Aleksandra Mitrović[1], Nenad Mitrović[2], Ivan Tanasić[3], Miloš Milošević[3], Dušan Antonović[1]

STRAIN FIELD MEASUREMENTS OF GLASS IONOMER CEMENT

MERENJE POLJA DEFORMACIJA U STAKLENOM JONOMERNOM CEMENTU

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Adresa autora / Author's address:
[1)] University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia
email: aleksandramitrovic1926@gmail.com
[2)] University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
[3)] University of Belgrade, Faculty of Dental Medicine, Belgrade, Serbia
[4)] University of Belgrade, Innovation Centre of the Faculty of Mechanical Engineering, Belgrade, Serbia

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- displacement
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Ključne reči
- glas-jonomer cement
- Riva Luting
- polje deformacija
- pomeranje
- lom
- 3D Digitalna Korelacija Slika

Abstract

Extensive evolution of glass ionomer cements (GIC) has marked a significant shift in the practice of luting indirect dental restorations limiting the use of zinc-phosphate and zinc-polycarboxylate cements to a few indications. GIC are now one of the materials of choice for cementation of all ceramics, fiber reinforced composite posts and veneers. GICs are determined by unique properties like chemical adhesion to tooth and base metals, low thermal expansion coefficients similar to dentin and minimal microleakage at the tooth-enamel interface due to low shrinkage. Shrinkage strain is identified as the cause, and the associated stress as the mechanism for the loss of marginal adaption and cohesive fracture within the material. The aim of this study is to measure the strain and displacement field in a conventional GIC (Riva Luting, SDI, Australia) related to different cement diameter, using 3D Digital Image Correlation (DIC) method. The experiment is done for samples with thickness of 1 mm combined with diameters of 4 mm (Group I) and 3 mm (Group II). The strain field is measured using 3D 11optical system Aramis 2M (GOM, Braunschweig, Germany). This study provides valuable data about strain behaviour and displacement as a possible failure factor in GIC, Riva Luting. Visible differences between Group I and Group II were observed.

Izvod

Značajan razvoj glas-jonomer cementa (SJC) je doveo do ozbiljnih promena u praksi indirektne dentalne restauracije lepljenjem, ograničavajući primenu cink-fosfatnih i cink-polikarboksilatnih cementa na svega nekoliko indikacija. SJC su danas jedan od glavnih materijala za cementaciju keramike, vlaknima ojačanih kompozita i prevlaka. SJC poseduju jedinstvene osobine poput hemijske adhezije za zub i osnovne metale, malog koeficijenta toplotnog širenja, sličnog kao kod dentina, i minimalnog mikro-curenja na vezi zub-gleđ, usled malog skupljanja. Deformacija skupljanja je identifikovana kao uzrok mehanizma gubitka kontakta i kohezivnog loma unutar materijala. Cilj ovog rada je merenje polja deformacija i pomeranja u uobičajenim SJC (Riva Luting, SDI, Australija), vezanim za različite prečnike cementa, primenom 3D Digitalne Korelacije Slika (DIC). Eksperiment je urađen na uzorcima debljine 1 mm u kombinaciji sa prečnikom od 4 mm (Grupa I) i 3 mm (Grupa II). Polje deformacija je izmereno primenom 3D optičkog sistema ARAMIS 2M (GOM, Braunšvajg, Nemačka). Ovo istraživanje daje korisne podatke o ponašanju pri deformaciji, koje predstavlja jedan od faktora otkaza u SJC, Riva Luting. Uočene su primetne razlike između Grupe I i Grupe II.

INTRODUCTION

The interaction between restorative dental materials and tooth covers aspects of dental anatomy and materials science is researched, /1/. Extensive evolution of glass ionomer cements (GICs) has marked a significant shift in the practice of luting indirect dental restorations limiting the use of zinc-phosphate and zinc-polycarboxylate cements to a few indications /2/. GIC and composite cements are now the materials of choice for cementation of all ceramics, fiber reinforced composite posts and veneers, /3/.

