Monitoring Crack Growth in Layered Polymer Composite Beams using Digital Image Correlation (DIC) System

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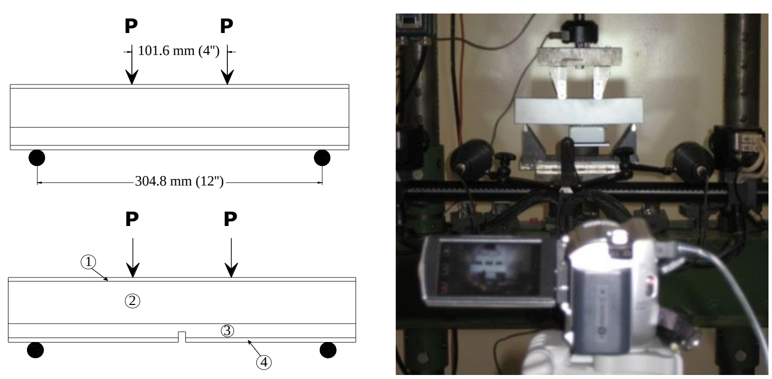
Abstract
In this study, deformation field of notched multilayered polymer composite beams were investigated using a Digital Image Correlation (DIC) system. The notched beams were made of four layers of different polymers: three layers of different types of composites polypropylene and one layer of epoxy. The multilayered polymer composites are used as subsea pipe thermal insulation. The Crack Mouth Opening Displacement (CMOD) and Crack Tip Opening Displacement (CTOD) were monitored using the DIC system with the delamination of layers. The CMOD and CTOD were measured to an accuracy of 0.001 mm.

1. Introduction
Fractures induce catastrophic failure of materials and their prediction is done using fracture mechanic concept. Fracture mechanics is a relatively new field of mechanics and it is concerned with the study of the propagation of cracks in materials. Its foundation was established by Griffith (Griffith, 1921) based on the work of Inglis' 1913 work on infinite plate loading by uniaxial stress. Griffith worked on brittle material (glass), and consequently established the Linear Elastic Fracture Mechanic which was extend to Elastic-Plastic Fracture Mechanics, by the introduction of J-integral for nonlinear elastic and ductile materials, with the work of Rice (Rice, 1968) in consideration to the work of Cherepanov (1960). The application of fracture mechanics resides in the detection of small cracks present during the fabrication of part or crack developed in service and their potential to grow into unstable cracks leading to catastrophic failure. The yield strength of the material, the working temperature and fatigue also play an important role in fracture mechanic failure. The latter make the material brittle or reduce it yield stress respectively. The interest of this study is to investigate crack evolution through the different layers of the composite beams in consideration of the initial crack location.

2. Experimental tests
The composite beams were approximately 362 mm (14.25 in) long, 70 mm (2.76 in) high in average, and 38 mm (1.5 in) width. The four point bending was configured as shown in Fig. 1 (a). The test setup with the DIC system is shown in Fig. 1 (b). The accuracy of the DIC in comparison with the strain gage reading was first checked for reliability.

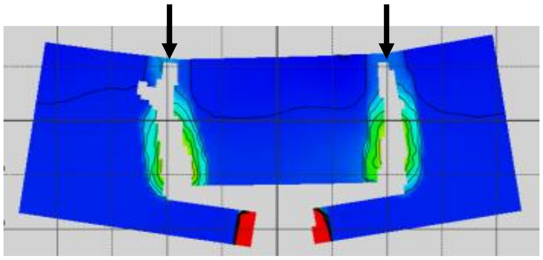


(a) (b)

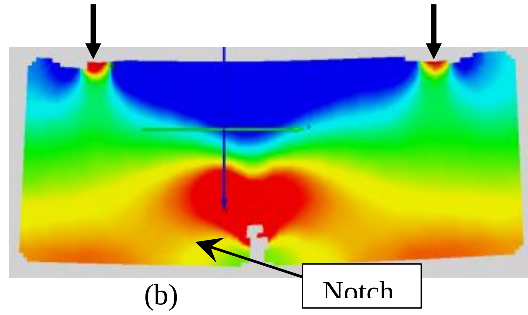
Figure1. Bending tests: (a) Sketch of the four points bending loading and (b) DIC setup picture.

3. Results and Discussion
The deformation fields of the notched composite beams were monitored using the digital image correlation system. Two types of test results are presented: monotonic quasi static loading until failure, shown in Fig. 2 (a), and monotonic cyclic loading, shown in Fig. 2 (b). In the case of specimen of monotonic loading, the notched was stopped in the brittle layer. The CMOD evolution up to the

specimen failure was monitored as shown in Fig. 3 (a). As shown in Fig. 2 (a), the crack evolved through layer 3 followed by the complete delamination of the layer 3 and 2 and the complete fracture of layer 2 following the path of the maximum stresses under the loading points.

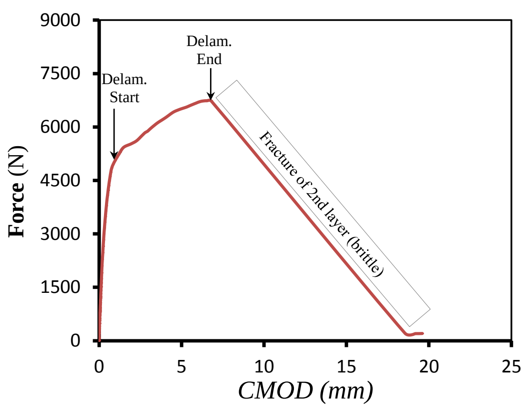


(a)

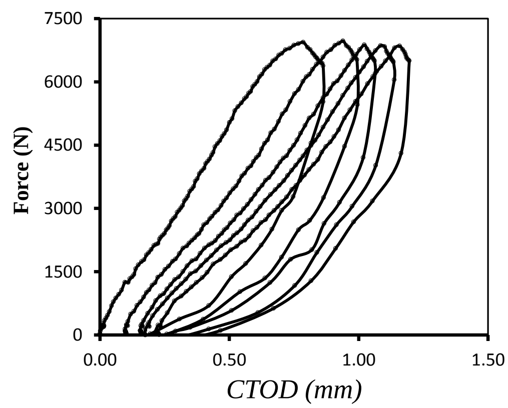


(b)

Figure 2. Lateral strain field distribution: (a) Monotonic loading, (b) Cyclic loading



(a)



(b)

Figure 3. CMOD and CTOD recorded using DIC system: (a) monotonic and (b) cyclic loading.
Note: Delam. = delamination

The bending strain field, in the case of cyclic loading, is shown in Fig. 2 (b). The maximum strain zone is in red around the crack tip. The CTOD evolution with applied load is also plotted in Fig. 3 (b). These fracture parameters, strain field, CTOD and CMOD were extracted from the deformation field on the notched composite beams captured by the Digital Image Correlation system.

4. Conclusion

The strain field, the CTOD and the CMOD of notched layered composite beams, in four points bending, were monitored using a Digital Image Correlation system. The advantage of the DIC system was that a complete deformation field, displacement and strain, can be obtained, specially the crack front strain distribution.

5. References

Griffith, A. (1921) “The phenomena of rupture and flow in solids.” *Philosophical transactions of the royal society*. 221, 163-198.

Rice, J. (1968) “A path independent integral and the approximate analysis of strain concentration by notches and cracks.” *Journal of Applied Mechanics*, 35, 379-386.