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Fatigue Resistance and Flexural Behaviour of a Fiber-Reinforced Resin Composite for Removable Partial Denture Clasps

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It is necessary to evaluate the fatigue resistance of fiber-reinforced resin composites (FRCs) subjected to repeated constant deflections corresponding to the undercut when FRCs are applied to removable partial denture clasps.
The aim of this study was to evaluate the fatigue resistance of FRC clasps (EG fiber: EG fiber of Estenia C & B) using a constant deflection fatigue test, and to compare it with that of a gold-palladium-silver alloy (Pd alloy). The flexural strength, Young's modulus and fracture behaviour of the EG fiber flexural specimens under three-point bending were also evaluated. A constant deflection fatigue test was carried out in air at room temperature either until 990,000 deflections were completed, or until clasp fracture, or permanent deformation was detected. Repeated constant deflections of either 0.25mm or 0.5mm were administered to the clasps by reciprocating movements of a loading rod. The clasp resistance against these repeated deflections, that is, the clasp fatigue limit, was measured in terms of the number of repeated cycles. For Pd alloy clasps, the mean value of the clasp fatigue limit was 184,900 ± 66,359 deflections of 0.25mm, and 91,908 ± 6,532 times for 0.5mm, respectively. In these conditions, all Pd alloy clasps were fractured at their clasp fatigue limit. On the other hand, for EG fiber clasps, no permanent deformation was detected even after 990,000 deflections, however, delamination of the glass fiber and a crack expanding horizontally the a longitudinal axis of the clasp were observed on the compression side. The mean values of three-point flexural strength and Young' modulus for the EG fiber were 907.3 ± 35.4 MPa and 24.2 ± 1.4 GPa, respectively. When the stress was increased to exceed the proportional limit, some decreases in strain due to brittle tensile failure of the glass fibers and matrix transverse splitting were observed in the stress-strain curves. The flexural specimen kept supporting the load, however, and no catastrophic failure was observed until the stress increased to its flexural strength.

Key words: removable partial denture clasps, fiber-reinforced resin composites, fatigue resistance,
constant deflections fatigue test

INTRODUCTION

In dental treatments, esthetic demand in restorations has increased with time. In particular, for clasp material, not only excellent mechanical properties but also an aesthetic appearance is demanded. Recently, resin posts and fixed dentures made of fiber-reinforced resin composites (FRCs) have been widely used to prevent the catastrophic fracture of fixed dentures, tooth fracture and metal allergy. FRCs are composed of matrix resins, fibers of unidirectional orientalion, fillers, and a light-curing catalyst. Previous studies[1-16] reported the mechanical properties and the possible clinical application of FRCs including the application of removable partial denture clasps.[17-20] The following findings clarified that these materials have some advantages, that is, they show excellent esthetics, Young's modulus comparable with that of dentine, and excellent mechanical properties due to fiber reinforcement. They can also be applied to patients who have metal allergies.

In FRCs, the EG fiber of Estenia C & B (EG fiber) has attracted special interest because it shows the highest flexural strength[3]. EG fibers are composed of matrix resin such as UDMA and TEGDMA, glass fibers of 11μm in diameter with unidirectional orientation, coroidal silica filler, and a light-curing catalyst.[10] The contains 50mass% of glass fiber, which corresponded to 40% in volume. It is necessary to evaluate fatigue resistance such as the fatigue limit of EG fiber clasp specimens subjected to repeating constant deflections corresponded to undercuts when the EG fiber is applied to removable partial denture clasps. Although pre-

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vious studies[17-20] reported the flexural strength and Young's modulus of EG fibers, the fatigue resistance of the material has not been clarified. The aim of this study is to evaluate the fatigue resistance of EG fiber clasps using a constant deflection fatigue test, and to compare it with that of a gold-palladium-silver alloy clasps. Moreover, the flexural strength, Young's modulus and fracture behaviour of the EG fiber flexural specimens under three-point bending were evaluated.