GIC is a commonly used term, although a more chemically appropriate one would be glass polyalkenoate cement, to refer to a material composed of polymeric water-soluble acid, basic (ion-leachable) glass and water, /1/. GICs are determined by unique properties like chemical adhesion to tooth and base metals due to their capability of forming chemical bonds with calcium ions in tooth or metal ions, low thermal expansion coefficients similar to dentin and minimal microleakage at the tooth-enamel interface due to low shrinkage, /4/. Despite numerous advantages of GICs, low mechanical strength, brittleness and poor wear resistance have limited the current GICs for use mainly at certain low stress-bearing sites. Much effort has been made to focus on improving mechanical strengths of GICs, /5/. However, shrinkage strain was found to be one of the major failure properties of GIC and composite restorations. This process leads to the debonding mechanism and fatigue, /6, 7/. Different contact or non-contact methods have been used to study polymerization shrinkage of dental materials, /8, 9/. One of non-contact method for measuring the shrinkage in this type of material is the Digital Image Correlation (DIC) method. DIC is a technique used in biomechanical investigations, material and structural testing, fracture mechanics, etc. So far in dental and bone biomechanics, /10, 11/, DIC was used to study bone reaction on loading impact, designs of different dental restorations and interactions between jaws and dentures, /12/. Thus, this study is aimed to visualize and determine strain in conventional GIC, Riva Luting, using the 3D Digital Image Correlation Method.

MATERIALS AND METHODS

The strain and the displacement field are measured using 3D optical system Aramis (GOM, Braunschweig, Germany). Prior to the experiment, system calibration is performed using the calibration panel for corresponding measurement volume. This volume was chosen based on the dimensions of measured area on the sample surface. After successful calibration, the measurements are performed. Calibration is a measuring process during which the measuring system using calibration objects, is adjusted so that the dimensional consistency of the measuring system is ensured. The calibration object contains the scale bar information, e.g. the specified distance between two defined reference points. During calibration, the sensor configuration is determined. This means that the distance and orientation of the cameras to each other are determined. In addition, the image characteristics of the cameras are determined (e.g. focus, lens distortions), /8/.

The tested material is glass ionomer cement Riva Luting (SDI, Australia). Riva Luting is a conventional, self-curing, glass ionomer luting cement designed for final cementation of metal-based restorations. It chemically bonds to metal substrates and the tooth. Riva Luting contains 80-90 wt% of glass powder and 10-20 wt % of acrylic acid homopolymer.

The experiment was done for samples of 1 mm thickness combined with diameters of 3 mm and 4 mm. The material was mixed according to manufacturer’s instructions and 3 samples are prepared in each group. Samples are prepared by filling ring-type moulds. The top surface of each sample is sprayed with fine black and white spray (Kenda Color Acrilico, KendaFarben) to create a stochastic pattern with high contrast for image analysis. Digital images are recorded automatically every 5 seconds for the total time of 180 seconds and analysed within specialist software (Aramis v. 6.2.0, GOM) to determine von Mises strain and displacement in Z direction. The experiment was performed at room temperature. For analysis, three sections (Sections 0, 1 and 2) were selected across the top sample surface to cover central and peripheral areas. Section 0 (peripheral, interface) is a circular section positioned at the material-mould interface of the sample. Sections 1 and 2 are linear sections positioned orthogonally to each other, crossing at the sample centre. The diameter of Section 0 and lengths of Sections 1 and 2 correspond to sample diameter. Two-stage points are positioned at the samples. Stage point 0 is positioned in the centre of the sample and Stage point 1 on the circumferential, peripheral segment of each sample.

