Structural Designing for Sheet Molding Compound

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SUMMARY

Static tensile test and tensile fatigue test were performed by using sheet molding compound (SMC). Load – displacement curve and AE monitoring had a knee point. Residual strength after fatigue was almost same to static strength when fatigue load was at the knee point. The knee point was valid for the index of structural designing in long life.

Keywords: SMC, Structural design, residual strength, knee point, fatigue strength

INTRODUCTION

Sheet molding compound (SMC) consists of glass fiber mat, unsaturated polyester and fillers and so on. SMC is a typical material of the compression molding materials, which used in industry of composite. Good surface smoothness and high productivity are strong point for products, so that products have been used in structural parts of transportation vehicles, water tank, bathtub and other variety of products. It is necessary to determine the suitable allowable stress for each application to keep the quality of the products. In the fatigue loaded case must have been considered when that use for structural parts [1-2]. Fracture properties of SMC were reported from 1980’s [3-7]. Evaluation for residual properties after low load fatigue test mentioned that initial stage of fatigue test occurred low modulus [8].

In this study, static tensile test and tensile fatigue test were performed. Then, the index of structural designing was investigated. The residual strength after low load fatigue test was noticed in the evaluation for the index of structural designing.

MATERIAL AND EXPERIMENTAL METHOD

Materials and Molding Method

SMC used in this study consists of random glass mats of short fiber (average of fiber length: 25mm) and unsaturated polyester resing as illustrated in Fig.1. Glass fiber
content is 30 wt%. The weight of material was 3.4kg/m².

SMC was produced by compression molding machine with 300mm×300mm of the cavity mold. Charge pattern was 100% and molding condition was as follows; mold temperature was 140 °C, mold closing speed was 14.7mm/s, and molding pressure was 5.6MPa.

**Static Tensile Test**

The dimensions of the specimen were 250mm×25mm×8mm, as illustrated in Fig.2. Static tensile test was performed by Instron universal testing machine (Type 4206; Instron Co., Ltd.). Gage length was 170mm, and test speed was 1mm/min. AE (Acoustic Emission) was monitored during tensile test. AE sensor was attached to the specimen where shown in Fig.2, and measuring amplitude was 40dB - 100dB.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen length L(mm)</td>
<td>250</td>
</tr>
<tr>
<td>Specimen width H(mm)</td>
<td>25</td>
</tr>
<tr>
<td>Specimen thickness b(mm)</td>
<td>8</td>
</tr>
<tr>
<td>Gage length L(mm)</td>
<td>170</td>
</tr>
<tr>
<td>Test speed V(mm/min)</td>
<td>1</td>
</tr>
</tbody>
</table>

Fig.2 The condition of static tensile test and the dimension of specimen.
Tensile Fatigue Test

The condition of tensile fatigue test and the dimension of the specimen are shown in Fig.3. The dimension of the specimen was the same as the case of the static tensile test. Fatigue testing machine (PAS-630; TOKYO KOKI Co., Ltd) was used; testing load was tensile - tensile sin load \((R \leq 0)\) in 10Hz. The test was stopped when the number of cycle exceeded \(10^7\).

Residual Strength after Tensile Fatigue Test

In the evaluation of residual strength, the following procedure was executed. At first, the tensile fatigue test was performed and was stopped in arbitrary cycle number. The number of cycle was \(10, 10^2, 10^3, 10^4, 10^5\) and \(10^6\). Afterward, the static tensile test of the specimen with damage (by fatigue test) was performed. In the tensile fatigue test on the evaluation of residual strength, two kinds of load level were applied. One was the load at knee point obtained from the static tensile test of the virgin specimen. The knee point was border point between a linear part and non-linear part. The other was the load at the fatigue strength obtained from the tensile fatigue test of the virgin specimen.

![Fig.3 The condition of tensile fatigue test and the dimension of specimen.](image)

<table>
<thead>
<tr>
<th>Specimen length (l) (mm)</th>
<th>250</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen width (b) (mm)</td>
<td>25</td>
</tr>
<tr>
<td>Specimen thickness (h) (mm)</td>
<td>8</td>
</tr>
<tr>
<td>Gage length (L) (mm)</td>
<td>150</td>
</tr>
<tr>
<td>Amplitude (H) (Hz)</td>
<td>10</td>
</tr>
</tbody>
</table>

EXPERIMENTAL RESULTS

Static Tensile Test

Fig.4 shows load - displacement curve in the static tensile test of virgin specimen. Tensile properties are shown in Table 1. The load increased linearly at first and exhibited a knee point. The knee point was border point between a linear part and non-linear part. The load level of knee point occurrence was 10% of tensile strength.

