Experimental Investigation on Interface Shear Strength of Composite PVC Encased Macro-Synthetic Fibre Reinforced Concrete Walls

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Abstract: Over the past decade, Polyvinyl Chloride (PVC) stay-in-place formwork has become a popular alternative for conventional formwork in concrete construction industry due to its relatively lower cost of construction and ease of assembly. The PVC panels are joined using connectors and serve as a permanent formwork into which fresh concrete is poured to form composite PVC encased concrete walls. This study has experimentally investigated the effects of using macro-synthetic fibre reinforced concrete on the interface shear strength of composite PVC encased walls in comparison with composite PVC encased walls filled with conventional plain concrete and reinforced concrete. Nine composite PVC encased concrete wall specimens were cast and tested using direct shear tests. Based on the load-deflection curves obtained from the direct shear tests, the maximum shear loads and interface shear strength values were determined for three different cases including i) test specimens filled with plain concrete, ii) test specimens filled with macro-synthetic fibre reinforced concrete, and iii) test specimens filled with reinforced concrete. The determined parameters as well as the measured load-deflection curves for the three cases were compared and the final findings have been discussed. Based on the outcomes of this study, it has become apparent that the tested composite PVC encased macro-synthetic fibre reinforced concrete wall specimens can noticeably exhibit higher interface shear strength values compared to the tested wall specimens filled with plain concrete. Since AS 3600 (2018) does not prescribe the shear plane surface coefficients for determining the interface shear strength of composite PVC encased concrete walls, in order to enable structural designers to determine the interface shear strength for those panels using AS 3600 (2018), those coefficients have been extracted from the test results for the three mentioned cases and proposed for practical applications.

Keywords: *Concrete structures, Composite PVC encased concrete walls, Shear capacity, Interface shear strength, Macro-synthetic fibre reinforced concrete, Practical applications, Load carrying capacity, Self-compacting concrete*

1. Introduction

Composite PVC encased concrete walls provide substantial advantages in terms of structural strength and durability enhancement, and pest infestation resistance, design flexibility, ease of construction and excellent resistance to impact [1]. Such walls have been constructed in the past 10 years to function as load bearing walls, non-load bearing walls, shear walls, retaining walls, and foundation walls [2]. Many researchers (e.g. Chahrour et al. 2005 [2]; Chahrour et al. 2006 [1]; Far & Nejadi [3, 4]) have studied structural behaviour of Composite PVC encased concrete walls under different load conditions. As indicated by several past studies (Soltani, 2016 [5]; Zhang et al. 2020 [6]) in concrete structures, integrity of the

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structural elements is essential and the highest load-carrying capacity will be achieved if there is no joints between different concrete units where the entire structure is made of a monolithic concrete structure. However, making a structure completely monolithic is not always practical and joints are unavoidable in construction [5]. As noted by Mohamed et al. (2012) [7] joints can be vertical or horizontal while the loads acting on these joints can be perpendicular or parallel to the joint interface. Such joints can be reinforced joints with transverse reinforcement or unreinforced joints while the capacity of the unreinforced joints can be significantly low in comparison with the reinforced joints [7]. The medium which is separating the two dissimilar concrete surfaces during the assemblage of precast and cast-in-place concrete in composite construction is called the "Interface" [6]. As mentioned by Muhammed et al. (2009) [8], the highly stressed interface is a potential failure plane, through which shear stress is transferred, and direct shear failure may occur. When load is applied, slip occurs between the two surfaces of concrete especially when there is no enough reinforcements connecting them together. The shear transfer occurs by two mechanisms: aggregate interlock and dowel action [9]. In fact, to achieve full composite action in reinforced concrete structures, the shear strength at the interface depends on the concrete cohesion, friction and dowel action (if shear reinforcement crossing the interface is provided) [8, 9].

