THE FRACTURE TOUGHNESS OF PVC / GRP SANDWICH SYSTEMS IN MARINE ENVIRONMENT

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ABSTRACT

The aim of this study is to investigate experimentally the fracture toughness of sandwich systems with the PVC foam core in marine environment with a Mode-I Cracked Sandwich Beam (CSB) test arrangement. Five CSB specimens at each condition were tested. To get the values under marine environment, one set of specimen was conditioned in a 5% solution of NaCl for a 120 h period at a constant temperature of 50°C. It has been found that the fracture toughness of the PVC foam core material slightly increases under marine environmental conditions. It can be concluded that under the conditions in this study the system with the PVC core was largely unaffected by the immersion process.
Keywords: PVC/GRP Sandwich Systems; Fracture Toughness; Mode-I Cracked Sandwich Beam Test; Environmental Effect

1. INTRODUCTION

In the early 1970, small craft designers realized that a stiffer and lighter structure can be achieved if a sandwich construction technique was used. By laminating two face sheets, inner and outer, to low density core, thus obtaining a structure composed of two highly reinforced sheets located at a considerable distance from the panel's neutral axis. These structures perform exceptionally well when subjected to bending loads produced by hydrodynamic forces [1].

The most common core materials used in all applications except aerospace structures are expanded polymer foams, which are often thermoset to achieve reasonably high temperature tolerances, though thermoplastics foams are used as well. Almost any polymer may be expanded, but the most common ones in sandwich applications are polyurethanes (PUR), polystryrenes (PS), poly(vinyl chloride)s (PVC), poly(methacryl imide)s (PMI), poly(ether imide)s (PEI) and polyphenolics (PF) [2]. The main features of foam cores in sandwich constructions are the ease of production, the relative ease of achieving a good bonding to the faces, good thermal insulation and cost and, for the closed foams, no water absorption problems [3].

During their operational use, sandwich systems are likely to encounter a range of hostile environments such as high temperatures, prolonged seawater exposure and dynamic loading conditions such as those resulting from blast and impact loading [4]. Despite some advantages, these materials suffer in some way from a reduction of the original properties that, if not well understood and prevented, can lead to unexpected structural failures. These aspects should be carefully considered during the design process for a marine structure [5].

The most important of structural failures of a sandwich system that occur during service is the delamination that occurs in the face-core interface, or within the core material. Low energy impact or manufacturing defects can result in separation of the face sheets from the core material. Under certain load and environmental conditions, these defects can grow and eventually cause the separation of the face sheet from the core. Mode-I tests are essential in the proper design of such materials in order to improve the interlayer bonding, as well as the fracture toughness of the sandwich core material [6].

Carlsson et al. [7] and Carlsson and Prasad [8] proposed several tests to investigate the Mode-I and

Table 1: Characteristics of Divinycell H-80 [10]

Property	Unit	Divinycell H-80
Nominal density	kg/m^3	80
Compressive strength	MPa	1.4
Compressive modulus	MPa	90
Tensile strength	MPa	2.5
Tensile modulus	MPa	95
Shear strength	MPa	1.15
Shear modulus	MPa	27
Shear strain	%	30
Poissons ratio		0.32

Mode-II interfacial fracture toughness of sandwich materials. Cantwell and Davies [9] introduced the single cantilever beam, a modified version of the Mode-I.

The effect of marine environment on the fracture toughness of the PVC foam core that are widely used in small craft constructive members has been investigated experimentally in this study. The interfacial fracture toughness is determined using a Mode-I Cracked Sandwich Beam (CSB) tests.

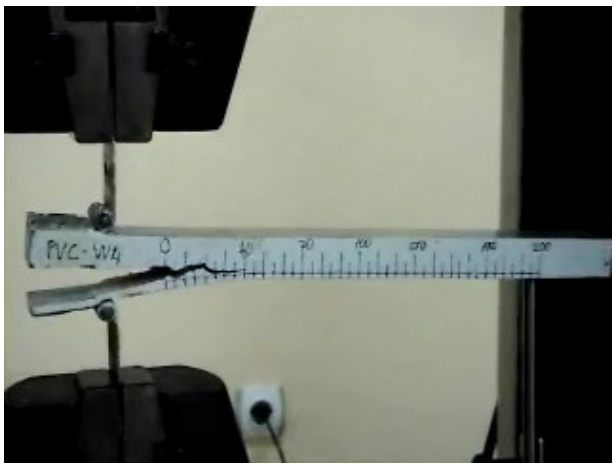

Fig. 1: Fracture toughness test using Mode-I CSB fixture

2. EXPERIMENTAL

2.1. Sample preparation

The PVC foam core (Divinycell H-80 of DIAB, the number of in the foam specification denotes the density in kg/m^3) was chosen as the specimen to be studied. Typical properties of the foam materials are summarized in Table 1. [10]. A typical CSB specimen on the test arrangement is shown in Fig. 1. Dimension of the specimen is 305 mm in length, 40 mm in beam, 15 mm of the core thickness, 2-3 mm of the face thickness.

