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Finite element modelling of CFRP/steel double strap joints subjected to dynamic tensile loadings

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ABSTRACT

This paper reports the numerical simulation of both CFRP/steel double strap joints with 1 and 3 CFRP layers per side at quasi-static and three dynamic tensile loading speeds of 3.35, 4.43 and 5 m/s. Simulations are implemented using both the implicit and explicit codes respectively using non-linear finite element (FE) package ABAQUS. In these analyses, failures of both CFRP sheet and adhesive are considered and a cohesive element is utilised to model the interface. The developed FE models for both types of joints were validated by comparing their quasi-static and dynamic findings with those obtained from previous experimental program. This comparison includes four different variables such as the ultimate joint strength, effective bond length, failure pattern and strain distribution along the bond length. It was found that FE models proved to be able to predict all these parameters for both quasi-static and dynamic analyses and their prediction matched well with test results.

1. Introduction

In recent years, the outstanding outcomes of strengthening and/or upgrading concrete structures using the technique of adhesively bonded carbon fibre reinforced polymer (CFRP) have attracted the engineers' attention to employ the same method for metal structures. However, in general, conducting experimental tests has many drawbacks. These include cost, time, difficulties and limitations in testing full scale members and the difficulties in implementing a parametric study on different variables. These shortcomings highlight the importance of developing finite element models which are capable of predicting the behaviour of the strengthened and/or upgraded structures. Therefore, finite element analysis (FEA) has attracted an increasing demand to analyse adhesively bonded joints since the composite materials have become common materials of strengthening and/or upgrading.

Some numerical studies have been successfully carried out to predict the static and dynamic behaviour and strength of adhesively bonded joints of similar and dissimilar substrates under different loading conditions. Under static tensile loading, the behaviour and strength of CFRP composite adhesively bonded steel plates were examined in [1–6]. Other studies numerically analysed joints of similar adherends such as steel/steel [7], aluminium/aluminium [8] and composite/composite [9–11]. In addition, finite element analysis of CFRP composite bonded to simply supported steel beams under bending were also reported in Refs. [12–14] and analysis for continuous beams were reported in [15]. However, the strength and behaviour of structural joints such as the single lap joints and T-joints, which were manufactured using rigid and elastic adhesives, were experimentally investigated and compared under static and impact loading [16]. On the other hand, compared to static loading, the dynamic behaviour and strength of adhesively bonded joints attracted limited attention in numerical studies. These investigations included joints of different substrates such as steel/steel [17], aluminium/aluminium [18] and composite/composite [19]. Numerical prediction of the dynamic strength and behaviour of joints of CFRP sheet bonded to steel plates has not been reported in the literature. To cover this gap in knowledge, this paper aims at investigating the numerical simulation of CFRP/double strap joints at quasi-static and the three dynamic loading speeds of 3.35 m/s, 4.43 m/s and 5 m/s using both implicit and explicit codes in ABAQUS. Results of numerical simulations are compared with experimental findings.

2. Summary of laboratory work

A total of 160 CFRP/steel double strap joints were prepared and tested at quasi-static and three dynamic loading speeds of 3.35, 4.43 and 5 m/s and this number included two types of joints with 1 and 3 CFRP layers per side. These joints were formed by bonding normal modulus CFRP sheet to steel plate using Araldite 420