Fig.5 shows result of AE measurement. AE hit appeared near the knee point, after
then hit increased rapidly caused by final fracture. Initial crack at a knee point was observed as shown in Fig.6. Therefore, a knee point was defined when initial crack occurring point. Fig.7 shows the fracture aspects of tested specimen. After the test, many cracks in the cross direction of loading direction were found on the specimen surface. In the fracture side, pulled out fiber bundle was observed.

![Load - displacement curve in the static tensile test](image1)

**Fig.4 Load - displacement curve in the static tensile test**

<table>
<thead>
<tr>
<th>Max. load (kN)</th>
<th>Tensile modulus (GPa)</th>
<th>Tensile strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.4</td>
<td>10.3</td>
<td>78.3</td>
</tr>
</tbody>
</table>

**Table 1 Tensile properties**

![Result of AE measurement monitored during static tensile test](image2)

**Fig.5 Result of AE measurement monitored during static tensile test**
Tensile Fatigue Test

Fig. 8 shows \( \gamma \)-N plot in the tensile fatigue test of virgin specimen. \( \gamma \) means ratio of the testing maximum load to the static tensile strength. In the case that the ratio was above 28%, a specimen fractured until cycle number \( 10^7 \). On the other hand, the fracture was not generated until cycle number \( 10^7 \) in the case that the ratio was under 28%. Therefore, fatigue strength was 28% of the static tensile strength. Fig. 9 shows the aspects of specimen after fatigue test. Many cracks in the cross direction of loading direction were also found on the specimen surface. The fiber bundle on the fracture surface was dispersed. These aspects were different from the results of static test; schematic drawing was shown in Fig. 10. Cracks in fiber bundles were more exist than the case of static tensile test.
Fig. 8 $\gamma$-N plot in the tensile fatigue test

Fig. 9 Fracture aspects after the fatigue test

(a) Outside View of specimen

(b) Surface of specimen

(c) Specimen side
Residual Strength after Tensile Fatigue Test

Results of residual strength are shown in Fig.11. In the case that fatigue testing load was at the knee point, residual strength and strength obtained by static tensile test were almost the same. This meant that loaded specimen at a knee point was not weakened in strength. In the case that fatigue testing load was at the fatigue strength, residual strength of specimen was 15% lower than the static tensile strength in the point of $10^5$ times.

Fig.11 Residual strength after tensile fatigue test under two levels of testing load

Fig.12 and Fig.13 show the photograph of the side in the specimen loaded at each load level. And Fig.14 and Fig.15 show the schematic drawing of the specimen side. In the case that testing load was at the knee point, many cracks existed in the interface inside fiber bundle. In the case that testing load was at the fatigue strength, cracks were observed in the interface inside fiber bundle and in the resin region. It was considered that the knee point stress hardly could make any cracks in the resin region in the fatigue test. In addition, fatigued specimen at the knee point stress kept the static tensile strength, so that the knee point stress fatigue did not cause specimen fracture. The knee point was useful for structural designing of material in long life.
Fig. 12 Fracture aspects of specimen side. Testing load was the load at the knee point.

Fig. 13 Fracture aspects of specimen side. Testing load was the load at the fatigue strength.
CONCLUSION

In this study, static tensile test and tensile fatigue test were performed and investigated the effect of mechanical fracture behavior to designing stress for SMC products. In the static tensile test, load – displacement curve had a knee point, when initial crack occurring 10% of the static tensile strength. Tensile fatigue strength was 28% of static tensile strength that was above value against the knee point. Residual strength after fatigue was measured and each specimen side observed. As a result, fatigue test with the knee point stress occurred cracks only in fiber bundle and residual strength was not lower than static tensile strength, fatigue with the fatigue strength caused cracks in fiber bundle and resin region. It was considered that the knee point over stress hardly makes resin cracks and specimen fracture. The knee point was valid for structural designing for SMC in long life.
References

4. Ki-Taek Kim and Young-Taek Im, Composite Structures, 35 pp.131-141 (1996)