Since structural material properties and characteristics significantly influence the performance of structural members [10-12], this study has aimed to investigate the effects of using macro-synthetic fibre reinforced concrete, instead of conventional concrete, on shear capacity at shear interface of composite PVC encased walls. In addition, since Australian structural design standards do not prescribe the shear plane surface coefficients for determining the interface shear strength of composite PVC encased concrete walls, in order to enable structural design engineers to calculate the interface shear strength for those panels using Australian Standards, the friction and cohesion coefficients for the studied composite PVC encased walls have been extracted from the test results and proposed for practical applications in this study.

2. Background

Many researchers (e.g. Birkeland and Birkeland, 1966 [13]; Mattock and Hawkins 1972 [14]; Walraven et al. 1987 [15]; Randl 1997 [16]) proposed several design expressions to predict the ultimate longitudinal shear stress at the concrete-to-concrete interface in concrete members. Walraven et al. (1987) [15] conducted a large experimental study using push-off tests and proposed a non-linear function to predict the shear strength of initially cracked interfaces. In that study, an innovative "Sphere Model" was developed to analyse the interaction between the aggregates, the binding paste, and the interface zone. Mohamed et al. (2012) [7] conducted an experimental study to determine the interface shear strength of concrete-to-concrete bond using the push-off method. The main objective of the latter study was to evaluate the relationship between interface shear strength and normal stress for four different surface textures; smooth, roughened in the longitudinal and transverse direction, and deep groove. It was concluded that for the roughened and deep groove surfaces, there is no specific effect on the maximum horizontal peak by increasing normal stress from 0 to 1 MPa.

Randl (1997) [16] proposed a design expression that explicitly includes the contribution of cohesion due to contribution of the interlocking between aggregates, friction due to contribution of the longitudinal relative slip between concrete parts that is influenced by the surface roughness and the normal stress at the shear interface and dowel action related to the contribution of the flexural resistance of the shear reinforcement crossing the interface. Current design standards of reinforced concrete structures, such as CEB-FIP Model Code (1990) [17], Eurocode 2 (2004) [18], CAN/CSA A23.3 (2004) [19], ACI 318-08 (2008) [20], and AS 3600 (2018) [21] present design expressions for the assessment of the longitudinal shear strength at the interface between concrete surfaces cast at different times. These design expressions are based on the "shear-friction theory" as proposed by Birkeland and Birkeland (1966) [13] which considers fundamental parameters including compressive strength of the weakest concrete, normal stress at the interface, shear reinforcement crossing the interface, and roughness of the substrate surface. Other parameters with a significant influence on the behaviour of RC composite members are neglected [10] (e.g. the differential shrinkage and the differential stiffness between old and new concrete surfaces). Table 1 summarises the shear friction provisions extracted from five different design standards for reinforced concrete structures, where τ_u is the ultimate shear strength of the interface, c & k_{co} are the coefficient of cohesion, σ_n is the normal stress acting on the interface due to external loading, f_{ctd} is the tensile strength of the weakest concrete, μ is the coefficient of friction; ρ is the reinforcement ratio, f_y &f_{sy} are the yield stress of shear reinforcements, f_{cd} is the design value of compressive strength of concrete, α is the angle between the shear reinforcement and shear plane, λ is a factor related to the concrete density, ϕ_c is the resistance factor for concrete (taken as 0.65), ϕ_s is the resistance factor for reinforcements (taken as 0.85), g_p is the permanent distributed load normal to the shear interface per unit length (*N/mm*), b_f is the width of the shear plane, A_{sf} is the area of fully anchored shear reinforcement crossing the interface (mm^2) and s is the spacing of anchored shear reinforcement crossing the interface.

This study focuses on the shear capacity at the shear interface of 275 mm Dincel structural walling panels according to Clause 8.4.3 of AS 3600 (Australian Standards for Concrete Structures) [21] in which the influence of cohesion, friction, and dowel action are considered as follows:

$$\tau_u = \underbrace{\mu \frac{A_{sf} f_{sy}}{s b_f}}_{\text{I}} + \underbrace{\mu \frac{g_p}{b_f}}_{\text{II}} + \underbrace{k_{co} f'_{ct}}_{\text{III}} \tag{1}$$

where, Part I contains the dowel action effects, Part II is related to the friction effects and Part III covers the cohesion effects. In Equation (1), AS 3600(2018) [21] has prescribed the shear plane surface coefficients including friction and cohesion coefficients (μ and K_{co}) which are normally extracted from Table 4.

