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MOISTURE DURABILITY PREDICTION OF ADHESIVELY BONDED JOINTS USING ACRYLIC ADHESIVES

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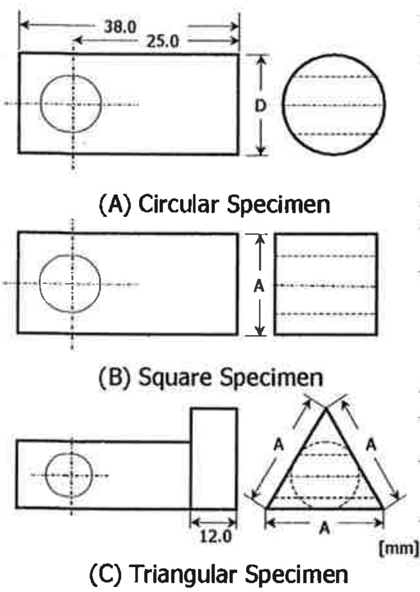
1. Introduction

Adhesives are increasingly being used in structural engineering applications, but a problem frequently encountered is that the mechanical properties of bonded joints, may rapidly deteriorate upon exposure of the joint to aggressive environmental conditions involving heat and humidity. Moisture durability is one of the most important factors of the reliability of adhesively bonded structure. Moisture diffusion to adhesive layer can be calculated by Fick's diffusion law. However, the relationship between the adhesive strength and calculated moisture distribution is not cleared.

In this study, the finite element method (FEM) was applied to acrylic adhesive layer of the tensile butt joints that was tested by humidity exposure for 5 days in 90% relative humidity at 80C. The time dependent distribution of moisture in adhesive layer was calculated. Analytical moisture content distribution was compared with failure mode of butt joints.

2. Experimental Results[1)]

The adherend and adhesive used in this study are SUS304 and acrylic adhesives (C-334, DENKA Co.) respectively. Figure 1 shows specimen configuration. Three types of specimen, that are circular, square and triangular, were tested. Adhesives were cured in 3 days in 25C and 4 days in 80C. Thickness of adhesive layer is between 0.1 and 0.2mm.



A	D [mm]	S [mm²]
1	12.0	113
2	16.0	201
3	18.1	256
4	20.4	327
5	22.0	380
6	25.0	491
7	30.0	707

B	A [mm]	S [mm²]
1	8.0	64
2	12.0	144
3	16.0	256
4	20.0	400
5	25.0	625
6	30.0	900

C	A [mm]	S [mm²]
1	20.8	187
2	27.7	333
3	43.3	812

Fig.1 Specimen configuration.

The static tensile test was performed by the universal testing machine (IS-5000, Shimazu Co.) with crosshead speed 1mm/min. Figure 2 shows the initial tensile strength of all specimens. Figure 3 shows the tensile strength retention P (%) after humidity exposure for 5 days in 90%RH at 80C. P of the circular specimen is highest in three type of specimen. The failure load is proportional to the bonded area (S) but the shape of specimen affects the moisture durability.

Figure 4 shows the typical failure surface before and after humidity exposure. In all specimens, the cohesive failure turns into the interface failure after humidity exposure.

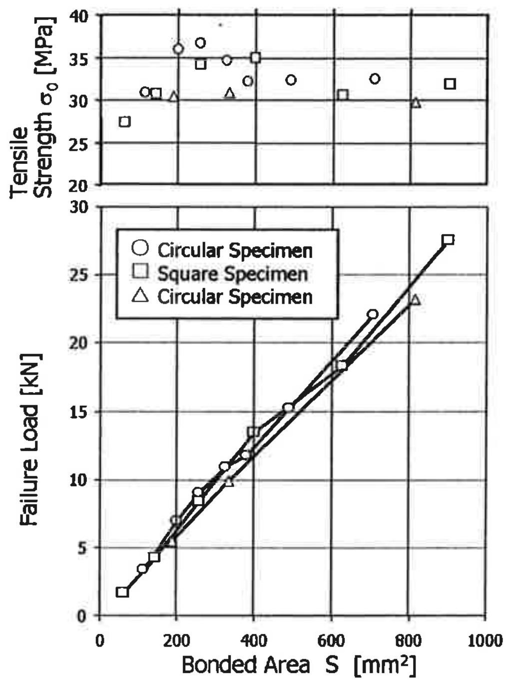


Fig.2 Tensile adhesive strength and bonded area.

