# STUDY OF DENTAL GYPSUM USING FIBRE SENSORS
## *Analysis of Different Water/Powder Ratios of High Strength Dental Stone*

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Abstract: In this work, we present a device to measure strain and temperature, based on fibre Bragg grating (FBG) sensors. The performance of these sensors was assessed in the study of a type of dental gypsum, namely high strength dental stone. It was intended to know the influence of the water/powder (W/P) ratios in the setting time and expansion. The results show that, a change in the W/P ratio influences the setting time as well as maximum strain values. The data was compared with the values foreseen in ANSI/ADA specification nº 25. The information that can be obtained with these sensors is quite important to dental prosthesis technicians, in order to achieve more accurate dental prosthesis and these sensors can be a good substitute to the actually device that is used to evaluate the setting expansion: extensometer.

## 1 INTRODUCTION

Optic sensors based on fibre Bragg grating (FBG) have attracted much attention in the past few years due to many advantages such as high sensitivity, immunity to electromagnetic interference, wavelength multiplexing, lightweight, low cost and easiness handling, which allows to be embedded into different materials. These characteristics have opened wide fields of applications, from optical communications to biomedicine. Thus, we can find FBGs in civil structures monitoring (Lima, 2007); sensing systems in vehicles, airplanes and ships (Castelli, 2002), in the detection of virus/antibodies (Petrosova, 2007) or even, in linear polymerization shrinkage monitoring of dental materials (Arenas, 2007).

In its simplest form, an FBG consists of a periodic modulation of the refractive index along the fibre length, which is formed by exposure of the core to an intense optical interference pattern of ultraviolet light. The sensing principle of a FBG-sensor is based on the monitoring of the wavelength shift of the reflected Bragg wavelength when it is subjected to strain and/or temperature changes. The Bragg wavelength is given by the following expression:

$$\lambda_B = 2\, n_{eff}\, \Lambda \quad (1)$$

where $n_{eff}$ is the effective index of the core and $\Lambda$ is the refractive index modulation period (Kersey, 1997).

Among the dental materials, gypsum is one of most used in dental prosthesis because of its ability to change properties by the addition of different chemical components. When powder particles of the gypsum are mixed with water, a chemical reaction occurs, according with the following equation (Phillips, 1991):

$$(CaSO_4)_2.H_2O + 3H_2O \longrightarrow CaSO_4.2H_2O + heat \quad (2)$$

All manufacturers of gypsum products have its own recommendations, concerning proper water/powder (W/P) ratio to be used, to obtain the best performance. However, if the W/P ratio is not correctly followed, accordingly to the manufacturer's recommendations, the gypsum might have different properties, namely the setting expansion.


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In this work the influence of the W/P ratios of a high strength dental gypsum stone (type IV) was experimentally studied, namely the setting time and expansion, using devices based on FBG. The setting expansion values obtained were compared with values foreseen in ANSI/ADA specification nº 25, which were measured using an extensometer.

## 2 EXPERIMENTAL SETUP

The FBGs were written into photosensitive optical fibre (Fibercore PS1250/1500), by illuminating it with ultraviolet light, using an automated phase-mask interferometer system (Nogueira, 2002).

Two sensors were used in this work. One of them was protected mechanically, in order to be only sensitive to temperature variations. For that, the sensor was placed inside a double needle (figure 1).

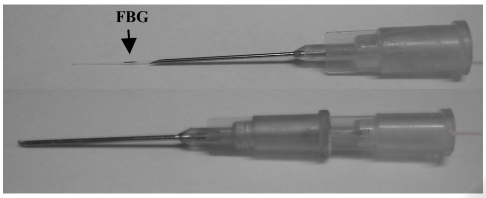


Figure 1: Temperature sensor.

The other sensor consisted in a free FBG, which was in close contact with gypsum, and is sensitive to strain and temperature variations. In the first analysis it was verified that there was sliding of the gypsum along the free FBG. In order to overcome this situation, two plastic spheres were glued to the fibre, down and above the sensor (figure 2), allowing a better response of the fibre to the gypsum expansion/contraction.

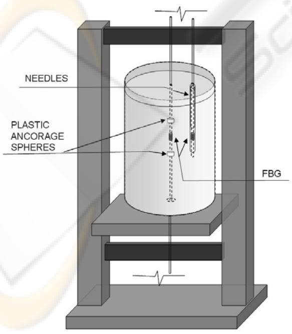


Figure 2: Schematic representation of the experimental setup.

The free sensor was put inside a hard metallic container (diameter = 3.5 cm and height = 7 cm) with a hole in the bottom, through which the fibre is pulled through. The fibre is then bonded to a support and slightly tensioned (about 700 $\mu\varepsilon$) allowing measuring both expansion and shrinkage.