In addition, according to Clause 8.4.4 of AS 3600 (2018) [21], where reinforcement is required to increase the longitudinal shear strength, it should consist of shear reinforcement anchored to develop its full strength at the shear plane. The centre-to-centre spacing (s) of the shear reinforcement shall not exceed the maximum spacing based on the following equation:

$$s_{max} = 3.5t_f \quad (2)$$

where, t_f is the thickness in mm of the topping or flanged anchored by the shear reinforcement.

Furthermore, according to Clause 8.4.5 AS 3600 (2018) [21], the average thickness of structural components subject to interface shear shall be not less than 50 mm with a minimum local thickness not less than 30 mm.

The interface area between different concrete surfaces in composite structures represents an unknown medium especially in shear transfer phenomenon [6, 22]. Therefore, in this study, contribution of concrete cohesion and friction to the interface shear strength of 275 mm Dincel structural walling panels filled with plain concrete, reinforced concrete and BarChip 48 macro-synthetic fibre reinforcement is experimentally investigated through the direct shear test.

3. Employed Materials

3.1.PVC Encasing

275 mm Dincel structural walling panels have been used in this study as the stay-in-place PVC encasing of the concrete wall specimens. Typical details and dimensions of those panels are shown in Figure 1 [23]. As the typical plan layout of 275mm Dincel structural walling panels shows in Figure 2, any length of wall at 275mm increments can be created by using 275mm Dincel panels. Construction sequence of Dincel structural walling panels has been extensively explained and demonstrated in [24]. Mechanical properties of Dincel panels and characteristics of BarChip 48 micro-synthetic fibres are presented in Tables 1 & 2 [3, 4]. Most horizontal reinforcement arrangements can be accommodated within Dincel 275 structural walling panels. For example, two layers of both horizontal and vertical reinforcement can be accommodated. Horizontal reinforcement can have 150mm increments (to match horizontal web holes), whereas vertical reinforcement can be placed anywhere within the open cells from the top (typically, vertical reinforcement is provided at 275mm centres to match panel widths). For boundary elements, where closed tie reinforcement is required, this can be also accommodated within the panels. Figure 3 demonstrates the use of

closed tie reinforcement within the panels. The same methodology can be used to place U bars at wall ends if required [23, 24].

It should be noted that the web holes provide continuation of concrete from panel to panel, and therefore concrete fills all the available panels/forms, which have been connected together. There is no requirement to roughen the surface as the entire assembly of panels/forms are core-filled in one go [24].

In order to determine mechanical properties of the employed PVC material in this study, five dog-bone coupon specimens from the Dincel panels were prepared according to ASTM D638 [25] specifications. As illustrated in Figure 4, tensile tests were conducted by applying a constant rate of 0.083 mm/s according to ASTM D638 [25] and the resulted average ultimate tensile strength, Young's modulus of elasticity, and Poison's ratio were determined and presented in Table 5. Stress-strain curve of the tested PVC material has also been obtained and plotted in Figure 4. The tensile strength reported in Table 5 is the highest point of the stress-strain curve (Figure 4) while the Yong's modulus which quantifies the relationship between tensile stress and axial strain (proportional deformation) in the linear elastic region of the material is determined by finding the slope of the linear zone of the stress-strain curve. Within the elastic region of a given specimen, Poisson's ratio is essentially constant, and is the negative of the ratio of transverse strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material. Therefore, the transverse strain (measured in the direction perpendicular to the applied force), and the axial strain (measured in the direction of the applied force) have been first determined in this study and then Poisson's ratio was calculated by finding the negative of the ratio of transverse strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material and reported in Table 5.