The face sheets in the species consisted of a Glass Reinforced Plastic containing E-glass fibre fabrics (Chopped Strand Mat, CSM) in an orthophitalic polyester resin (Dewester 196 from the Dewilux Inc.), which is widely used in boat building. The areal weights of CSMs were 300, 450 and 600 g/m2. With the fabrics of the face sheets, a face thickness of 2-3 mm was achieved. The weight fraction of glass of the face sheets was 34%. Face sheets of the sandwich panels were produced by had lay-up by a boat builder in Izmir. The same person laid the glass fibres to overcome possible differences of workmanship practice. Hand lay-up was the preferred method both due to its wide usage in the boat building industry and the case of obtaining a uniform thickness throughout the lamination.

Five CSB specimens at each condition (totally ten)

were machined, since the aim of this job was to obtain a spectrum of results representing the fracture behaviour at dry and wet conditions. After machining the CSB specimens, the abraded surfaces of both the face and the hinge were cleaned with acetone and dried in air. Aluminum hinges were adhesively bonded by the same composite system to the top and bottom face sheets. The hinges, which were mounted to a distance of 25 mm from the one end, acted as load points for CSB specimen.

In order to simulate a crack at the interface, a delamination with a distance of 35 mm from the one end was cut using a fine saw blade into the interface region.

Two sides parallel to thickness directions of the specimens which will be conditioned in salt-infused steam were painted with an epoxy-based paint against the water absorption through these sides.

2.2. Conditioning

The effect of sea water exposure on the interfacial fracture properties of materials was studied by conditioning with steam of a 5% solution of sodium chloride (NaCl) for a 120 h period at a constant temperature of 50°C in a conditioner at the mechanical laboratory of Turkish Standards Institution. Specimens were properly placed in the testing machine so as to be exposed to sea water from all directions homogenously. The specimens, conditioned with salt-infused steam were let to dry in the ambient temperatures until their humidity content dropped to the same values as the non-salt treated specimens.

2.3. Experimental procedure

The specimens were tested on a Shimadzu universal testing machine. During the tests, specimens were supported against rotation and tested at a crosshead displacement rate of 4 mm/min according to ASTM-D5528. After a crack propagation of 3-5 mm, the specimens were unloaded with a high rate (max. 25 mm/min). Mall et al. [11] found that the interlaminar fracture toughness decrease with increasing loading rate. Since 4 mm/min was close to maximum allowable rate in the above mentioned standard (5 mm/min), obtaining the lower fracture toughness values from the tests would be expected.

During the tests, crack propagations were monitored by a video camera. Specimens were loaded until a pre-indicated crosshead displacement, indicating a crack was observed and then unloaded down to a load of 10 N. This test was continued until the specimens failed totally. Applied loads and crosshead displacements were recorded throughout the tests. It was observed that the load dropped as the crack grew in a steady fashion.

3. INTERFACIAL FRACTURE PROPERTIES OF THE SYSTEMS

The resistance to delamination growth can be characterized by the strain energy release rate (G), where the critical energy release rate (G_c) is used as a measure of the interlaminar fracture toughness.

The strain release rate was calculated from the load and displacement values obtained during the fracture tests using the area method. Although this method does not provide initial fracture toughness and the debond growth resistance tends to be generally lower, it is simple to apply to obtained data [12]. The area under a single load/unload cycle was calculated numerically using the trapezoidal rule. Critical energy release rate, also defined as the fracture toughness was obtained using the expression below:

$$G_c = \frac{1}{b} \cdot \frac{\Delta E}{\Delta a} \tag{1}$$

where,

ΔE: the area corresponds to the energy released as the crack grows,

$\Delta\alpha$: the crack extension noted during the test,

b: the width of the specimen.

The value calculated is the average energy consumed for the crack extension $\Delta\alpha$.

4. RESULTS AND DISCUSSION

Randomly selected examples of load-displacement curves under dry and wet conditions are shown in Figs. 2-3. As the crack propagates, the load drops rapidly. This phenomenon can be observed from