Relatively to the W/P ratio, three different values were considered. One corresponds to the value recommended by the manufacturer, which is 0.22, one corresponding to a 15% decrease of the water quantity (W/P = 0.19) and another corresponding to a 15% increase of the water quantity (W/P = 0.26). These values were chosen, according with the reaction' stoichimetry and the W/P ratio recommended by manufacturer. Through reaction' stoichimetry we verified that a 15% decrease of water quantity relatively to W/P ratio recommended by manufacturer is the minimum value requested to occur reaction thus. With a decrease of water below 15% it is impossible to have a full reaction of gypsum. The choice of the other W/P ratio is related to the fact that we consider that usually there is a tendency to add a larger amount of water than the one recommended, facilitating the handling of gypsum.

For each case, the water was added to powder and spatulated, during 45 seconds. Then, the mixture was flowed into the metallic container and finally, the temperature sensor was inserted into the mixture. The Bragg wavelength measurement was made every 5 seconds, during 3 hours, simultaneously for the two sensors. The resolution of the system (sensor+interrogation system) allows measurements of displacement and temperature with a precision of about 1 $\mu\varepsilon$ and 0.1 ºC respectively.

The measurements were repeated several times for each W/P ratio, being the results presented in this work a result of an average.

## 3 RESULTS AND DISCUSSION

The evolution of strain and temperature with time, for the two sensors used in the experiments are showed in the graphs of figures 3 and 4, respectively.

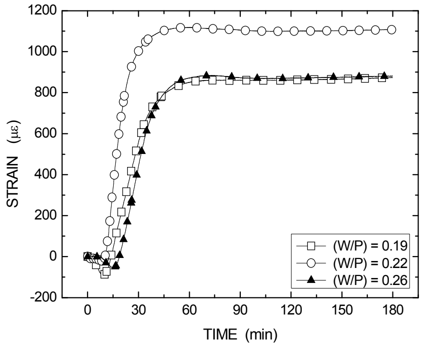


Figure 3: Evolution of strain during setting reaction, for gypsum type IV, for three different (W/P) ratios.

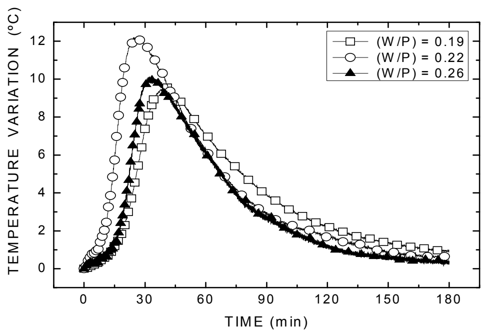


Figure 4: Evolution of temperature during setting reaction, for gypsum type IV, for three different (W/P) ratios.

The strain curve was obtained by subtracting the effect of temperature, obtained with the temperature sensor, in the measurements accomplished by the free FBG. The sensitivity coefficients of the FBG to temperature and strain was 10.6 pm/ºC and 1.1 pm/με, respectively. These values were previously measured.

According with the results obtained, we can observe that when we change the W/P ratio recommended by manufacturer, the maximum strain value and maximum thermal amplitude, reached during the setting reaction of dental gypsum are different (table 1), although the behaviour is similar.

Table 1: Values of maximum strain and maximum thermal amplitude for the W/P ratios analysed.

| (W/P) ratios | Maximum strain (με) | Maximum thermal amplitude (ºC) |
|---|---|---|
| 0.19 | 874 | 9.5 |
| 0.22 | 1120 | 12.3 |
| 0.26 | 884 | 10.1 |

Initially, we observe a shrinkage of dental gypsum, being more accentuated in the case of the W/P = 0.19, where it reaches about -90 με. Following, there is an increase of strain, along with an increased of temperature. After 55 min, for W/P = 0.22 and after 65 min, for W/P of 0.19 and 0.26, the setting expansion stabilized and temperature returned slowly to its initial value (room temperature).

Although there is a modification on the setting expansions values when the W/P ratio change, the results obtained experimentally are within the range established by ANSI/ADA specification nº 25, that, in this case, is between 0% and 0.15 %. This range was determined using an extensometer that allows the measurement of length changes within 0.01 mm resolution in a specimen with a length of 100 mm, (100 με of resolution). The proposed device, based on FBG, allows a real time measurement of the evolution of the strain and temperature in the material. Moreover, the resolution is around 1 με. Thus, the use of this device can be an incentive to the revision of actual ANSI/ADA specification nº 25, where we suggest the measurement of the setting expansion, using optic fibre sensors to the detriment of the extensometer because this technique present more resolution, with more reliable results.

When the gypsum is dry, it is also possible to measure the linear thermal expansion coefficient. This thermal property is other information quite important to dental prosthesis technicians, which is defined as the change in length per unit of length of gypsum, when its temperature is raised or lowered 1ºC.

# 4 CONCLUSIONS

In this work we presented a device for strain and temperature measurements, based on FBGs.

These sensors were applied in the study of the influence of the W/P ratios of dental gypsum, in the setting time and expansion. Also the sensor shows applicability in the determination of thermal expansion coefficient.

The sensors' response showed that, a modification of the amount of water influences the value of maximum strain and, this difference might interfere in the outcome of the technicians work. So, it is advisable following the manufacturer's recommendations.

The present devices can also be a useful tool for gypsum' manufacturers, allowing a real time monitoring of strain and temperature along the production process, what can be very important in the control and improvement of the gypsum's properties.

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