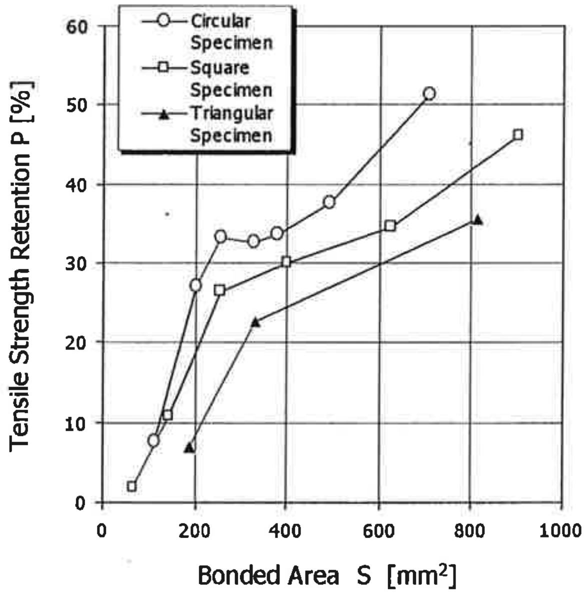


Fig.3 Tensile strength retention P (%) after humidity exposure for 5 days in 90%RH at 80C.

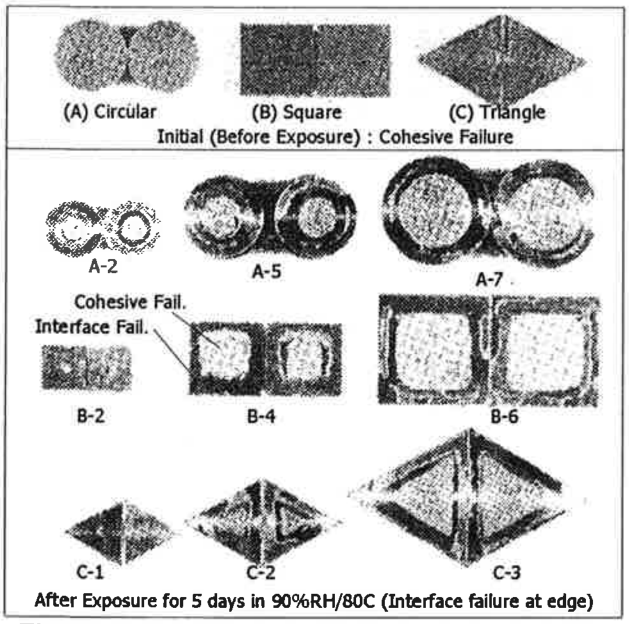


Fig.4 Typical failure surface before and after humidity exposure.

3. Finite Element Analysis

The non-linear Fickean two-dimensional model was applied to adhesive layer. Fick's law for the two-dimensional diffusion of a penetrant within an isotropic material is given by

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}\right), \qquad (1)$$

where C is the penetrant concentration, which is a function of position and time, and D is the diffusion coefficient[2)3)]. The time dependent distribution of moisture in the adhesive was calculated. Figure 5 shows an example of FE model (A-7 specimen).