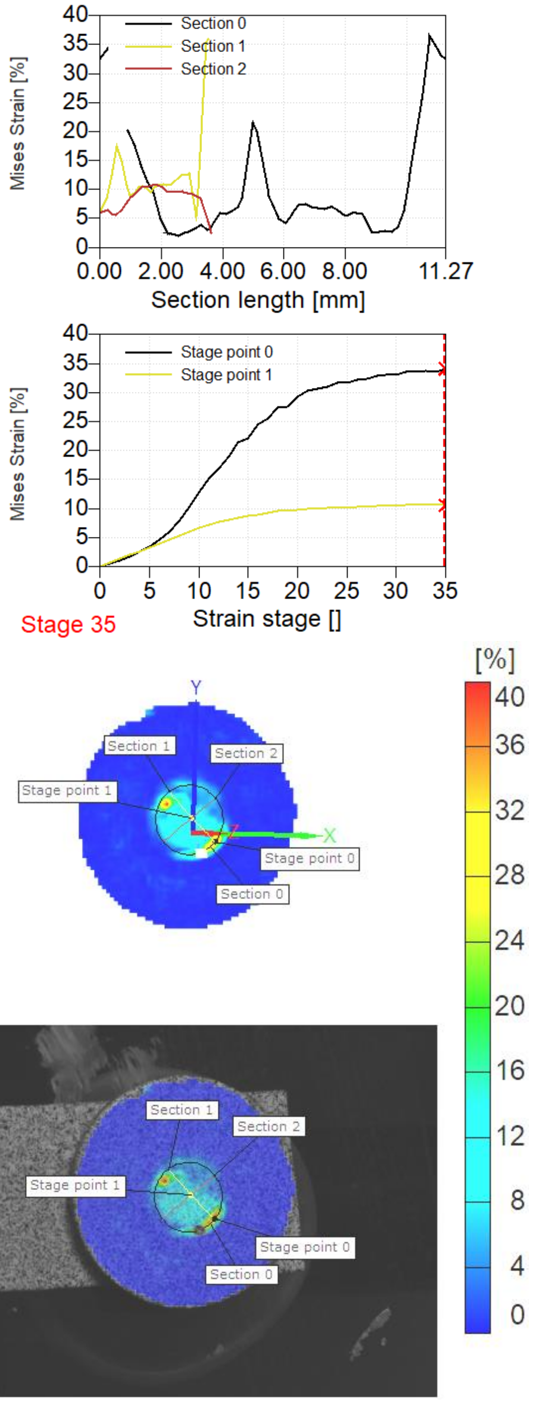

Figure 1. Von Mises strain field in ∅4×1 mm sized Riva Luting cement.

RESULTS AND DISCUSSION

According to Aramis software, higher strain values are found in ∅4×1 mm (Group I) Riva Luting cement compared to ∅3×1 mm Riva Luting cement (Group II).

Section 0 in ∅4×1 mm Riva Luting cement (Fig. 1) shows the highest strain value of 40 % while the lower strain values (10 %) are found in Section 1 and in Section 2 (Fig. 1). Unlike Group I, strain values are significantly lower for the Group II. The highest strain values (5 %) are found in Section 0 (Fig. 3) and 3 % regarding Section 1 and Section 2.

The highest displacement value is measured in Section 0 and in Section 1, in Group I (0.1 mm, Fig. 2).

