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Evaluating the Effect of Various Quantities of Silica Nanoparticle Addition on the Mechanical Properties of a Light Cure-resin Modified glass Inomer

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ABSTRACT

Background: low flexural and compressive strength of visible light cure-resin modified glass inomer (VLC-RMGI), despite its improved physical properties, is a draw back in areas of stress. Incorporating Silica Nanoparticles (Si-NPs) seems to enhance mechanical properties of VLC-GI, while its beneficial characteristics like fluoride release, remains intact. The aim of this study is investigating the mechanical changes induced by adding different quantities of Si-NPs to a VLC-RMGI. **Methods:** Different mechanical properties of light cure Fuji II (Fuji II LC) (including flexural strength, compressive strength, flexural modulus, and compressive modulus) was evaluated in five groups (n=5) containing 0%, 0.2%, 0.5%, 1%, and 2% Si-NPs by weight. Depth of cure was evaluated using a digital micrometer. All groups were kept in incubator (37°c, 100% humidity), followed by tensile strength test (three point bending test, initial force magnitude: 0.02N, speed: 0.5mm/min), immediately, in 24 hours and thirty days. Microstructure of the fractured surfaces was recorded by SEM. Data was analyzed using Kolmograph-smirnov, Tukey and Two-way ANOVA tests. **Results:** Mechanical properties of Fuji II LC significantly increased by storage and time lapse ($p<0.05$). The highest percentage of NPs, resulting in enhanced GI strength was the 0.5% group ($p<0.05$). Higher percentages, despite increased results as compared to the control group, did not surpass the optimum for the 0.5% group, showing a significant decrease ($p<0.05$). **Conclusion:** Fuji II LC with a maximum of 0.5% Si-NPs was shown to gain superior mechanical properties.

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INTRODUCTION

Glass Inomers are one of the first generations of man's innovative substitutes for amalgam restorations. It was supposed to be as wear resistant while the esthetics was improved. GI was later found to have many cons and pros. The outweighing pros however, maintained its usage in clinical practice. GI was first introduced by Kent and Wilson (1972, UK). At first it seemed to be a superior material due to chemical bonding, similar Coefficient of thermal expansion and heat transfer to tooth structures, and negligible polymerization shrinkage (despite composite resins). Nevertheless it is not used widely as a restorative material, since the mechanical properties are not ideal. A tougher, visible light cured GI was introduced in 1980, to present enhanced properties, while fluoride release and chemical bonding to enamel and dentine was kept intact. Thus VLC-RMGI is more commonly used today, due to better physical properties. In spite this however, research is ongoing to find a GI that best resembles the mechanical properties of tooth structures.

A new promising domain vastly practiced in different industries is Nanotechnology. Nanoparticles are very popular, owing to their specific characteristics, one of which is enhanced mechanical properties. A readily available and biocompatible Nanoparticle is silica; if incorporated into VLC-RMGI, it won't interfere with the crosslink reaction, while it could strengthen the material. The aim of this study is investigating the mechanical changes induced by adding different quantities of Si-NPs to a VLC-RMGI.

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MATERIALS AND METHODS

Preparation of modified glass inomer:

Si-NPs (Degussa, 10-20 nm) were added to VLC-RMGI (Fuji II LC, GC) powder in 5 different groups (0%, 0.2%, 0.5%, 1%, and 2% by weight), using mortar and pestle for 20 minutes, until a uniform distribution was achieved. SEM (Tescan, vega, Czech) was used to investigate the distribution of NPs in prepared specimens.

Flexural strength measurement:

A two part steel mold (2×2×25mm) was chosen, as stated by ISO 4049. GI powder and liquid was mixed in factory recommended portions, on a glass slab, in less than 25 seconds. The cement was then transported into the mold until completely filled. A glass slide was placed on it and it was cured (LED, Demetron, Kerr, USA). The 8 mm diameter circular tip of the light cure was placed five overlapping times on the cement, curing 20 seconds each time. The same procedure was repeated on the other side of the specimen, ensuring complete curing on all surfaces. All specimens were then placed in distilled water and incubator (100% moisture and 37°c). Three point bending test (Universal testing machine, Zwick Roell, Germany) was used in three time intervals (immediately after fabrication, after 24 hours and one month). The following formula was used to evaluate the flexural strength:

$$\delta = \frac{3PL}{2bd^2}$$

In which δ =flexural strength, b =width, d =diameter, P =maximum force in bending point, L =distance between two supporting points

Compressive strength measurement:

A two part brass mold (4mm diameter and 6mm height) was chosen, as stated by ISO 9917. The same pattern was used to fabricate the GI. The curing was performed from four sides, making it a total of 80 second light curing procedure. The compression strength for the specimens was measured by the same Universal testing machine in the same time intervals. The following formula was used:

$$CS = \frac{4P}{\pi d^2}$$

In which d =diameter, P =maximum force in failure point, CS =compression strength

Data analysis:

Kolmograph Smirnoff test was used to make sure of normal distribution of data. Two-way ANOVA test was not applicable here, because several interactions between variables were significant. Instead one-way ANOVA and Tukey HSD tests were utilized.

