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Comparative analysis of a light-cured composite material reinforced with selected synthetic fibers

Introduction

Current recommendations of minimally invasive dentistry place great demands on light-curing composite materials (composites). The main lines of research being carried out to improve the physical and chemical parameters of composites focus on the introduction of *Fiber-Reinforced Composite* (FRC) as a reinforcing phase while reducing the weight of the composite material. Glass fibers are most commonly used, much less frequently carbon and polyamide fibers (aliphatic, such as nylon, or aromatic, such as aramid). In FRC structures, the role of fibers is to improve the mechanical properties of the organic polymer matrix. Restorations made of fiber-reinforced composite are lighter compared to those made of traditional materials such as ceramic or metal. The high mechanical strength of the FRCs translates to their ability to effectively compensate bite forces. The desirable resistance to forces, while maintaining a low rest mass of reinforcing fibers, make FRCs widely used in many areas of dentistry, such as prosthodontics, restorative dentistry, implantology, periodontics and orthodontics. However, FRC composites are not without flaws and are prone to structural change processes that generally result in adverse changes in the mechanical properties and other characteristics of these materials. Most of the literature items relating to the analysis of FRC composites and their degradation mechanisms distinguish characteristic degradation stages that occur most frequently in succession: matrix cracking (imperfections), delamination associated with adhesion cracking (fiber-matrix cracking and layer cracking) fiber wear, which can lead to complete degradation of FRC. For this reason, it seems reasonable to determine the properties of materials that can be used in the fabrication of prosthetic restorations.

Aim of the study

The main objective of the study was to evaluate data on the physical and mechanical characteristics of materials that can be used in the fabrication of fiber-reinforced fixed prosthetic restorations: classic bridges made of composite and special (adhesive) bridges, composite crowns and crown-root inlays.

The specific objectives of the work were planned:

1. Evaluation of the strength parameters of the composite material reinforced with one single strand of synthetic fibers.
2. Evaluation of the strength parameters of the composite material reinforced with two single strands of synthetic fibers.
3. Comparative analysis of the strength parameters of the composite material reinforced with one single strand versus two single strands of synthetic fibers.
4. Analysis of the mechanical structural changes resulting from strength testing.
5. Evaluation of defects in the composite material-fiber system formed at the stage of sample manufacturing.

Material and Methods

The test material included composite samples reinforced with single (one or two) strands of fibers. Fiber strands used were glass (SKL), carbon (WGL) and aramid (AMD), as well as hybrid strands created for purpose of this work: glass-carbon (SKL-WGL), carbon-aramid (WGL-AMD) and glass-aramid (SKL-AMD). Light-curing Gradia Direct Posterior composite in colour A2 (*GC Corporation, Tokyo, Japan*) and composite-compatible bonding material G Bond (*GC Corporation, Tokyo, Japan*) were used in the study. The composite was reinforced by strands of the aforementioned fibers connected to each other without twisting. The weight ratio of fibers in all hybrids was 1:1.

A total of 130 samples were tested, with the test group consisting of a total of 120 composite samples with the presence of synthetic fibers used as reinforcement and the control group (KONT), which included a series of 10 composite samples without the addition of fibers. The study group was divided into two subgroups, each consisting of 6 runs of 10 samples. Samples in subgroup one was reinforced with one single fiber strand (SKL 1, WGL 1, AMD 1, SKL-WGL 1, WGL-AMD 1, SKL-AMD 1), while samples in subgroup two were reinforced with two single fiber strands (SKL 2, WGL 2, AMD 2, SKL-WGL 2, WGL-AMD 2, SKL-AMD 2). Samples for strength testing were prepared in accordance with the guidelines of the International Standard PN-EN ISO 4049:2019-07. The specimens were subjected to strength tests in the form of the *Three Point Flexure Strength* (TFS) test, which made it possible to determine the maximum bending force, deflection arrow, flexural strength and Young's modulus. Static bending tests in a three-point loading system were carried out using a certified Zwick 1435 testing machine (*Zwick/Roell GmbH & Co. KG, Germany*) with a strain gauge force measuring head sensor in the range up to 0.5 kN. Following the strength tests, the damaged samples were analysed using a Keyence VHX-900F optical microscope (*Keyence International, Belgium*) and a Hitachi TM 3000 Scanning Electron Microscope (*Hitachi High Technology Corporation, Japan*). Each sample was observed at 100x, 200x, 400x, 500x and 1000x magnifications.

