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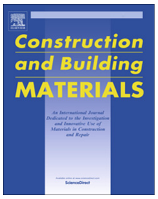

Effective bond length and bond behaviour of FRP externally bonded to timber

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HIGHLIGHTS

- A new model for effective bond length for FRP-to-timber joints has been developed.
- High agreement between measured and predicted effective bond length has been achieved.
- A modified single shear test setup has been successfully developed.

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ABSTRACT

Despite a large number of studies on estimating the effective bond length from the characteristics of the component materials, key parameters governing the effective bond length for FRP-to-timber joint have not been suggested by any of the current Codes and developed theories to date mostly cover FRP-to-concrete joints. Also, most theoretical bond strength models have been derived based on effective bond length. Therefore, to achieve a satisfactory bonded joint, the effectiveness of bond length is required to be accurately considered. This research study investigates 136 FRP-to-timber joints subjected to pull-out tests in order to determine the stress and strain distribution profiles along the interface and subsequently analyses the results to undertake direct measurement of the effective bond length. In addition, a modified test set up has been developed and is presented. A novel theoretical model has been established through regression analysis of bond length data and accordingly a new predictive model for effective bond length for FRP-to-timber joints has been developed. A comparative analysis between the results of the experimental pull-out tests results and those predicted from the analytical model indicates a satisfactory correlation is achieved between measured and predicted effective bond length, verifying the validity of the new model.

1. Introduction

There are large numbers of timber structures worldwide that have reached the end of their design service life. Moreover, ageing, inappropriate maintenance, surface degradation due to insect and fungal attack, environmental action, and increased service loads have caused many structures to gradually deteriorate and result in significant reduction in load capacity and subsequent safety. Consequently, either entire structures or key components require strengthening, rehabilitation or replacement [1–3].

In the past, retrofitting and strengthening of deteriorated timber structures was primarily accomplished through the use of conventional methods such as cutting out and replacing plates or connecting external steel plates to the surface of the structural members [4–6]. However, even though steel has a much higher Young's modulus and ultimate strength than wood, this may not be effective for strengthening as these plates are heavy, bulky and increase the dead load to the structure. Moreover, added steel plates susceptible to further corrosion damage; their installation is rather difficult and requires heavy lifting equipment [7,8]. This repairing method also regularly needs long periods of service interruption as well as high maintenance cost and large amounts of labour [1,9,10]. In addition, difficulties in handling and forming acceptable butt joints in the field make this method much less attractive [11].

Disadvantages associated with traditional rehabilitation or retrofit methods, have resulted in researchers developing new tech-

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niques using new materials such as advanced fibre reinforced polymers (FRPs) to tackle these issues [12]. Recent applications have demonstrated that fibre composites can be effectively and economically used for new structures, as well as in the strengthening and retrofitting of existing civil infrastructure [13–15]. FRP composite materials are able to carry high loads safely and increase the stability of structures and in some cases, are the only reasonable and applicable materials that can be used for retrofitting, particularly in places where it is impossible to gain access for heavy machinery [16]. These materials have a major role both in the field of strengthening and retrofitting of existing structures and in the new structural design [7]. External bonding of FRP composites has emerged as an innovative and widespread method for strengthening and retrofitting of infrastructure over the last three decades [7,8,17,18]. Although FRPs have a number of advantageous properties such as high elastic modulus, high fatigue performance, high stiffness and strength to weight ratios and superior resistance to corrosion [7,8,19,20], they still have some important limitations.

One of the most common problems associated with the use the externally bonded FRP sheets is the premature failure due to debonding which limits the full utilisation of the material strength of the FRP [21,22]. Debonding can be defined as the single most important failure mechanism of retrofitted beams [23,24] that occurs at much lower FRP strains than its ultimate strain [25]. Debonding directly impacts the total integrity of the structure, with the subsequent outcome that the ultimate capacity and desirable ductility of the structure may not be achieved.

Mostofinejad and Shameli [25] reported that several attempts have been made to improve the performance of FRP techniques to eliminate or postpone debonding failure of the FRP attached to concrete. Fracture mechanics-based models have been developed (both theoretically and experimentally) by many researchers to predict the initiation of debonding in retrofitted concrete elements and the peak load that the composite layers can resist before debonding [26–29]. However, performance of FRP composite externally bonded to timber, considering debonding and failure modes, has not been fully investigated [30] and to date, limited attempts have been made to investigate the bond behaviour of FRP to timber beams. Despite the large number of studies on externally bonded elements using FRP composites, there is a significant knowledge gap to gain a comprehensive understanding of potential parameters such as bond width, bond length, material properties and geometries that influence bond strength. Therefore, for the safe and economic design of externally bonded FRP systems, particularly when FRP is attached to timber, a sound understanding of the behaviour of FRP-to-timber interfaces needs to be developed and consequently, further understanding of the bond is essential.

Table 1
Detail of the tested specimens.

Timber type	Identification of specimen	FRP Thickness (mm)	Bond Length (mm)	Bond Width (mm)	Number of specimens
Laminated Veneer Lumber	LVL 50-35-01	1 × 0.117	50	35	5
	LVL 100-35-01		100	35	5
	LVL 150-35-01		150	35	5
	LVL 200-35-01		200	35	5
	LVL 50-35-02	2 × 0.117	50	35	5
	LVL 100-35-02		100	35	5
	LVL 150-35-02		150	35	5
	LVL 200-35-02		200	35	5
	LVL 50-45-01	1 × 0.117	50	45	5
	LVL 100-45-01		100	45	5
	LVL 150-45-01		150	45	5
	LVL 200-45-01		200	45	5
	LVL 150-45-02	2 × 0.117	150	45	5
Hardwood	H 50-45-01	1 × 0.117	50	45	5
	H 100-45-01		100	45	5
	H 150-45-01		150	45	5
	H 200-45-01		200	45	5
	H 50-45-02	2 × 0.117	50	45	5
	H 100-45-02		100	45	5
	H 150-45-02		150	45	5
	H 200-45-02		200	45	5
Laminated Veneer Lumber	LVL 50-55-01	1 × 0.117	50	55	5
	LVL 100-55-01		100	55	5
	LVL 150-55-01		150	55	5
	LVL 200-55-01		200	55	5
	LVL 250-55-01		250	55	3
	LVL 150-55-02	2 × 0.117	150	55	5
	LVL 250-55-02	2 × 0.117	250	55	3

Table 2
Position of the strain gauges along the bonded length.

Bond length	Distance of the strain gauges from the loaded end (mm)						
	SG2	SG3	SG4	SG5	SG6	SG7	SG8
50	15	40					
100	15	50	85				
150	15	50	85	120			
200	15	50	85	120	155	190	
250	15	50	85	120	155	190	225