RESULTS AND DISCUSSIONS

Flexural strength:

As shown in figure1, flexural strength increased in time within all groups. This increase was not significant for the control group after day one ($p=0.37$). Also the results for the 0.2% and 2% w/w groups were only significant after one month ($p=0$). The groups 0.5% and 1% w/w represented significant increase in both time intervals ($p=0$). Addition of NPs up to 1% weight significantly increased the flexural strength compared to the control group ($p<0.05$) at the first testing time (day zero). After one month the difference was still significant between the control and other groups ($p=0$). However, the only statistically significant higher strength was evident between groups 0.5% and 0.2% ($p>0.05$).

Flexural modulus:

Flexural modulus increased within each weight group ($p<0.05$) with the exception of 2% w/w group. Also as illustrated in figure2, at the first testing point, groups 0.2% and 1% w/w showed a significant increase of modulus to the control group ($p<0.05$). After one month the results were significantly increased between groups 0%- 0.5%, 0.2%-0.5% and 0.5%-2% weight.

Compressive strength:

As seen in figure3, in groups 0%, 0.2%, 0.5% w/w, the compressive strength rapidly increased as time passed ($p<0.05$). The results were also significantly enhanced between the above groups in different testing times ($p=0$).

Compressive modulus:

Figure 4 illustrates that within each weight group, the results were not as harmonious. The control group as well as 0.2% and 2% groups had a compressive modulus significantly elevated. Groups 0.5%, 1% and 2% presented a higher modulus at point zero, while after one month only group 2% kept a statistically higher modulus as compared to other groups.

Discussion:

As the control groups in this study illustrated, RMGI is considered a material with low mechanical properties; it is not as esthetic as resin composite either. It is however very commonly utilized in many fields, such as high risk patients with several lesions, class III and V lesions in non-stress bearing areas, cervical lesions and ART technique, due to chemical bonding and fluoride releasing properties. Harmonic with other studies, the results in compressive tests were sporadic, which can be in response to differences in material hardness and specimen diameters [1]. On the other hand, flexural strength can predict a better clinical performance under transverse tensions. Keeping in mind that most masticatory forces are compressive though, dictates to consider it when studying mechanical properties of materials in oral environment.

GI displays higher strength rates in time, due to more cross links and the creation of a silicagel phase. Almost coordinately, water sorption and plasticizing effect of water induces a weaker non-erosion resistant GI. Fuji II LC Glass Inomer was significantly stronger after 24 hours, but this was not the matter after one month, probably indicating complete maturation of the cement in only one day. In the different Si-NPs incorporated groups however, the strength kept increasing in most of the groups, even after one month. Silicagel phase formation and higher cross linkage are some suggestive reasons for such higher mechanical properties. Mohammad Atai *et al.* claimed that the addition of more than 0.5% NPs to adhesive, would not result in any further bond strength enhancement. NPs in general have a tendency to agglomerate; this tendency seems to increase as the percentage of NPs increase [2]. This was shown to be true in this research as well, where higher percentages (>0.05%) of Si-NPs had an adverse effect on the flexural strength.

Another study carried in 2005 proved that the compressive strength of RMGI increases as it is stored in water, but still is was lower than other materials [3]. The results of this study also indicate a higher compressive strength for RMGI, in time. Addition of NPs up to 0.5% w/w did also increase the strength significantly, both on the time of application and 30 days later, inducing RMGI to be a stronger material under compressive forces, combining the effect of both time and NP incorporation. It is safe to claim that incorporation of Si-NPs up to 0.5% would increase the overall mechanical properties of RMGI. Higher percentages, as stated by M. S. Shojai *et al.*, would present agglomerated fillers as a defect point, which would cause lower strength as compared to the 0.5% group [4].

Conclusion:

As stated in this research, incorporation of 0.5% w/w Si-NPs would result in a stronger RMGI with a 500% enhanced flexural modulus. These findings could be an onset of a newer and stronger RMGI to be utilized in clinic. However further research must be carried out to finalize and validate the matter.

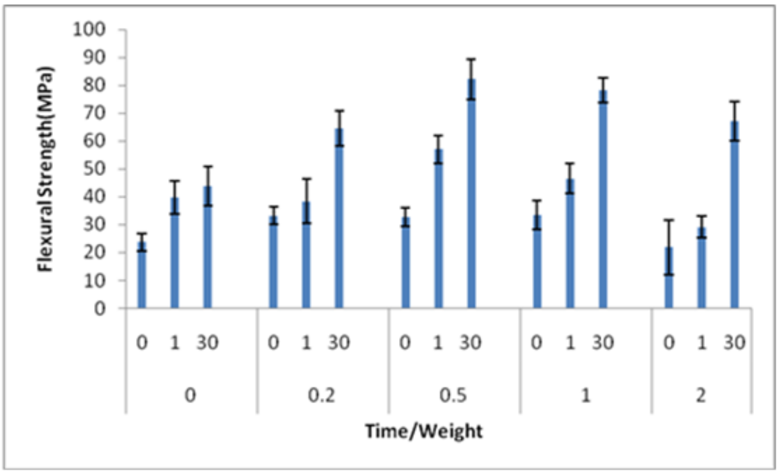

Fig. 1: Mean and standard deviation of flexural strength for different weight groups in three testing times.