3.2.Macro-Synthetic Fibre Reinforcement

BarChip 48 macro-synthetic fibres have been used as the fibre reinforcement in this study. It is a high performance polypropylene fibre used as optimised structural reinforcement in precast, paving and flooring works. BarChip 48 macro-synthetic reinforcement system works by distributing hundreds of thousands of high tensile strength fibres throughout the entire concrete mix. They reinforce every part of the concrete structure, front to back and top to bottom, leaving no vulnerable unreinforced concrete cover [25]. Table 6 summarises the characteristics of BarChip 48 micro-fibres provided by the manufacturer.

4. Experimental Testing Program

4.1. Test Specimens

All nine composite PVC encased concrete walls were prepared and poured with concrete having compressive strength of 40 MPa and 200mm slump and cured on site at UTS Tech Lab. The gaps (interface) between panels are filled with concrete as demonstrated in Figure 5. The concern regarding inadequate concrete compaction on site (due to improper or no vibrator use) in relation to permanent formwork systems has been addressed with the promotion of Self Compacting Concrete (SCC) during the construction. Each specimen consists of two 275 mm Dincel structural walling panels filled with concrete identified as top panel and bottom panel. The panels were 1200 mm long with 275 mm thickness and filled with concrete having 200 mm slump and compressive strength 40 MPa at 28 days. All nine composite PVC encased concrete walls were prepared, poured with concrete, and cured on site at UTS Tech Lab by Dincel technicians. The entire process has been overseen and reviewed by UTS scholars prior, during and post pour. All reinforcement details, mix designs and mix properties were reviewed and approved by suitably qualified UTS Tech Lab staff. Concrete compression cylinders were taken from the fresh concrete mix. To determine the compressive strength of the cylinders, concrete cylinder compression testing according to ASTM C39/C39M [26] have been carried out and the compressive strength of the specimens were calculated by dividing the maximum load achieved during the test by the cross-sectional area of the specimen. Figure 6 illustrates an overview of concrete cylinder compression testing according to ASTM C39/C39M [26] in process at UTS Tech Lab.

The experimental testing program has aimed to investigate the effects of using macro-synthetic fibre reinforced concrete (BarChip 48 macro-synthetic reinforcement system), as a substitute of conventional reinforced concrete, on shear capacity at the shear interface of composite PVC encased 275 mm Dincel structural walling panels. In addition, the contribution of friction and cohesion to the interface shear strength of each specimen was aimed to be investigated. To achieve these goals, direct shear testing was conducted on the test specimens, which were cast with plain concrete, reinforced concrete and BarChip fibre reinforced concrete, and tested at the age of 28 days with the following details:

- Three composite PVC encased concrete wall specimens, named *Shear-Plain*, with plain concrete;
- Three composite PVC encased concrete wall specimens, named *Shear-BarChip*, with BarChip 48 macro-synthetic fibre reinforced concrete; and
- Three composite PVC encased concrete wall specimens, named *Shear-Reo*, with reinforced concrete (normal ductility class deformed reinforcing bars grade D500N with yield strength 500 MPa according to AS3600-2018 [21]).

In Shear-Reo specimens, the rectangular concrete prisms were prepared after fixing four deformed steel bars, 4N12 (Figure 7) throughout the panels length to represent the dowels (according to Clause 8.4.4. AS 3600 2018 [21]). Muhammed et al. (2009) [8] explained that the shear stress transmitted by the dowels is enhanced by increasing the area of dowel bars or the number of these dowel bars. As the area or number of dowels are increased, the slip is decreased and this is mainly attributed to the contribution of the bar stiffness in the overall stiffness of the member.

4.2. Test Setup and Procedure

Composite members are generally designed to act monolithically. In concrete-to-concrete bonds, the horizontal shear stress between the two concrete surfaces is resisted by the shear capacity at the interface [27]. To ensure whether this bond fails or not under constant normal and horizontal force, an experimental testing program was conducted using direct shear test method. This method has been used by several researchers (e.g. Choi et al., 1999 [28], Lam et al., 1998 [29], Gohnert, 2003 [30]) to study the composite action between the two members in order to determine the interface shear strength. Figure 8 illustrates the schematic of the test setup and the dimensions of the test specimens while Figure 9 shows an overview of the direct shear test configuration at UTS Tech Lab. The base panels in the test setup were fixed to the test frames and the top panels were pushed by the load cell.