MATERIALS AND METHODS

An FRC (EG fiber of Estenia C & B EG fiber set, Kuraray Med. Inc.) was used in this study. A Pd alloy (Tokuriki Kinpara Ace 12S, Tokuriki) was used as a control. Shown in Fig.1 is the shape and size of the clasp specimens for the constant deflection fatigue test. EG fiber clasp specimens formed in a silicon mould were light-cured with a light curing unit (α-light II N, Morita Co.) for 5 minutes. After this process, the clasp specimens were post-cured at 110℃ in a heat curing device (KL-310, Kuraray Med Inc.) for 5 minutes according to the manufacture's instructions. After polymerization, the surface of the clasp specimens was polished with silicon carbide abrasive paper of #1200. Three clasp specimens were fabricated for each condition. The Pd alloy clasps were made according to the following method: wax patterns formed in the silicon mould were invested in a cristobalite investment material (Cristobalite Q, Dentsply-Sankin K.K.). The Pd alloy was cast with apparatus based on centrifugal force. The Pd alloy clasps were sandblasted with glass beads with a mean grain size of 74㎛ at an air pressure of 8 kPa. The surface of the clasps was polished with #1200 silicon carbide paper.

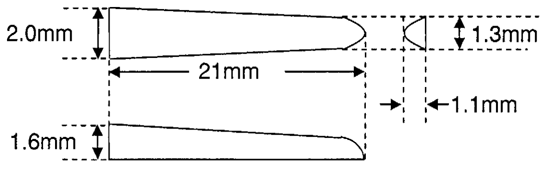

Fig.1 Schematic illustration of a clasp specimen for a constant deflection fatigue test.

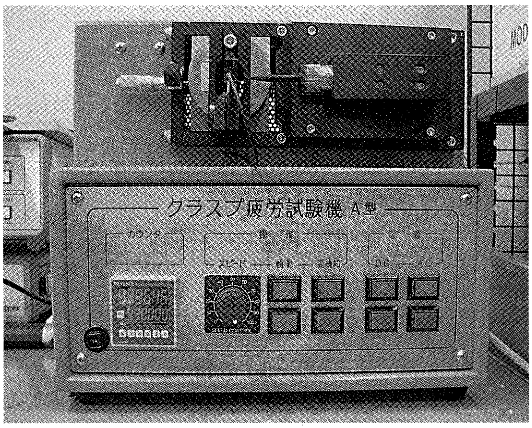

Fig.2 A photograph of the constant deflection fatigue machine.

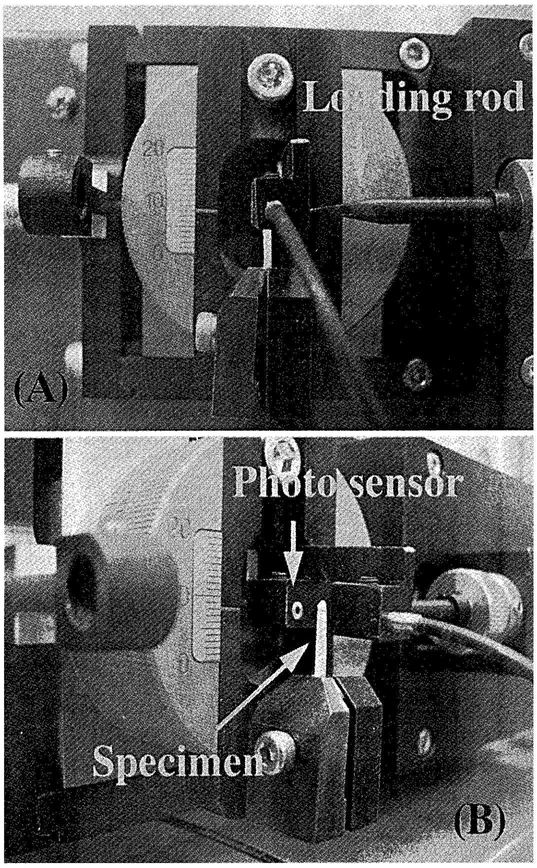

Fig.3 Magnified photographs of the fatigue machine. (A): Repeated constant deflections can be applied to the clasp by reciprocating movements of a loading rod. (B): The permanent deformation that occurred due to repeating constant deflections was detected with a photo sensor attached to the fatigue machine.