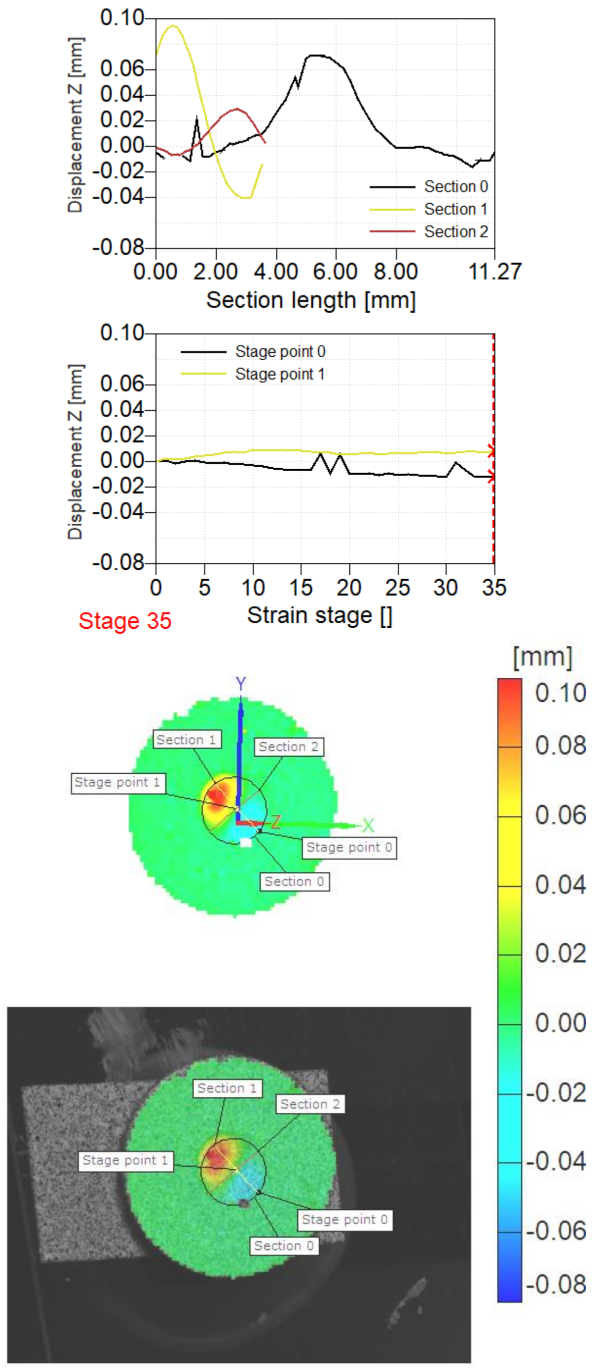

Figure 2. Displacement field in ∅4×1 mm sized Riva Luting cement.

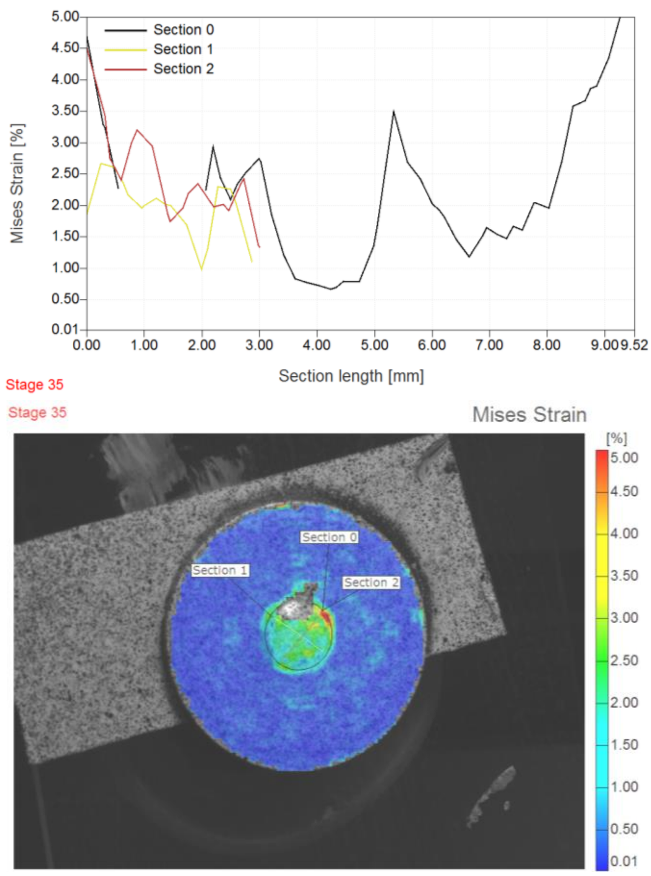

Figure 3. Strain field in ∅3×1 mm sized Riva Luting cement.

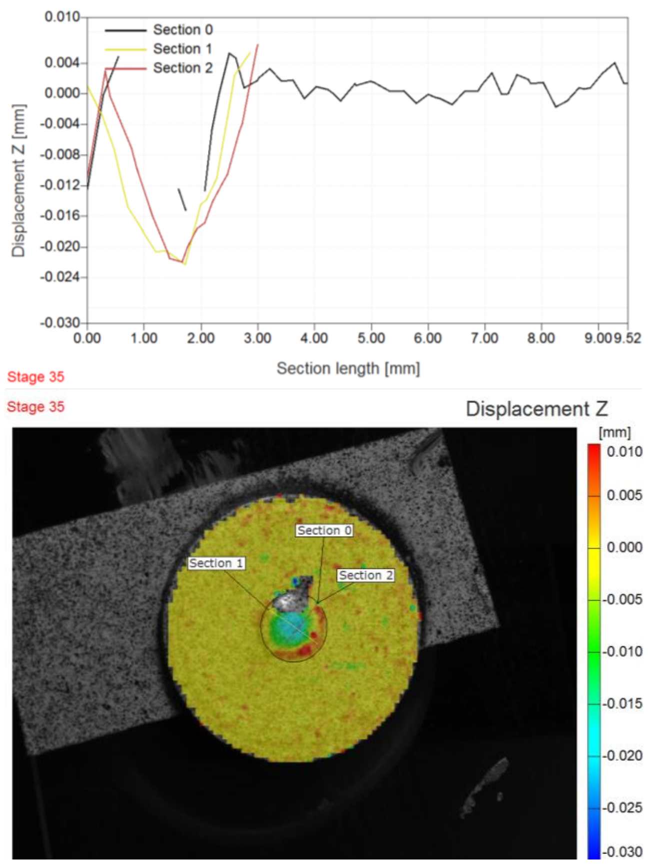

Figure 4. Displacement field in ∅3×1 mm sized Riva Luting cement.