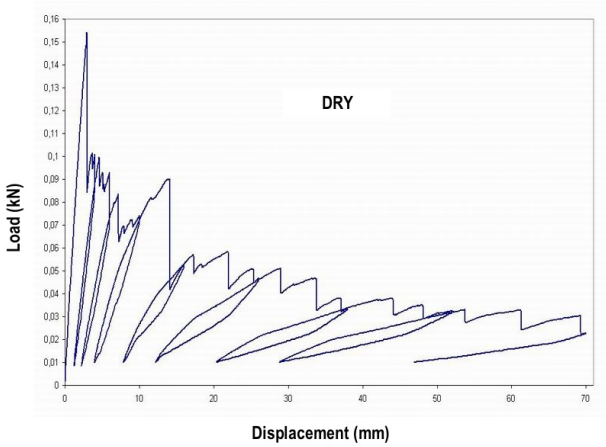

Fig. 2: Load-displacement curves in dry condition

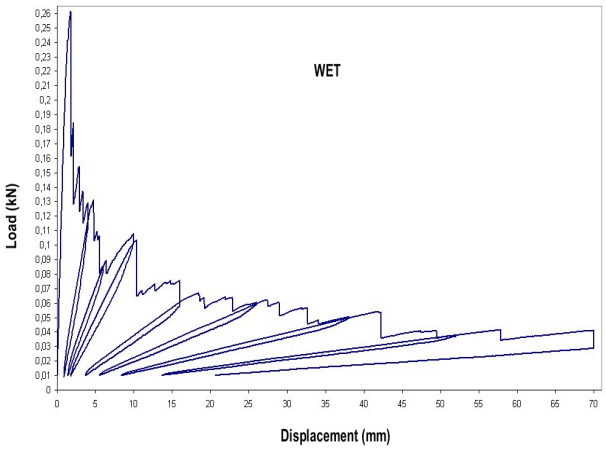

Fig. 3: Load-displacement curves after conditioning

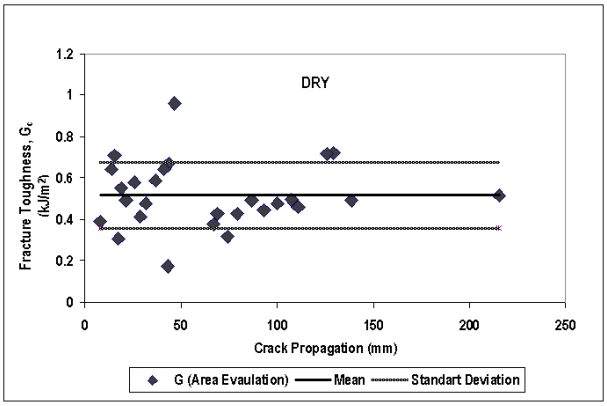

Fig.4: Fracture toughness for various crack lengths in dry environment

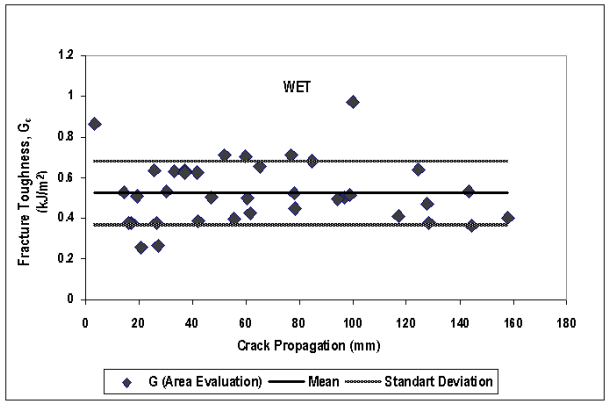

Fig.5: Fracture toughness for various crack lengths after conditioning

those curves.

The results of the areas method outlined above was applied to the load –displacement curves, and the results obtained are shown in Figs. 4-5. Critical energy release rates (fracture toughness) versus crack propagation are indicated in those figures.

The mean values of fracture toughness of cores are 0.517 (kJ/m^2) (± 0.159, Standard Deviation) in dry condition and 0.529 (kJ/m^2) (± 0.155, Standard Deviation) after conditioning. The fracture toughness of the PVC core material increased slightly as a result of the conditioning process.

Majumdar et al. [13] have conducted debond fracture toughness tests for two different foam densities. In their study, it was observed that debond fracture toughness values has increased substantially with increasing foam density. Also density of the foam had an effect on the propagation of the initial crack. With lower density foams, it was observed that initial interface crack kinked into the core and propagated as a sub-interface crack (1-2 mm below the interface). The same behaviour of crack propagation has been observed in this study (Fig. 6). Crack propagation during the tests was also generally stable.

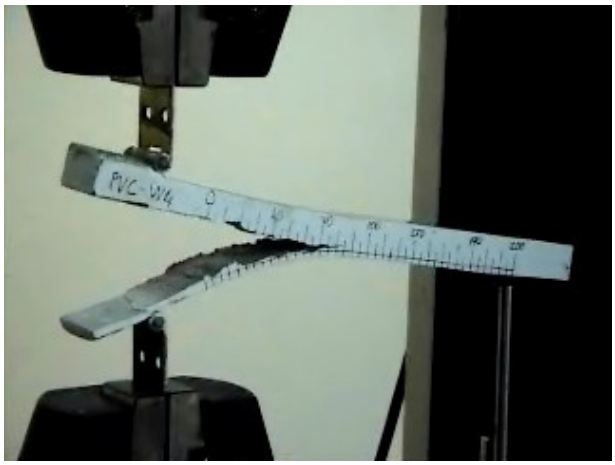

Fig.6: Crack propagation through sub-interface

5. CONCLUSIONS

Experimental comparison of the interfacial fracture toughness of sandwich systems having GRP and the PVC core in two environments (atmospheric and immersion) has been studied by Mode-I CSB test method. It has been found that the fracture toughness of the PVC foam core material slightly increases under marine environmental conditions. The cracks propagated along a plain 2-3 mm below the skin-core interface because of the low density of the core.

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