The load was applied using a hydraulic cylinder and controlled using a closed loop PID control system called FCS SmartTest One. During the test, the horizontal load applied to the top specimen was increased steadily until the maximum shear capacity of the specimen was achieved and the bond failure happened. Figure 10 illustrates the failure for Shear-Plain, Shear-Barchip and Shear-Reo specimens respectively. Figure 11 shows a Shear-BarChip failed interface where no crushed aggregates or fibre breakage have been observed. In the tests, relative slip was measured by having a sensor above and another one below the shear line. The sensors provided relative slip quite well as they were placed near each other, just either side of the shear plane. The restraint from lifting was provided by 2× M36 rods of length 700mm, grade 10.9, so the rotation/lift was minimal. No strain gages were installed on the dowel bars. The bond failure load then was defined as the load at which the interface bond was broken. The samples were restrained from lifting with a setup that offered minimal friction through the use of high load capacity skates. Boundary conditions were created so any stresses from moments and compression were negligible, to encourage the samples to fail in pure shear. The corresponding slip was measured through laser displacement sensors and the relative movement between the top panel (panel above the shear plane) and the bottom panel (panel below the shear plane) was defined as shear deflection or interface slip.

5. Results and Discussion

The load-deflection curves for all the test specimens have been obtained from the direct shear test results. In order to compare and interpret the results properly, the average load-deflection curves obtained from direct shear tests have been developed and presented in Figure 12. As it can be seen in Figure 12, for all the test specimens, the applied horizontal load keeps increasing until the bond between the two panels is broken. Then, if horizontal load is further applied, it will drop, since not much force is needed to cause sliding of the top panel. Complying the Mohamed et al. (2012) [7] suggestion, the interface shear strength was then calculated by determining the shear load before interface slip occurred. This is mainly attributed to the fact that once interface slip occurs, full composite action is lost and therefore interface shear strength does not exist anymore. However, as explained by Espeche and León (2011) [10] there is still yet no conclusive evidence on the allowable interface slip before the structure losses its composite behaviour. Cholewicki and Szulc (2007) [31] suggested a limited interface slip of 2 mm while Scott (2010) [32] determined it by its post-cracking load and recommended the shear strength right after the bond failure where the shear load drops and consequently giving lower interface shear strength. In this study, as recommended by Liu et al. (2020) [22] and Farzad et al. (2019) [33], the interface shear strength is determined by dividing the maximum horizontal load over the interface (shear plane) area.

Table 7 summarises the measured shear deflection and shear strength parameters in test specimens interfaces. Comparing the curves in Figure 12 and the determined values in Table 7, it is noted that the maximum shear load and the interface shear strength of *Shear-BarChip* specimens have increased by 93.5% compared the corresponding values determined from the *Shear-Plain* specimens. Therefore, it has become apparent that using BarChip 48 macro-synthetic fibre reinforced concrete instead of plain concrete in the tested composite PVC encased walls leads to 93.5% interface shear capacity enhancement for the studied composite PVC encased concrete wall specimens. In addition, comparison between the results in Figure 13 and Table 7 has revealed that the shear capacity at the interface of *Shear-Plain* specimens (specimens filled with plain concrete) is 31% of the interface shear capacity of *Shear-Reo* specimens (specimens filled with reinforced concrete) while *Shear-BarChip* specimens (specimens filled with BarChip 48) have achieved almost 60% of the interface shear capacity of *Shear-Reo* specimens. It is an important observation that shows employing BarChip 48 macro-synthetic fibre reinforcement in composite PVC encased walls can produce more than half of the interface shear capacity achieved by a fully reinforced composite PVC encased walls while only one third of this capacity can be reached by using conventional plain concrete. These findings correlate very well with the fact that the shear strength of non-reinforced construction joints is resisted only by the concrete cohesion and friction along the interfacial failure plane. In other words, for the steel reinforced concrete construction joints, an increased shear strength is accepted under the assumption that the shear force is primarily resisted by the dowel action of the transverse reinforcement.

