A Study on the Fatigue Characteristics of Bonded Parts of the Carbon Fiber Reinforced Dental P.M.M.A.

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In this paper we describe an experimental study. Reported in this article are results of tensile fatigue test under constant stress amplitude applied to bonded section of carbon fiber reinforced dental P.M.M.A., which tensile fatigue test was conducted in comparison with that of the parent material in order to find out fatigue characteristics of the bonded section of the dental P.M.M.A.

As a result of the research of test and experiments, it is found that:
1) It is noted that fatigue characteristics of composite material of C.F. 1 wt.%/P.M.M.A. are good.
2) For adhesion of composite material of C.F. 1 wt.%/P.M.M.A., a scarf joint should be adopted.
3) Adhesion by heat-cured type acrylic resin is effective.

1. INTRODUCTION

Dental material in cavum oris is always subjected to repeated load and is under stress, thus fatigue characteristics of the dental material itself in cavum oris become a matter of concern. Many of the dental material in cavum oris has combined structures, and the load, when applied repeatedly, produces fatigue. Generally speaking, failure of the dental material in cavum oris under repeated load occurs at the combined structure. Reported in this article are results of tensile fatigue test under constant stress amplitude applied to bonded section of carbon fiber reinforced dental P.M.M.A., which tensile fatigue test was conducted in comparison with that of the parent material in order

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to find out fatigue characteristics of the bonded section of the dental P.M.M.A. Reported in this article as well are mechanical properties of composite materials which were made by way of trial using carbon fiber to reinforce P.M.M.A.

2. EXPERIMENTAL MATERIAL AND EXPERIMENTAL METHOD

Series of experiments consisted of tension, bending and fatigue tests of composite materials of P.M.M.A./chopped strands, tension and fatigue tests of bonded materials of such composite materials, tension, bending and fatigue tests of bonded material of the P.M.M.A./prepreg composite material, and observation by S.E.M. of fatigue fracture of composite material of P.M.M.A./chopped strands. Test pieces were made of (i) acrylic resin of heat-cured type (Denture Acrylic, SHOFU "Bio" Resin) heated for 45 minutes in 100°C under 100kg/cm² pressure and molded by natural cooling, (ii) the same acrylic resin as above, but at first mixed with chopped strands of carbon fiber (Toreca T300; 3,000 filaments) which was cut into 3mm in length, washed with acetone and dried, thence heat- and pressure-molded, and (iii) prepreg of C.F./epoxy. Adhesion was by acrylic resin of low temperature cured type and of heat-cured type; but in case of P.M.M.A./prepreg composite material, self-adhesion was adopted. Apparatuses used for experiments were Shimazu’s Autograph IS-2000 for tension and bending tests and Shimazu’s Servopet Lab-5P for fatigue test with which tension was applied to pre-

![Fig.1 Specimens for fatigue test.](image)

### Table 1 Mechanical properties of C.F./P.M.M.A. composite materials.

<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>Content ratio of carbon fiber (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Tensile strength (kg/mm²)</td>
<td>7.0</td>
</tr>
<tr>
<td>Young’s modulus (kg/mm²)</td>
<td>200</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>329</td>
</tr>
<tr>
<td>Bending strength (kg/mm²)</td>
<td>9.0</td>
</tr>
<tr>
<td>Bending elastic modulus (kg/mm²)</td>
<td>260</td>
</tr>
<tr>
<td>Deflection (mm)</td>
<td>—</td>
</tr>
</tbody>
</table>
3. EXPERIMENTAL RESULTS AND CONSIDERATION

Table 1 shows summary of results of tension and bending tests conducted with trial-manufactured carbon fiber reinforced P.M.M.A. having 0-3 wt.% carbon content. It is known from Table 1 that strength and elastic modulus increased, while elongation and deflection decreased, as C.F. content became bigger, and effectiveness of reinforcement of P.M.M.A. is proved. Fig.1 shows shape and size of test piece for fatigue test, which applied correspondingly to fatigue test piece for Baldwin SF-01. S-N curves of P.M.M.A. parent material and of bonded materials of P.M.M.A. bonded with acrylic resins of heat-cured type and low temperature type are shown in Fig.2. It is known from this figure that fatigue strength was 2.0, 1.8 and 1.4kg/mm² respectively, which means that fatigue strength of the specimen bonded with heat-cured type acrylic resin was 90% and the specimen bonded with low temperature type acrylic resin was 70% against that of the parent material respectively. Fatigue limit with repeated stress with any of the specimens was $10^6$. Fig.3 is the comparison of S-N curve of self-adhered material of C.F./P.M.M.A. sandwich material and fluid acrylic resin with that of bonded material of P.M.M.A.. Fatigue strength of self-adhered material of composite material and fluid acrylic resin

