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MIXED-MODE QUASI-STATIC FRACTURE BEHAVIOR OF GFRP/BALSA SANDWICHES

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1. INTRODUCTION

Fiber-reinforced polymer (FRP) decks are resistant to corrosion, while being lightweight and allow the rapid installation of new, and widening or upgrading of existing bridges by replacing heavy concrete decks [1]. FRP decks include two main categories: pultruded decks and sandwich decks. Sandwich decks frequently exhibit significant technical advantages over pultruded decks, such as greater geometrical flexibility. Sandwich decks consist of two face sheets and either honeycomb or foam cores reinforced with internal FRP webs for shear resistance. Compared to the honeycomb structure and sandwich structures with foam core, an alternative material that has high shear capacity and can provide uniform support to the face sheets in composite sandwich bridge decks is balsa wood. This material has been used for the construction of the Avançon Bridge deck, installed in Bex, Switzerland, 2012 [2].

Although this material configuration (FRP/Balsa) is widely used in several applications, numerous questions regarding its fracture behavior still need to be addressed. Understanding and modeling of the fracture behavior of these systems is necessary for the efficient design of engineering structures. Mixed-Mode fracture is observed in actual loading conditions, of sandwich structural components. The most commonly used specimen for the characterization of the mixed-Mode I/II fracture behavior of composite sandwiches is the mixed-Mode bending (MMB) specimen. The MMB specimen proposed by Reeder and Crews [3] is a combination of the double cantilever beam (DCB) and the end notched flexure (ENF) specimen, both standardized specimens for measuring pure Mode I and Mode II interlaminar fracture of unidirectional laminates respectively. A wide range of Mode I and Mode II loading combinations can be experimentally investigated by the MMB configuration. The partitioning of the experimentally obtained total strain energy release rate, G_{tot}, into the G_{I} and G_{II} when mixed-Mode conditions exist is challenging [4-5], especially in asymmetric specimens.

In the current study, quasi-static mixed-Mode fracture experiments have been performed in order to study the behavior of bridge deck sandwich panels composed of GFRP skins and balsa wood core. In the current study, the components of strain energy release rate were calculated using the extended global method that was developed for the asymmetrical mixed-Mode specimens in [4].

2. EXPERIMENTS

The specimens were designed based on a sandwich bridge deck installed in the area of Bex, Canton of Vaud, Switzerland in 2012. The specimens were produced by infusion technique at the facilities of 3A Composites. All experiments were performed at the Composite Construction Laboratory (CCLab) at the Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland. The specimens had a total length of 600 mm, from which 68 mm was occupied by a pre-crack between the upper skin and the balsa core created by the positioning of a Teflon layer during fabrication.

A mixed-Mode bending experimental device (see Fig. 1), developed at CCLab, was used to apply different controlled mode-mixity ratios with either Mode I or Mode II dominant fracture components. Nine specimens were investigated with half span lengths, L, between 170 and 200 mm in order to study the fracture behavior at different mode-mixity ratios.

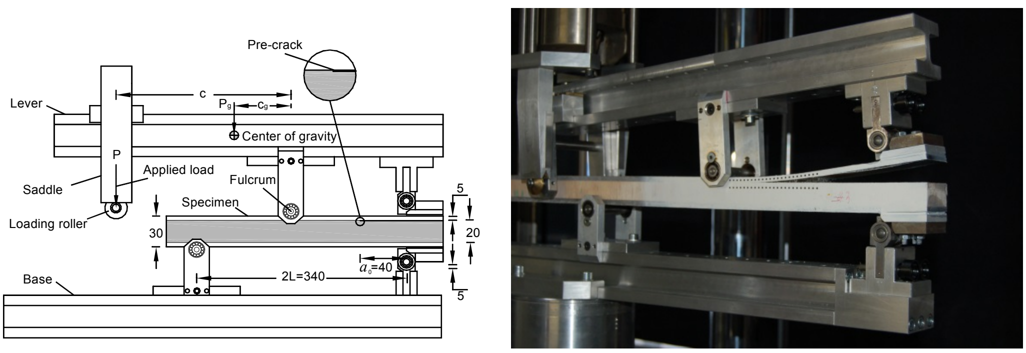

Fig. 1: Photo and schematic of the MMB fixture used.

The MMB experiments were performed under displacement control at a constant rate of 1 mm/min using a 25 kN MTS machine, calibrated to 20% of its capacity. The load was applied at the lever, via in-house developed piano hinges, at a distance c from the fulcrum, see Fig. 1. The position of the loading lever determines the mode-mixity for the experiment [6]. The lever, with a bending stiffness significantly higher than that of the MMB specimen, was assumed to be rigid. The applied load, the mid-span load, and the left support reaction are applied via bearing-mounted rollers to reduce frictional force. The applied loads and displacements were continuously recorded. The MMB experiments were performed with three different lever lengths, c=227, 197, and 80 mm, achieving mode mixities (G_I/G_{II}) between 0.13 and 6.47. The crack length was measured by means of a video extensometer. All experiments were performed at ambient environmental conditions. Representative, experimental results are presented in Fig. 2 for specimens with mode-mixity of G_I/G_{II}=6.47.