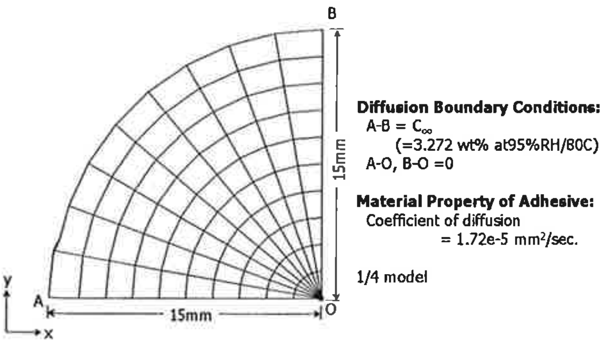


Fig. 5 Finite element mesh division for A-7 specimen.

Figure 6 shows the calculated moisture distribution in the adhesive layer at four different times. The observed failure mode (Fig.4) was also shown. The moisture area of over 20% of saturated moisture content (C_∞) shows the interface failure after exposure. Figure 7 shows the calculated moisture distribution at 5 days of other specimen. The failure mode correlates with the moisture area because over 20% of C_∞ area shows the interface failure.

The adhesive strength was recovered by drying after exposure and the cohesive failure area was spread (Figure 8). Over 80% of C_∞ area shows the interface failure. It is thought that the interface may be broken by water when the water content reaches 80% of C_∞ and the residual adhesive strength can be predicted by the calculation of moisture content distribution.

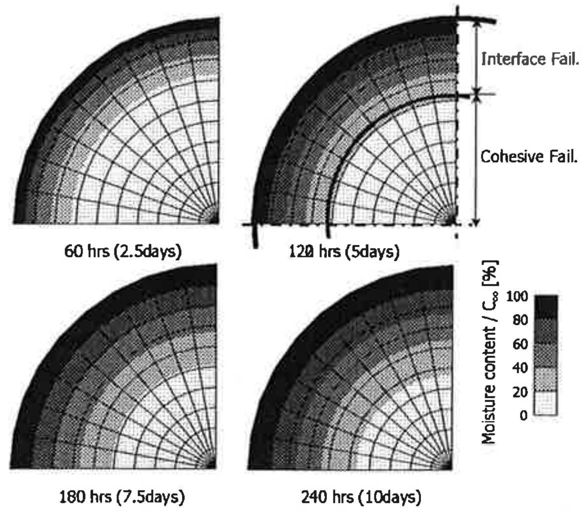


Fig.6 Time dependent distribution of moisture and the observed fracture surface.

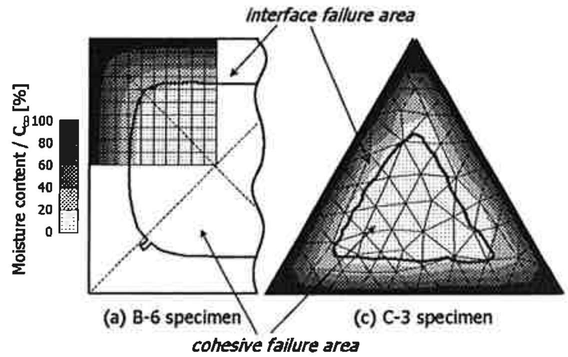


Fig.7 Calculated moisture distribution after exposure for 5 days and the observed fracture surface.

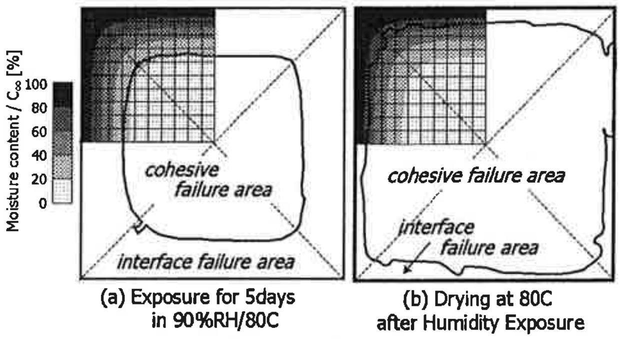


Fig.8 The change in the fracture surfaces by drying after humidity exposure.

References

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