Constant deflection fatigue tests of the clasps were carried out with a fatigue machine (Clasp Fatigue Machine Type A, Ito Eng.) in air at room temperature. Fig.2 shows a photograph of the fatigue machine, and magnified photographs of the fatigue machine are shown in Fig.3 (A) and (B). The flat inner surface of the clasps was placed at a right angle to a loading rod, and an 8.6㎜ part from the bottom of the clasp was fixed (Fig.3 (A)). Repeating constant deflections can be applied to clasps by the reciprocating movements of the loading rod. Constant deflections of either 0.25㎜ or 0.5㎜ were applied to 2㎜ from the point of the clasps at a loading frequency of 1.83Hz assuming that the clasp was inserted and removed from an abutment tooth with a undercut of either 0.25mm or 0.5mm. As shown in Fig.3 (B), permanent deformation due to the repeating constant deflections was detected with a photo sensor attached to the fatigue machine. The reciprocating movement of the loading rod was stopped when permanent deformation was caused in the clasp specimen. The fatigue test was carried out either until 990,000 deflections were completed, until the clasp specimens fractured, or until permanent deformation was detected. The resistance of the clasps against repeated deflections, that is, the clasp fatigue limit, was measured in terms of the number of repeated cycles. After the fatigue test, the surface of the clasps was observed using a digital microscope (VHX-100, Keyence Co. Ltd.)

A stainless steel mould was used to prepare the EG fiber flexural specimens, which were cured using the same methods as the clasps for the constant deflection fatigue test. The top and bottom surfaces of the flexural specimens were polished 1mm×4mm×30mm with #2400 silicon carbide abrasive paper using an automatic polishing machine (Abramin, Marumoto Struers Inc.). Before flexural tests, all EG fibre flexural specimens were immersed in 37℃ distilled water for 1week.

The Three-point flexural test was carried out with a universal testing machine (EHF-FB5KN-10LA; Controller 4826, Shimazu Co.) in air at room temperature. The load was applied to the center of the flexural specimens at a loading rate of 0.5N/sec using a three-point flexural jig with a support distance of 30mm. Loading was continued until the flexural specimens failed, and the maximum load sustained was measured.

Three-point flexural strength, σ_f, was calculated using the following equation:

$$\sigma_f = 3wL/2ab^2 \qquad (1)$$

where, a and b are the width and the thickness of a flexural specimen, respectively. L is the support distance, and w is the maximum load sustained. Three specimens were used for each condition, and the mean value and standard deviation of the three-point flexural strength were calculated.

Young's modulus of the EG fibre flexural specimen immersed in 37℃ distilled water for 1week was estimated as follows: A strain gauge (Epoxy foil strain gauge, F-2-12, Minebea Co., Ltd.) was bonded to the central part of the tensional surface with a cyano-acrylate adhesive (Strain gage cement, CC-33A, Kyowa Electronic Instruments Co., Ltd.). The stress-strain curves of the EG fibre specimens during three-point bending were measured at a loading rate of 0.5N/sec using a universal testing machine. The output of the strain gauge was amplified (Strain Amp, DSA-606B, Minebea Co., Ltd.) through a bridge box (DB, Kyowa Electronic Instruments Co., Ltd), sampled at a sampling rate of 50Hz by an analogue to digital converter (MP100, Monte System Co., Ltd.), and analyzed using a data analysis program (AcqKnowledge, Monte System Co., Ltd.). The output from the load cell attached to the universal testing machine was also recorded by computer by synchronizing it with the output from the strain gauge. The measurement was repeated 6times for each of three specimens up to 50N. Finally, to evaluate the fracture behavior of the EG fibre specimens, all specimens were fractured with the strain gauge under three-point bending at a loading rate of 0.5N/sec.

RESULTS and DISCUSSION

From the results of constant deflection fatigue tests, for the case of Pd alloy clasps, the mean values of the clasp fatigue limit were 184,900±66,359 deflections of 0.25mm, and 91,908±6,532 of 0.5mm, respectively. In these conditions, all Pd alloy clasps were fractured at their clasp fatigue limit. On the other hand, for the EG fiber, no permanent deformation was detected even after 990,000 deflections. If a patient removes the partial denture five times a day, the total number of deformation cycles is calculated to be 18,250 times over ten years. Hamano et al.[17] also calculated that the accepted clasp fatigue limit should be 20,000 times over 20years. It was found from our result, that both EG fiber and Pd alloy clasps show enough sufficient resistance against repeated constant deflections corresponding to undercuts.

