International Journal of Adhesion & Adhesives 57 (2015) 13–21

Contents lists available at ScienceDirect

International Journal of Adhesion & Adhesives

journal homepage: www.elsevier.com/locate/ijadhadh

Bond characterization of adhesively bonded joints made with the resin infusion (RI) process

S.A. Hadigheh [a,*], R.J. Gravina [a], S. Setunge [a], S.J. Kim [b]

[a] School of Civil, Environmental and Chemical Engineering, RMIT University, Melbourne, VIC 3001, Australia
[b] Wagners CFT, Queensland, Australia

ARTICLE INFO

Article history:
Accepted 2 August 2014
Available online 13 October 2014

Keywords:
Resin infusion
FRP
Concrete
Modified single lap shear test
Thickness
Bond

ABSTRACT

In this research, the bond characteristics between concrete and FRP plates processed with resin infusion technique are studied. The bondline thickness is varied and a new modified single lap shear (MSLS) test set-up is implemented to monitor the interface during the experiments. Based on MSLS test set-up, the relative displacement between FRP adherend and substrate can be monitored with higher precision. Nonlinear analysis of the MSLS test results indicates that the maximum applied load increases for thicker bondline until a certain amount of thickness, optimum bondline thickness, beyond which no increase in load is achieved. Therefore, a relationship is proposed to estimate the maximum applied load based on bondline thickness. In addition, the interfacial performance of RI processed plates is also compared with the pultruded laminates bonded to the concrete. Results show that the samples processed by RI technique follow the same debonding mechanism as the pultruded specimens.

1. Introduction

The repair of concrete structures via bond of fibre reinforced polymer (FRP) materials onto the substrate has been extensively carried out by two commonly used methods, pultruded laminates or wet lay-up (or hand lay-up) systems. In the pultruded plate repair system, prefabricated plates are bonded to the substrate by epoxy adhesives. The wet lay-up method involves the impregnation of unidirectional or weaved fibres by a low-viscosity epoxy adhesive using rollers or brushes. However, with the wide application of the composite materials in the strengthening of infrastructures, new processing techniques with higher quality are necessary to achieve the reliable FRP repairing systems.

Resin infusion (RI) and resin transfer moulding (RTM) have been used in marine, petroleum and composite manufacturing industries in a large scale to reduce production cost, make complex geometry with large components, produce composites with high fibre volume fraction and to improve the quality of the products [1]. As well as marine industry [2–4], RI and RTM techniques have been used widely in other fields such as aerospace for production of light weight profiles with low operation cost and increase of the payload [5]. From material science and manufacturing point of view, several investigations have been carried out to study the efficiency of the resin injection method or resin transfer moulding compared with other commonly used processing techniques [6–10].

In RI and RTM, the reinforcement is placed on a rigid mould and covered with a layer of the peel ply and the flow medium. The whole system is isolated by another rigid mould while the vacuum is induced into the system. The vacuum distributes the resin over and inside of the reinforcement. Using the vacuum results in the production of the components with better mechanical properties, lower porosity levels and accurate fibre management [11,12]. The flow of the resin will be improved using higher permeable flow medium both in the plane and transverse directions. The resin spreads along the flow medium plane and then penetrates downward into the prefabricated fibres. Therefore, a 3D model is required to simulate the resin infusion process. Since the thickness of composite is very small compared with other dimensions therefore, the resin flow in the thickness direction is negligible [13] and the flow model is called 2½ dimensional. It was shown [1] that flow path along the transverse direction follows a parabolic profile.

In resin transfer moulding, the mould consists of two rigid parts while the resin infusion is sealed with one rigid mould and a vacuum bag [14,15]. The advantage of using flexible vacuum bag in RI (also known as resin infusion under flexible tooling, RIFT) system facilitates to make complex profiles with low cost. The vacuum bag is fixed to the mould using vacuum sealant tapes around the bag. In RI process, the resin application is under control and transferred from the resin reservoir through the injection units and finally into the mould using vacuum forces. Therefore, the chemical emission and contact with the composite will be

* Corresponding author. Tel.: +61 3 9925 1709.
E-mail address: seyedali.hadigheh@rmit.edu.au (S.A. Hadigheh).

http://dx.doi.org/10.1016/j.ijadhadh.2014.10.001
0143-7496/

minimized in the RI process compared with wet lay-up and pultruded laminate techniques.

Although the use of RI system is common in marine and aerospace industries, very less attention has been paid to the application of this system in the strengthening of structures using FRP materials. Since the resin infusion process can be applied to large components with high mechanical properties and low cost [16,17], it is suitable for structural strengthening of infrastructures. The successful application of the vacuum-injection system in shear strengthening of the reinforced concrete beams is compared with the hand lay-up method [18]. Results showed that the strength of the fractured beams can be restored to the same amount in uncracked beams [18].