![Fig.2 Relation between stress amplitude and number of cycles to failure for adhered P.M.M.A..](image-url)
was 0.7 kg/mm², which was only 35% of that of P.M.M.A. parent material and 39% of that of P.M.M.A. bonded material. Fig. 4 is the comparison of S–N curves of composite materials having 0.5 and 1.0 wt.% of C.F. mixed in acrylic resin and the S–N curve of P.M.M.A. parent material. Fatigue strength of the C.F. 0.5 wt.%/P.M.M.A. material was 2.2 kg/mm², while that of C.F. 1.0 wt.%/P.M.M.A. material was 2.3 kg/mm², which corresponded to 110 and 115% of that of the parent material respectively. S–N curves of P.M.M.A. material reinforced with 1 wt.% of C.F. and two kinds of bonded materials bonded with heat-cured type acrylic resin are shown in Fig. 5. Fatigue strength was 2.3, 2.1 and 1.7 kg/mm², while

![Figure 3](image1.png)

**Fig. 3 Relation between stress amplitude and number of cycles to failure for self adhered C.F. prepreg/P.M.M.A. sandwich and fluid acrylic resin.**

![Figure 4](image2.png)

**Fig. 4 Relation between stress amplitude and number of cycles to failure for C.F./P.M.M.A. composite materials.**
Fig. 5 Relation between stress amplitude and number of cycles to failure for adhered C.F./P.M.M.A. composite materials.

Table 2 Tension test results of adhered P.M.M.A. and C.F./P.M.M.A. composite materials.

<table>
<thead>
<tr>
<th>Joint type</th>
<th>Tensile strength (kg/mm²)</th>
<th>Young's modulus (kg/mm²)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid acrylic resin - PMMA</td>
<td>4.4</td>
<td>248</td>
<td>2.0</td>
</tr>
<tr>
<td>Fluid acrylic resin - PMMA</td>
<td>5.3</td>
<td>227</td>
<td>2.7</td>
</tr>
<tr>
<td>Fluid acrylic resin - CF 10wt%/PMMA composite material</td>
<td>4.8</td>
<td>269</td>
<td>2.2</td>
</tr>
<tr>
<td>Fluid acrylic resin - CF 10wt%/PMMA composite material</td>
<td>5.5</td>
<td>235</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Table 3 Tension test results of self adhered C.F. prepreg and C.F. prepreg/P.M.M.A. sandwich structure.

<table>
<thead>
<tr>
<th>Joint type</th>
<th>Tensile strength (kg/mm²)</th>
<th>Young's modulus (kg/mm²)</th>
<th>Elongation (%)</th>
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</thead>
<tbody>
<tr>
<td>Fluid acrylic resin - PMMA</td>
<td>4.4</td>
<td>248</td>
<td>2.0</td>
</tr>
<tr>
<td>Self-adhesion - Fluid acrylic resin - CF prepreg</td>
<td>1.5</td>
<td>296</td>
<td>0.5</td>
</tr>
<tr>
<td>Self-adhesion - Fluid acrylic resin - CF prepreg/P.M.M.A sandwich structure</td>
<td>3.2</td>
<td>280</td>
<td>1.3</td>
</tr>
</tbody>
</table>
(a) P.M.M.A.; $\sigma=2.3\text{kg/mm}^2$

(b) P.M.M.A.; $\sigma=3.0\text{kg/mm}^2$

(c) Adhesion with C.F. 1.0 wt.%/P.M.M.A.; $\sigma=1.8\text{kg/mm}^2$

(d) Adhesion with C.F. 1.0 wt.%/P.M.M.A.; $\sigma=1.8\text{kg/mm}^2$

(e) Adhesion with C.F. 1.0 wt.%/P.M.M.A.; $\sigma=3.0\text{kg/mm}^2$

(f) Adhesion with C.F. 1.0 wt.%/P.M.M.A.; $\sigma=3.0\text{kg/mm}^2$

Photo. 1 The appearances of fatigue fracture of P.M.M.A. and C.F./P.M.M.A. composite material by S.E.M. (Hitachi HSM-2A).
Joint efficiencies of butt joint and 45° scarf joint were 74% and 91% respectively, which were in proportion to adhesion area. Tensile strength, elastic modulus and elongation of various bonded materials of P.M.M.A. and C.F.R-P.M.M.A. are shown in Tables 2 and 3. It is known that tensile strength and elongation of C.F. prepreg are low, but this is considered to be due to resin content ratio (40%). It is also found that a scarf joint is superior with regard to adhesion strength and elongation, and is correlative with adhesion area. Photo.1 shows S.E.M. pictures of fatigue fracture of bonded section of P.M.M.A. and C.F.R-P.M.M.A. bonded with C.F.R. acrylic resin. Stress concentration on account of existence of reinforcement was little, and the fracture on the contrary looked like fatigue failure on adhesion interface.

4. CONCLUSION

The following summary can be made from the results of the present research. 1) It is noted that fatigue characteristics of composite material of C.F. 1 wt.%/P.M.M.A. are good. 2) For adhesion of composite material of C.F. 1 wt.%/P.M.M.A., a scarf joint should be adopted. 3) Adhesion by heat-cured type acrylic resin is effective.

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