brand underwent. In other words, the displacement was higher with the brands that presented lower abrasive wear resistance and lower in the more resistant brands. The recorded displacement was on average 500 μm for the Ketac Fil Plus specimens, 150 μm for Vitro Fill, and 100 μm for Vidrion R.

Conclusions

In the first stage of the assays, when the exposure time of the test specimens was not controlled, no significant differences were found in the abrasive wear resistance values of the brands evaluated here ($p > 0.05$). The differences in performance between the two groups in Figure 4 demonstrate that the exposure time to ambient air, manifested by drying out of the material, interfered in the results. The specimens that were out of the water for longer were the ones that showed the highest aggressiveness values, in other words, the lowest abrasive wear resistance.

In the second stage, the American brand of conventional GIC (Ketac Fil Plus) was markedly less resistant to abrasive wear than the Brazilian brands Vitro Fill and Vidrion R.

The results were more stable and reliable in response to the care taken during the assays of stage two.

Among the controlled test conditions, the one that appeared to exert the strongest influence on the abrasive wear resistance of GIC was the material's exposure time to air, i.e., when the material was not protected by a layer of varnish or immersed in distilled water, confirming previous studies on this theme and indicating the need to control these parameters in assays of the mechanical properties of this material.

Acknowledgements

The authors acknowledge FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo, Brazil) for funding this research.

References

BIANCHI, E. C. D.; BIANCHI, A. R. R.; FREITAS, C. A. Avaliação do desgaste abrasivo de resinas compostas. In: CONGRESSO DE ENGENHARIA MECÂNICA NORTE/NORDESTE, 4, 1996, Recife. **Anais**... Recife, v. 1, p. 169-174, 17-20 jun. 1996.

BRADEN, M.; PEARSON, G. J. Analysis of aqueous extract from filled resins. **Journal of Dentistry**, v. 9, n. 2, p. 141-143, 1981.

COELHO, R. T. **Estudo experimental da propriedade de dressagem de rebolos na retificação de precisão usando o método do disco retificado**. São Carlos, 1991. Tese – (Mestrado em Engenharia Mecanica), Escola de Engenharia de São Carlos, Universidade de São Paulo – USP.

FAN, P. L.; EDAHL, A.; LEUNG, R. L.; STANFORD, J. W. Alternative interpretations of water sorption values of composite resins. **Journal of Dental Research**, v. 64, n. 1, p. 78-80, 1985.

FEILZER, A. J.; KAKABOURA, A. I., De-GEE, A. J., DAVIDSON, C. L. The influence of water sorption on the development of setting shrinkage stress in traditional and resin-modified glass ionomer cements. **Dental Materials**, v. 11, n. 3, p. 186-190, 1995.

HIRASAWA, T.; HIRANO, S.; HIRABAYASHI, S.; HARASHIMA, I.; AIZAWA, M. Initial dimensional change of composite in dry and wet conditions. **Journal of Dental Research**, v. 62, n. 1, p. 28-31, 1983.

KENT, B. E.; LEWIS, B. G.; WILSON, A. D. The properties of a glass ionomer cement. **British Dental Journal**, v. 135, n. 7, p. 322-326, 1973.

MONTGOMERY, D. C.; RUNGER, G. C. **Estatística Aplicada e Probabilidade para Engenheiros**. 2ª ed. Rio de Janeiro: LTC Editora, 2003.

MUSANJE, L.; SHU, M.; DARVELL, B. W. Water sorption and mechanical behaviour of cosmetic direct restorative materials in artificial saliva. **Dental Materials**, v. 17, n. 5, p. 394-401, 2001.

PUGH, B. Wear. In: **Friction and Wear**. London: Newnes-Butterworths, 1973. p. 141-172.

SMALL, I. C. B.; WATSON, T. F.; CHADWICK, A. V.; SIDHU, S. K. Water sorption in resin-modified glass-ionomer cements: an in vitro comparison with other materials. **Biomaterials**, v. 19, n. 6, p. 545-550, 1998.

WILSON, A. D.; KENT, B. E. A new translucent cement for dentistry: The glass ionomer cement. **British Dental Journal,** v. 132, n. 4, p. 133-135, 1972.