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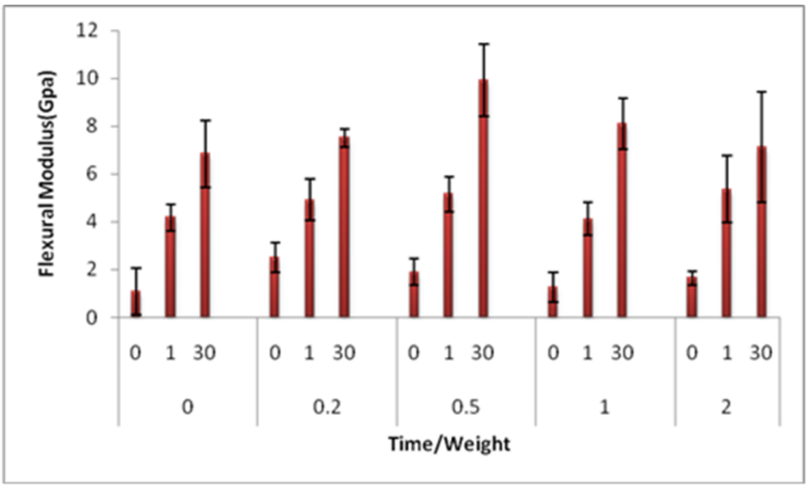

Fig. 2: Mean and standard deviation of flexural modulus for different weight groups in three testing times.

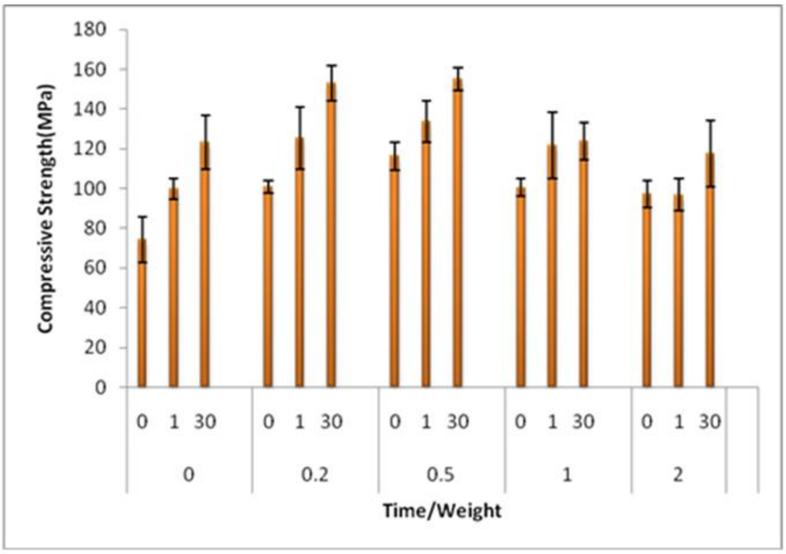

Fig. 3: Mean and standard deviation of compressive strength for different weight groups in three testing times.

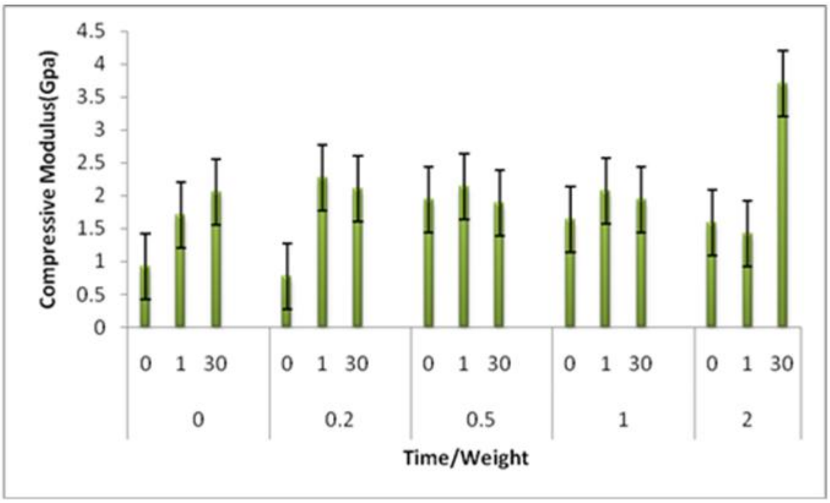

Fig. 4: Mean and standard deviation of compressive modulus for different weight groups in three testing times.

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