In ∅3×1 mm Riva Luting sample, the highest displacement value is 0.006 mm in Section 0. Generally, displacement fields show similar highest displacement values in Section 1 and in Section 2, considering samples in Group II. However, there is a significant difference between Section 1 and Section 2 in the Group I.

Previous study reported that the DIC method could be employed for strain detection in composite cements, /13/. This study is aimed to investigate the highest strain/displacement values in glass ionomer cement Riva Luting using DIC. Although the time to first failure and the retentive strength of glass ionomers have been studied previously, /6/, there is little information on the highest strain and displacement values of GICs. Thus, this study is conducted to measure these values in conventional GIC during and after the hardening process.

The results show variations in the range of measured strain and displacement values. Diagrams above each figure show the highest strain/displacement values along section length (Section 0, Section 1, and Section 2) while Stage points are presented for Stages 0-35. The final Stage 35 represents the time needed for the hardening process, according to the manufacturers.

According to the results, it can be noticed that the properties of glass-ionomer cement are additionally influenced by how the cement is prepared (mixing protocol), and not only by sample size. This is particularly important regarding ∅4×1 mm sized Riva Luting samples, where an unexpected high strain value (40 %) is found. Furthermore, the powder-liquid ratio, the concentration of the polyacid and the particle size of the glass powder could influence the results. The mentioned factors are highlighted in clinical dentistry as determinants commonly responsible for failure of the dental GIC due to contraction, /1, 2/. Besides this, the highest strain value in ∅4×1 mm sized Riva Luting sample may be explained through mechanical properties of GIC due to the presence of alumino-silicate glass powder and lower tensile strength, /4/.

Considering the tested samples, certain models and regularities of the biomechanical behaviour of the presented cement are noticed. Strain fields show non-uniform strain distribution, mostly oriented in two regions, centrally and peripherally. The peripheral region (Section 0, interface) indicates higher strain values than the central (Section 1 and Section 2). Regarding all sections, higher strain values are found in ∅4×1 mm sized Riva Luting samples, compared to ∅3×1 mm sized Riva Luting samples. Group I and Group II show a non-homogeneous strain field, especially in the centre of the sample. The peripheral zone was subjected to the highest strain values in both groups.

Displacement fields showed opposite directions i.e. negative values inside Sections for both cements. Negative values indicate displacement in the perpendicular direction, since the Z-axis is pointed toward the cameras, /14/. A consistency of presented results is noticed for the highest displacement values in the ∅3×1 mm sized Riva Luting samples related to Sections 1 and 2, as seen in Fig. 4. However, the highest displacement value is registered in ∅4×1 mm Riva Luting for Section 0 and Section 1, as seen in Fig. 2.

Increased non-uniformly distributed shrinkage strain and displacement in the peripheral region were detected. For clinicians this is very important due to fact that interface-surfaces placed between restoration and tooth structure might be deteriorated over time due to high strain and displacement values. Additionally, high strain values in Riva Luting cement can cause cement failure, /5/, from the restoration or the tooth, due to shrinkage.

CONCLUSIONS

This study shows the significant role of DIC method for investigating the shrinkage strain and displacement of GIC. It can be concluded that variability in sample preparation influences the values of strain and displacements. Group I and Group II show a non-homogeneous strain field, especially in the centre of the sample. The peripheral zone is subjected to the highest strain values in both groups. Maximum deformation value could be measured with the DIC method but also by monitoring the change in the deformation field, even after the recommended time of polymerization. This represents the advantage of the DIC method compared to other methods. For this reason, DIC presents a powerful tool for investigating possible failure in dentistry research field. The results are also material-dependent and correlated to the composition of the material. The role of each component in the final properties of the material have not been clarified yet. The complex formulation of tested GIC is only partially disclosed by manufacturer, making it difficult to explain the strain differences through material components.

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