Shown in Fig. 4 is a optical microscopic image of the EG fiber clasp after 990,000 deflections of 0.5mm were completed. Delamination of the glass fiber and a crack expanding horizontally to a longitudinal axis of the clasp specimen was observed on the compression side near the grip end[21]. Although no permanent deformation was detected after 990,000 constant deflections, the occurrence of these micro fractures may cause serious problems for clasps made of the EG fibers in the oral environment. Therefore, it is necessary to clarify when and how the glass fibers were delaminated and the crack occured during constant deflection fatigue tests. In particular, the clarification of fracture behavior in EG fibers under compression might be important.

The mean value of three-point flexural strength for the EG fibers was 907.3±35.4MPa. All flexural specimens

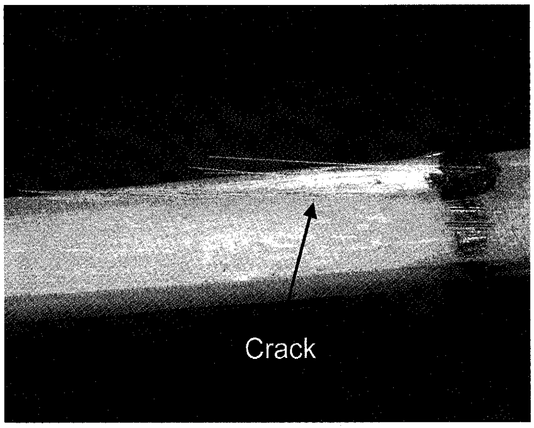

Fig.4 An optical microscopic image of the EG fiber clasp after 99, 000 deflections of 0. 5㎜ were completed. Delamination of the glass fibers and a crack expanding horizontally to the longitudinal axis of the specimen was observed on the compression side near the grip end.

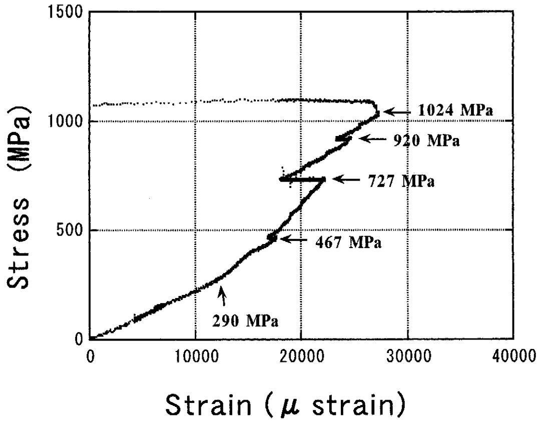

Fig.5 A typical example of the stress-strain curve for an EG fiber flexural specimen immersed in 37℃ distilled water for 1week under three-point bending.

were immersed in 37℃ distilled water for 1week before flexural tests, because removable partial denture clasps are in direct contact with saliva in the oral environment. Fujii et al.[16] reported that the mean three-point flexural strength of EG fibers in dry condition was 1000±89MPa. Since the size of the flexural specimen, the support distance of the flexural jig, and the loading rate are different, it is not possible to compare the mean flexural strength directly. However, one reason why the mean flexural strength decreased by about 10% compared with that measured by Fujii et al. might be the effect of water sorption. Although the water sorption of the EG fibers was not measured, Fujii et al. also showed that the flexural strength of the EG fibers decreased to about 800MPa after water a sorption test in 37℃ distilled water for 8days.

The mean value of Young's modulus of EG fibers immersed in 37℃ distilled water for 1week under three-point bending was 24. 2±1. 4GPa. Nakamura et al.[3] also measured Young's modulus of dry EG fibers to be 25. 4±1. 3 GPa, calculated based on the deflection of the flexural beam specimen assuming that deflection under bending followed simple beam theory for isotropic materials. On the other hand, in our experiments, the strain on the flexural specimen was measured directly using a strain gauge. Although the influence of water sorption on Young's modulus of EG fibers is uncertain, the measuring method was different, and Young's modulus was almost equalled.