The vacuum bag curing was applied to bond the concrete to the shuttering in composite beams, consisted of fibre reinforced polymer materials and concrete [19]. The resin injection method was able to satisfy the level of composite action in the composite beams. In addition, the vacuum resin infusion is used in fabrication of FRP bridges for replacement of the deteriorated structures (e.g. Bennett's Creek in US [20] and West Mill Bridge in Oxfordshire, UK). The significant strength was achieved for the replaced bridges which is reported after prototype and field proof tests with the application of a full-scale load. The strengthening was carried out with less construction time and cost effectiveness [21,22]. In addition, the successful application of the resin infusion system in concrete-filled FRP tubes in strengthening of the bridge structures [23] and enhancement of the punching resistance of GFRP composite sandwich panels [24] has been reported.

2. Research significance and objectives

Various researches have been undertaken to investigate the bond behaviour between concrete and the FRP considering commonly used processing techniques such as, wet lay-up or pultruded systems. These studies mainly address the effects of different parameters on the bond performance via experimental, analytical and/or the numerical approaches. Nevertheless, the influence of the application of different FRP manufacturing methods has received less consideration in the interface study. Among wet lay-up, pultruded and RI processing techniques, the available experimental data about the bond characteristics between concrete and the resin infusion is limited.

Therefore, the interfacial behaviour between concrete and FRP plates, processed by the resin infusion technique, is investigated in this article. Single lap shear tests are performed on several adhesively bonded joints using a modified test set-up, proposed and successfully tested by the authors [25,26]. In addition, the bondline thickness of samples is varied between 2 and 6 mm in the experiments. The current research provides an experimental database regarding the interface behaviour between concrete and RI processed FRP plates with the focus on the bondline thickness. In addition, the bond performance between concrete substrate and the FRP is compared for samples which are manufactured by RI and pultrusion methods.

3. RI application technique

Prior to the application of RI technique, the surface of the sample should be cleaned to avoid any deficiency inside of the bond between substrate and the FRP plates. The dry plate preform is placed on the mould (here, concrete) and fixed by applying the spray adhesive. Subsequently, the peel ply and the flow medium are placed on the plates. The flow (infusion) medium is used to aid the resin to be distributed and spread over the bond area. To take off the disposable parts, a peel ply layer is arranged between the flow medium and the vacuum bag. Then, the whole system is covered by a specific plastic bag in order to produce the vacuum condition during the RI technique. The vacuum bag can be sealed all around by the vacuum sealant tapes (the double sticking tape). The inlet and outlet tubes are located at the start and the end point of the mould to supply resin and remove the air, respectively. The inlet tube is attached to the resin hose (or resin tank) and the outlet tube is connected to the vacuum hose (or vacuum pump).

The vacuum pulls the resin down through the flow medium, plate preform and the interface between the FRP and the mould (substrate). Therefore, the epoxy can fast saturate the dry fibres and bond them together as well as to the substrate. When the resin covers all the area, the inlet tube (resin supply) is closed and the bonded area is kept under the vacuum condition until the resin is cured under ambient temperature. The excessive resin is trapped in a resin trap tank before it flows to the vacuum pump. A schematic view of the resin infusion is shown in Fig. 1.

The presence of the vacuum minimizes the formation of dry spot areas on the cured FRP which leads to higher quality of the composite. Therefore, the vacuum pressure has an important role on the performance of the RI system. Although 78–98 kPa pressure is reasonable to produce the vacuum, it depends on the substrate porosity, higher vacuum pressure is necessary. If sufficient pressure is not used, the composite may be of low fibre volume fraction with some unsaturated spots on the plates [5].

4. Test methodology and materials

4.1. Specimen fabrication and material characterization

In this section, the experimental programme to investigate the FRP-to-concrete bonded joints is described. The modified single lap shear (MSLS) test is conducted on the concrete prisms pre-

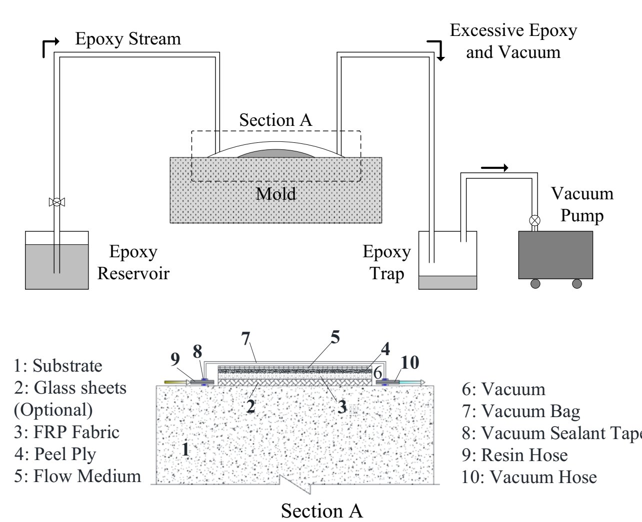

Fig. 1. RI application process.

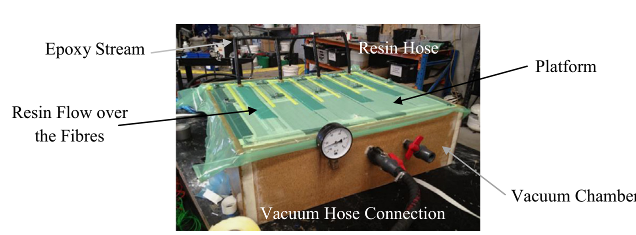

Fig. 2. Application of RI on the concrete specimens.