6. Proposed Cohesion and Friction Parameters for the Studied Specimens

As stated earlier, AS 3600(2018) [21] has prescribed the shear plane surface coefficients, presented in Table 4, for concrete-to-concrete interfaces. The interface shear strength can be calculated by using those coefficients in Eqn. (1) for concrete surfaces. However, AS 3600

(2018) [21] does not prescribe the shear plane surface coefficients for determining the interface shear strength of composite PVC encased structural walling panels. Therefore, to enable structural designers to use Clause 8.4.4 AS 3600 (2018) [21] equation (Eqn. 1) in order to determine the interface shear strength for those panels, similar friction and cohesion coefficients need to be proposed.

According to AS 3600 (2018) [21], the interface shear strength can be determined from Eqn.1 in which:

$$\sigma_n = \frac{g_p}{b_f} \tag{3}$$

Therefore, Eqn. 1 can be simplified as follows:

$$\tau_u = \mu\left(\frac{A_{sf} f_{sy}}{s b_f} + \sigma_n\right) + k_{co} f'_{ct} \tag{4}$$

To determine friction and cohesion parameters (μ and K_{co}) and extrapolate the data from the test results reported in Section 5 and to provide calibration of the design parameters, regression calibration method for models with two predictor variables has been adopted in this study. The term ($\frac{A_{sf} f_{sy}}{s b_f}$) in Eqn. 4 is related to dowel action effects which can be neglected in case of using plain concrete or BarChip 48 macro-synthetic reinforcement and can be assumed as a constant value in case of using steel reinforced concrete. Hence, friction and cohesion parameters can be determined by drawing interface shear strength (τ_u) - normal stress (σ_n) graph in which the term $k_{co} f'_{ct}$ is the value crossing the y-axis, and dividing them over the tensile strength (f'_{ct}) will give the concrete cohesion, k_{co}. This method is vastly used in geotechnical engineering to determine the cohesion factor for different soil types [34].

Table 8 summarises the shear plane surface coefficients including friction and cohesion coefficients (μ and K_{co}) for composite PVC encased 275 mm Dincel structural walling panels extracted from the test results in this investigation using the above mentioned method. As presented in Table 8, both the plain and steel reinforced concrete specimens have similar values of 0.45 and 0.48 for the friction and cohesion coefficients, respectively. This finding correlates very well with Mohamad and Ibrahim (2015) [27] in which concrete-to-concrete interface shear strengths in two cases with and without dowel reinforcements were evaluated. In fact, as shown in Figure 12 and Table 7, in case of using plain concrete, the horizontal load (shear load) increases linearly with small interface slip (0.1 mm) until it reaches the peak shear load. At this point, the interface bond starts to fail where a sudden drop in load by increasing interface slip is observed. While, the specimens with dowel reinforcements indicate larger interface slip at every loading increment. This is mainly attributed to the fact that the steel reinforcements provide enough resistance to prevent sudden bond failure as experienced by the specimens without steel reinforcements. In case of using steel reinforcements, after reaching the peak shear load (shear deflection of 5 mm), no sudden drop in shear load is observed but it is approximately maintained at this point by increasing the interface slip. In other words, for the specimens with dowel reinforcements, an initial crack is formed where the concrete cohesion begins to fail. As the crack continues to develop, the steel reinforcements provide additional tensioning at the interface and prevent widening of the crack. Moreover, the steel reinforcements provide additional clamping stresses to prevent sudden failure of the bond. Therefore, the advantage of adding steel reinforcements at the interface is preventing the sudden separation of the two concrete layers. Likewise, specimens with steel reinforcements contribute higher shear strength due to the clamping stress from the dowel action effects.