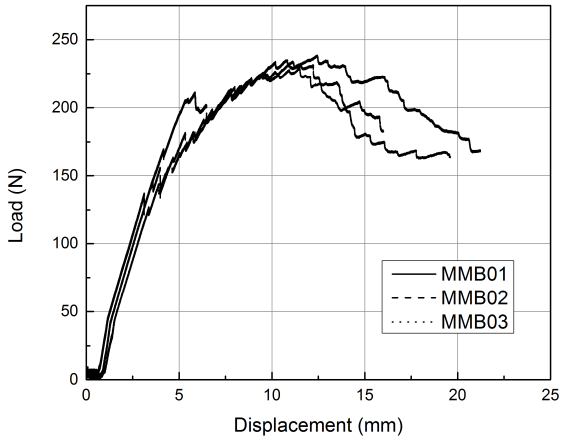

Fig. 2: Load-displacement diagram for c=227mm and L=170mm, specimens MMB01-MMB03.

The total strain energy release rate can be calculated by the experimental compliance method, ECM, based on experimentally derived values of loads, displacements, and crack lengths, as follows:

$$G = \frac{P^2}{2B}\frac{\mathrm{d}C}{\mathrm{d}a} \tag{1}$$

where P is the applied load, C is the compliance of the specimen, a is the crack length and B is the specimen width. The MMB specimen compliance is defined as:

$$C = \frac{\delta_P}{P} \tag{2}$$

where δ_p is the load-point displacement. From among different models for fitting compliance-crack length curves, Eq. (3) was selected because it better fits the experimental results:

$$C = C_0 + ma^3 \tag{3}$$

The "extended global method" [4], has been used for the mode partitioning of the examined specimens. Typical results for two different mode-mixities of 6.47 and 3.92 in the form of the *G-α* (or R-curves) are presented in Figs. 3 and 4. A mixed-Mode failure criterion can therefore be derived by plotting the results from all experiments as shown in Fig. 5. Appropriate interpolation between known values of mode-mixity allows the estimation of other combinations between G_I and G_{II}, see [5] for details.

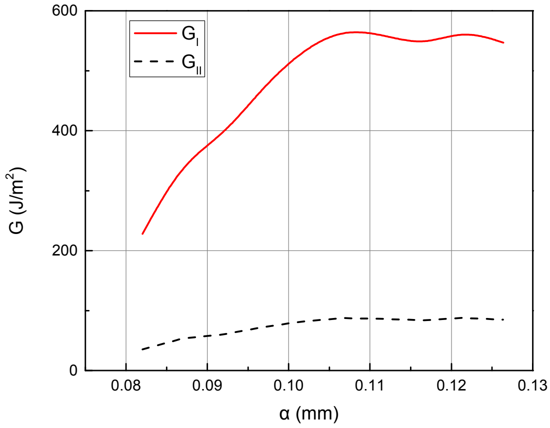

Fig. 3: R-curves of a MMB specimen with mode-mixity, G_I/G_{II}=6.47.

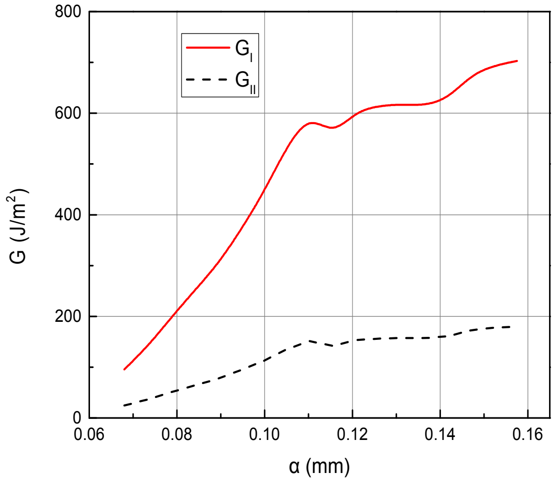

***Fig. 4:** R-curves of a MMB specimen with mode-mixity of* G_I/G_{II}*=3.92.*

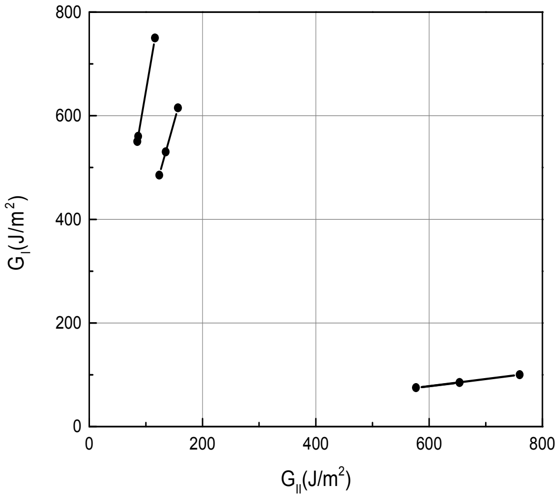

***Fig. 5:** Mixed mode failure criterion.*

3. CONCLUSIONS

The fracture behavior of sandwich beams composed of GFRP skins and balsa wood core has been investigated. The quasi-static mixed-mode behavior has been characterized by experiments using the mixed-mode bending (MMB) fixture of CCLab. In total nine specimens at three different mode-mixities have been acquired. By implementation of the derived quasi-static data, a mixed-Mode failure criterion can be established. Such failure criterion can be used for the estimation of other mode-mixities by interpolation between known values. By the same experimental setup, fatigue crack growth curves can also be derived, and used for the definition of the fatigue threshold, the value of strain energy release rate (corresponding to a value of applied load) below which no crack propagation is expected to happen.

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