Shown in Fig.5 is a typical example of a stress-strain curve for a EG fiber flexural specimen when loading was applied until fracturing of the flexural specimen. In the EG fiber specimen, the proportional limit and the three-point flexural strength were 290MPa and 1024MPa, respectively. When the stress was increased exceeding the proportional limit, some decreases in strain (at stresses of 467MPa, 727 MPa and 920MPa) due to brittle tensile failure of the glass fibers and matrix transverse splitting were observed. However, the flexural specimen kept supporting the load and no catastrophic failure was observed until the stress increased to its flexural strength (1, 024MPa). In previous studies[1-16] on the mechanical properties of FRCs, only flexural strength was measured, with comparison of the materials. Since EG fibers show the complex fracture behavior as shown in Fig.5, when EG fibers are used as clasps, it is necessary to design the generated stress to be below the proportional limit. Secondly, the effect of repeating constant deflections on stress at which the delamination of glass fibers and matrix transverse splitting occurred before catastrophic fractures should be clarified.

Fig.6 (A) and (B) show photographs of a combination clasp on the cast of an upper first premolar. The retentive and reciprocal arms of the clasp were fabricated with EG fibers and Pd alloy, respectively. As shown in Fig.6 (B), the combination clasp has a good esthetic appearance. As water sorption might influence the mechanical properties of EG fibers, it is necessary to examine its effect on fatigue resistance. Moreover, the effects of wear between the EG fiber clasp and an abutment tooth on the fatigue life and retentive force of the clasp should be clarified.

CONCLUSIONS

Within the limitations of this study, it is suggested as fol-

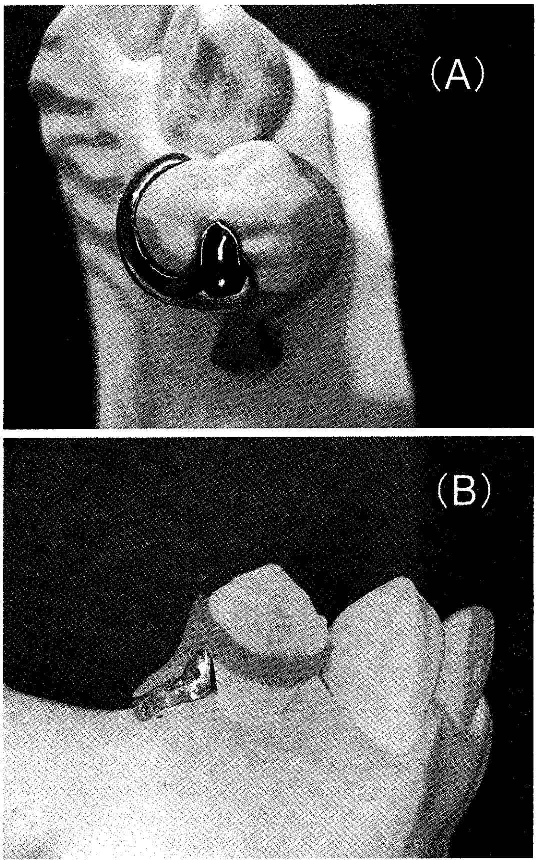

Fig.6 A combination clasp on the cast of an upper first premolar. The retentive and reciprocal arms were fabricated with EG fibers and Pd alloy, respectively.

lows:

1) For EG fiber clasps, no permanent deformation was detected after 990,000 constant deflections of 0.5mm. However, delamination of the glass fibers and a crack expanding horizontally to the longitudinal axis of the clasp specimen was observed on the compression side.

2) The mean values of three-point flexural strength and Young's modulus for the EG fibers were 907.3±35.4MPa and 24.2±1.4GPa, respectively. When stress was increased exceeding the proportional limit, some decreases in strain due to the brittle tensile failure of the glass fibers and matrix transverse splitting were observed in the stress-strain curves; however the flexural specimen kept supporting the load and no catastrophic failure was observed until the stress increased to its flexural strength.

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