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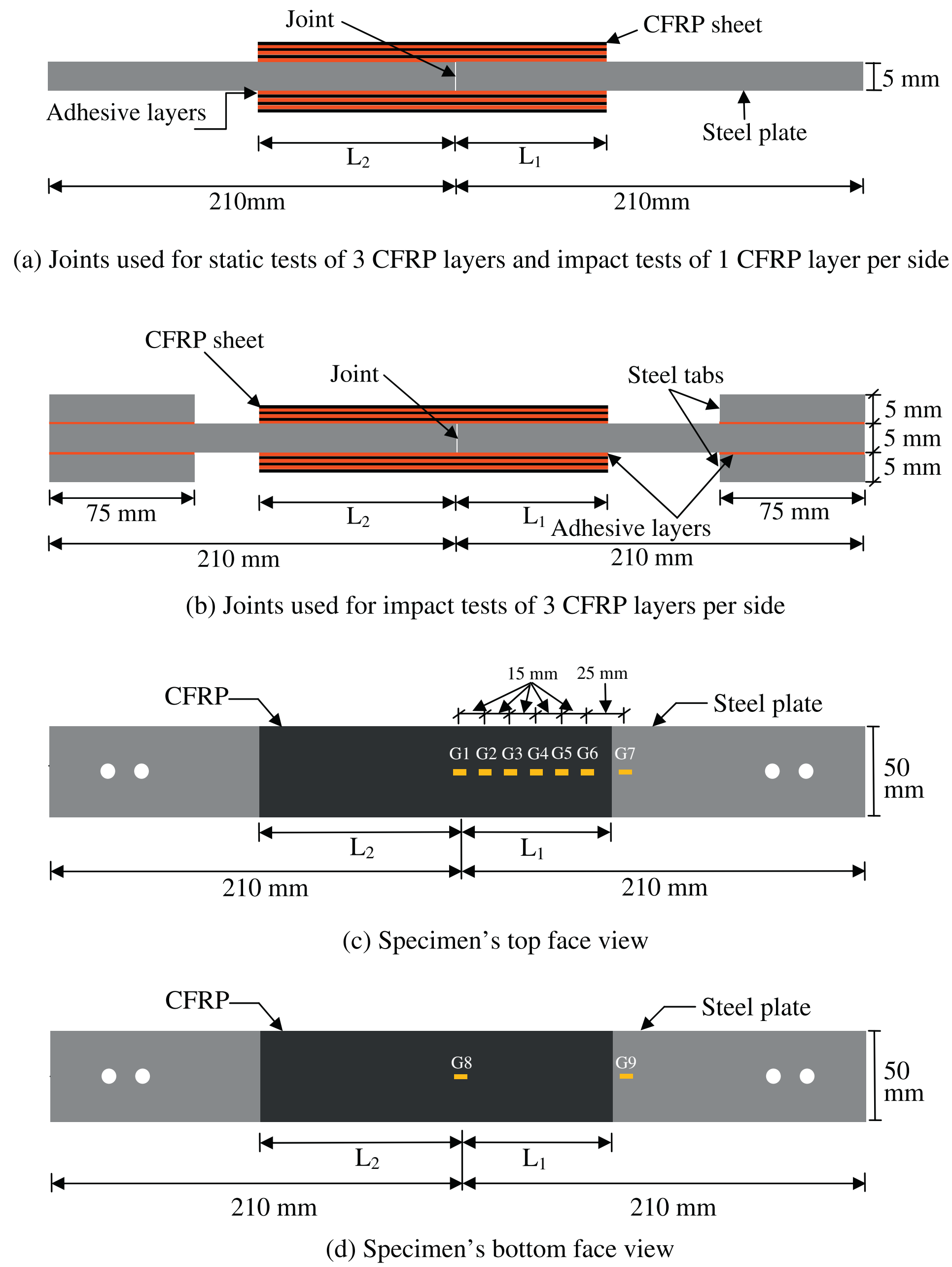

Fig. 1. A schematic view of the specimen's geometry and instrumentation used in the experimental program (not to scale).

adhesive (Huntsman Duxford, UK). In this experimental program, on average, two or three CFRP/steel samples were tested for both joints with 1 and 3 CFRP layers. Of these, 62 joints were produced with 1 CFRP layer per side and 98 joints with 3 CFRP layers. Details of manufacturing these joints, test procedure and experimental results can be found in the authors' previous study [20]. A schematic view of the specimen's geometry and instrumentation used the experimental program is shown in Fig. 1.

3. Finite element model

Based on dimensionality, it is well known that numerical simulation can be conducted using either 2-D or 3-D modelling and each has certain advantages and shortcomings. Even though 2-D modelling is much easier to simulate and the analysis does not require very powerful computers, its results are always less accurate, particularly when analysing large-scale structures. Conversely, more precise results are expected from 3-D modelling, although this is more likely to pose difficulties when running on normal computers. The appearance of such difficulties depends on the size of the analysed structure. In this study, since the dimensions of the analysed samples are not too large and the analysis can be run using a normal PC, 3-D modelling was chosen to simulate both the quasi-static and dynamic analyses for both types of joints (with 1 and 3 CFRP layers per side). This is in order to obtain more accurate results and to enable clear comparisons between the failure modes for both quasi-static and dynamic loadings.

Three-dimensional models are developed in ABAQUS software to numerically investigate the effect of increasing the test speed on the bond between steel plate and CFRP patch using double-strap joint samples. To clearly highlight this effect, non-linear quasi-static and dynamic analyses have been carried out using both ABAQUS implicit and explicit codes respectively. Due to material and geometry symmetry conditions, only one eighth of