Results

Analysing the obtained strength test results, it can be concluded that among the specimens reinforced with one single strand of fibers, the highest values in terms of the four tested strength parameters were obtained by the specimens from the AMD 1 group. They achieved a maximum bending force of 63 N, which was three times greater than that of the KONT group. The presence of one single strand of aramid fibers resulted in a threefold increase in deflection, while Young's modulus increased by more than 140%. Compared to the KONT group, the AMD 1 samples were more than 280% stronger in flexural strength. Worse results were obtained by samples from the SKL-AMD 1 and SKL 1 groups. Samples WGL 1, WGL-AMD 1 and SKL-WGL 1 showed the least improvement in the four tested strength parameters, and the achieved values of the tested parameters were at a similar level.

The strength tests carried out showed that among the specimens reinforced with two single strands of fibers, many analogies to the results achieved in the tests of specimens with the presence of one single strand of fibers were noted. Samples from the AMD 2 and SKL-AMD 2 groups proved to be the most resistant to bending. Reinforcement with two single strands of aramid fibers or glass-aramid hybrid improved the bending strength by nearly three times, while the value of the maximum bending force increased by about 40 N. The lowest bending strength at the same time the lowest values of the maximum bending force were shown by samples from the WGL 2 group. Almost twice the value of Young's modulus compared to the KONT group, and thus the most rigid were the samples from the SKL 2, AMD 2, WGL-AMD 2, SKL-WGL 2 groups. These samples reached a Young's modulus value of more than 8 GPa.

Comparing the results of the strength parameters of specimens reinforced with one single strand of fiber to those reinforced with two single strands of fiber, it can be concluded that the fiber content of the specimen affects all the strength parameters tested, but has the greatest effect on Young's modulus. Samples reinforced with glass fibers, aramid fibers and a glass-carbon hybrid showed significant increases in stiffness. Analysis of the data revealed that the greatest difference in average Young's modulus values occurred in the case of the glass-carbon hybrid, as an increase in content from 2% w/w to 4% w/w resulted in an increase in Young's modulus of 2.35 GPa, and this increased the stiffness of the sample by almost 40%.

Analyses of the samples using optical microscopy and SEM confirmed that many similarities were observed in both the samples reinforced with one single and two single fiber bundles. Degradations such as cracks in the fiber-composite boundary layer (known as debonding), cracks in the composite matrix, delamination and fiber failure were evident. Degradations were both local and covered a large area involving multiple layers or the entire sample. Very often, different types of degradation were observed in a single sample. The most common phenomenon, debonding, i.e., fiber-composite boundary layer cracking, was observed in about 90% of the test group's samples.

Conclusions

The analysis of the results obtained in the study led to the following conclusions:

1. Aramid fibers used in both single and double strands can be recommended as reinforcement for composite restorations due to their strength parameters.
2. In clinical application, a hybrid of glass and aramid fibers may be considered among samples reinforced with two single strands of fibers.

3. The use of carbon fibers in clinical work with a weight content of 4% in the composite material is not recommended because of the decrease in flexural strength and reduction in stiffness of the FRC material.
4. The boundary of the fiber-composite interface was the weakest point in the layering that fiber-reinforced composite materials form.
5. As the number of layers of FRC materials increases, the likelihood of cracks running through the entire thickness of the sample and the appearance of delamination increases.
6. The manual method of making specimens can be successfully used when making prosthetic restorations under clinical conditions, as it did not impair the obtained results of strength parameters.