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Structural behaviour of a prefabricated composite wall system made from rigid polyurethane foam and Magnesium Oxide board

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HIGHLIGHTS

- ▶ Rigid polyurethane foam and Magnesium Oxide board were used for a composite wall.
- ▶ The behaviour of the composite wall is governed by the strength of the MgO board.
- ▶ Single and two-panel wall systems exhibited the same strength and stiffness.
- ▶ The tie-down anchor bolts increased the strength by 15% but not the stiffness.

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ABSTRACT

This paper presents the structural behaviour of an emerging prefabricated wall system made up of glass fibre reinforced rigid polyurethane foam (PUF) and Magnesium Oxide (MgO) board. Full-scale wall specimens were prepared and tested under transverse bending, compression and shear. The results of the experimental investigation showed that the behaviour of the composite walls is governed by the strength of the MgO board. A complete interaction between the rigid PUF and MgO board was achieved using epoxy adhesives. In compression, a 17% lower failure load was measured for wall specimen with the MgO board attached to the wall frame with a 10 mm offset from the bottom plate than the wall with the sheathing flushed to the bottom plate. Under in-plane shear test, the single and two-panel composite wall systems exhibited similar shear stiffness and strength. The provision of tie-down anchor bolts increased the shear strength by almost 15% but has no significant contribution to the shear stiffness. Finally, the results confirmed the potential of this composite wall system in residential modular construction.

1. Introduction

In Queensland and throughout Australia, there is a continuous challenge of building more houses due to the enormous housing backlog [1]. In addition, more than 20,000 homes have suffered some degree of inundation in the 2011 Queensland floods [2] which require reconstruction efforts that are likely to place pressure on state's budget over the next few years. The construction of these flood affected homes alone is already valued at $4 billion dollars [3]. The anticipated increase in the cost of conventional housing materials like steel, concrete, timber, and bricks due to the government proposed carbon tax combined with skills shortage in the construction sector is expected to further create enormous challenges to the government in delivering available decent and affordable housing to many. These problems have encouraged the housing industry to find alternative materials and cost effective construction systems.

Currently, there is an increasing interest in using new generation of composites from recycled materials and other renewable resources to replace the less eco-friendly structural and non-structural materials for housing and construction. The many advantages of these composite materials include environmental friendship (renewable resource, recyclable, and biodegradable), low energy consumption, low cost, light weight, and good specific mechanical properties. These new generation composites have numerous potential advantages in prefabricated housing construction such as better quality control, improved health and safety of workers, and faster build times. Prefabricated housing systems are easy, fast and economic to install as it requires minimal handling and reduces energy in transportation [4]. Through prefabrication, composite wall systems are mass produced in a factory under strict quality control resulting in minimal resource wastage and enhancing value for end-users [5]. Consequently, an increasing

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range of prefabricated composite wall systems are now available for modular housing construction.

Despite its many advantages, the acceptance of prefabricated composite walls has been low due to lack of standards and design. Currently, the design and construction methods using new composites materials follow that of conventional housing systems as there is limited knowledge on the performance behaviour of this construction system under imposed loads. Because of the lack of appropriate design guidelines, Singleton and Hutchinson [6] indicated that new techniques involving new materials into construction particularly those associated with factory based 'system building' have noticeably failed to meet expectations by the owners. The collective perception is that prefabricated composite walls do not meet the minimum standards provided by the codes and do not have long term performance. A detailed understanding of the structural performance of new prefabricated wall system is therefore needed to enable emerging composite materials to provide efficient solutions that are currently available with conventional housing materials and systems.

Kendall [7] has identified the absence of assessment criteria as the most important inhibitor to the acceptance of new materials in housing and construction. Moreover, Griffith [8] indicated that most of the blame for inadequate performance of prefabricated building components is failing to understand the latest technology and the behaviour of innovative materials. There is also no provision in most building codes on the performance requirements regarding strength and serviceability for prefabricated composite wall systems. Up to date, there is inadequate scientific research undertaken to substantiate the benefit of using new composite materials in prefabricated system of construction. Thus, most engineers continue to rely upon experimental test data in evaluating the structural performance of composite walls [9].

Dobrila and Premrov [10] investigated the behaviour of composite timber frame–fiberboard wall panels and found out that inserting a diagonal strip to the timber frame increases shear resistance and ductility of a composite wall. In another study, Rio Merino et al. [11] experimentally investigated the physical and mechanical properties of cork–gypsum products to determine its suitability for prefabricated partition walls. Wu [12] investigated the structural behaviour of composite walls consisting of glass fibre reinforced gypsum (GFRG) panels. He concluded that the structural behaviour of this building system is more complicated than wall systems from conventional construction materials. These studies showed that experimental testing is vital not only for research and development but also to gain a detailed understanding of the structural performance of an emerging wall system. More importantly, the information obtained from structural testing provides engineers and manufacturers as well as the end-users with confidence on the quality of prefabricated composite wall products.

In this paper, the potential of a new prefabricated wall system made from sustainable composite materials in modular residential and building construction is explored through a better understanding of their structural performance. The composite wall is made up of glass fibre reinforced rigid polyurethane foam (PUF) for structural framing with Magnesium Oxide (MgO) board sheathing on both sides bonded by epoxy adhesives. The rigid PUF is now becoming an important material in the construction industry [13]. The addition of glass fibre reinforcing improves the strength and load carrying capacity of rigid PUF which leads to its use as a structural member [14]. More recently, this material is being used as a core in sandwich structures for flooring and wall panels. Similarly, MgO board is an emerging panel used in residential and building construction in China, Middle East and United States because this material is highly sustainable, consumes low energy, resistant to fire, strong and resistant to mould and mildew [15]. The combination of these emerging construction materials is anticipated to provide a cost effective and structurally efficient prefabricated composite wall system.

The main aim of this study is to develop a better understanding, through simulated testing, of the structural performance of a prefabricated composite wall system made up of rigid PUF and MgO board and extend the understanding into the critical problems associated with their application in modular construction such as effective design, quality assurance and issues of attachments. The main behavioural parameters of this composite wall are characterised to provide designers and engineers with sufficient information on the strength and serviceability and to further explore their application into industrialised building systems. Finally, improvements are suggested to expedite the implementation of this composite wall in modular prefabricated construction through a more functional and economical design.

2. Experimental program

The experimental activities presented in this paper deal with the behaviour of prefabricated composite wall system made from MgO Corp Board (CM-11-A007) and glass fibre reinforced rigid polyurethane foam (PUF) subjected to flexure, compression and in-plane shear. This prefabricated composite wall is part of a panelised modular building system called ''Redisystem'', which is designed and engineered by Redisystem Pty Ltd., Australia.

2.1. Material properties

The composite wall is made up of glass fibre reinforced polyurethane foam as the main frame elements with 10 mm thick MgO Corp Board (CM-11-A007) sheathing on both sides. A typical MgO board and rigid PUF are shown in Fig. 1. Experimental characterisation using coupon specimens was performed using flexure, tensile, compressive, and shear tests to determine the mechanical properties of the rigid PUF and the MgO board. Table 1 summarises the mechanical properties of these building materials.

2.2. Wall specimens

The composite wall specimens were fabricated by the industry partner and were delivered to the structural testing facility. The details of the prefabricated composite wall specimens are shown in Fig. 2. The overall dimension of the composite wall is 1.2 m (width) × 2.4 m (height), which is the standard size of a single panel as shown in Fig. 2a. The studs of the composite walls are made from 38 × 100 mm rigid PUF spaced at 600 mm on centres with one of the studs has a grove for the shear key as shown in Fig. 2b. The top and bottom plates were made of double studs glued together. The MgO board was used as sheathing on both sides which was bonded to the perimeter of the wall frame and the intermediate studs using TechniglueCA, a two pack structural epoxy adhesive supplied by ATL Composites Pty Ltd. to form the composite wall. There was no diagonal bracing and noggings provided in the wall frames with the intention of maximising the in-plane shear resistance of MgO board and cost competitiveness of this type of wall construction. The description of the test specimens are provided in Table 2.

In Table 2, specimens BT-1 and 2 are the two replicates for the four-point flexural transverse test while specimens CT-1, CT-2 and CT-3 are the wall specimens for compression test. As it is a common practice in Australia that the sheathing is pro-

Fig. 1. Glass fibre reinforced rigid PUF and MgO Corp Board (CM-11-A007).