In addition, Table 8 indicates similar values for friction coefficient (μ) for all three specimens. This is mainly attributed to the fact that friction coefficient is primarily influenced by the surface roughness and the normal stress at the shear interface [7, 16]. Since in case of using 275 mm Dincel structural walling panels, the normal stress acting on the interface (σ_n) is very small, the friction coefficient (μ) can be assumed to have a similar value of 0.48 for all cases. However, cohesion coefficient is related to the contribution of the interlocking action between aggregates and can be affected by different surface textures [35-37]. Since using BarChip 48 fibre reinforced concrete inside Dincel panels creates a rougher shear plane compared to plain concrete specimens, a higher cohesion coefficient (k_{co}) 0.94 is determined for Shear-BarChip specimens in this study. In conclusion, the friction and cohesion coefficients presented in Table 8 for composite PVC encased 275 mm Dincel structural walling panels filled with plain concrete, reinforced concrete and BarChip 48 macro-synthetic fibre reinforcement can be used by practicing structural engineers to determine interface shear strength of composite PVC encased 275 mm Dincel structural walling panels in conjunction with Clause 8.4.4 AS 3600 (2018) [21].

To assess the reliability of the presented coefficients in Table 8, Table 9 compares the average interface shear loads resulted from the tests with calculated values of interface shear strength using the proposed coefficients in Table 8 in conjunction with Clause 8.4.4 AS 3600 (2018) [21] (Equation 1 in Section 2 of this paper). Comparing the experimental and calculated results in Table 9, it can be seen that the proposed coefficients, when used in equation presented in Clause 8.4.4 AS 3600 (2018) [21], can predict the real test results with acceptable accuracy.

7. Conclusions

In this study, the effects of using macro-synthetic fibre reinforced concrete, instead of conventional concrete, on the interface shear capacity of composite PVC encased walls have been experimentally investigated. Nine composite PVC encased concrete wall specimens were cast and tested using direct shear test at UTS Tech Lab. Based on the load-deflection curves obtained from the direct shear test, the maximum shear loads and the interface shear strength values were determined for three different cases including i) test specimens filled with plain concrete, ii) test specimens filled with macro-synthetic fibre reinforced concrete, and iii) test specimens filled with reinforced concrete. Based on the outcomes of this experimental investigation, it has been observed that the maximum shear load and the interface shear strength of the test specimens filled with macro-synthetic fibre reinforced concrete are 93.5% higher than the corresponding values determined from the test specimens filled with plain concrete. Therefore, it has become apparent that using BarChip 48 macro-synthetic fibre reinforced concrete instead of plain concrete in the studied composite PVC encased walls generates almost double the interface shear capacity of the composite PVC encased concrete wall specimens. In addition, it is understood that the shear capacity at the interface of *Shear-Plain* specimens (specimens filled with plain concrete) is 31% of the interface shear capacity of *Shear-Reo* specimens (specimens filled with reinforced concrete) while *Shear-BarChip* specimens (specimens filled with BarChip 48) have achieved almost 60% of the interface shear capacity of *Shear-Reo* specimens. It is an important observation that indicates employing BarChip 48 macro-synthetic fibre reinforcement in composite PVC encased walls can produce up to 60% of the interface shear capacity achieved by a fully reinforced composite PVC encased walls while only one third of this capacity can be reached by using conventional plain concrete.

AS 3600 (2018) [21] does not prescribe the shear plane surface coefficients for determining the interface shear strength of composite PVC encased 275 mm Dincel structural walling panels. Therefore, in order to enable structural design engineers to use Clause 8.4.4 AS 3600 (2018) [21] equation for determining the interface shear strength for those panels, the friction and cohesion coefficients have been extracted from the test results in this study and proposed in Table 8 for practical applications. The suggested values in Table 8 enable practicing structural engineers to calculate the interface shear strength of composite PVC encased structural walling panels filled with plain concrete, reinforced concrete and BarChip 48 macro-synthetic fibre reinforcement using Clause 8.4.4 AS 3600 (2018) [21] equation .

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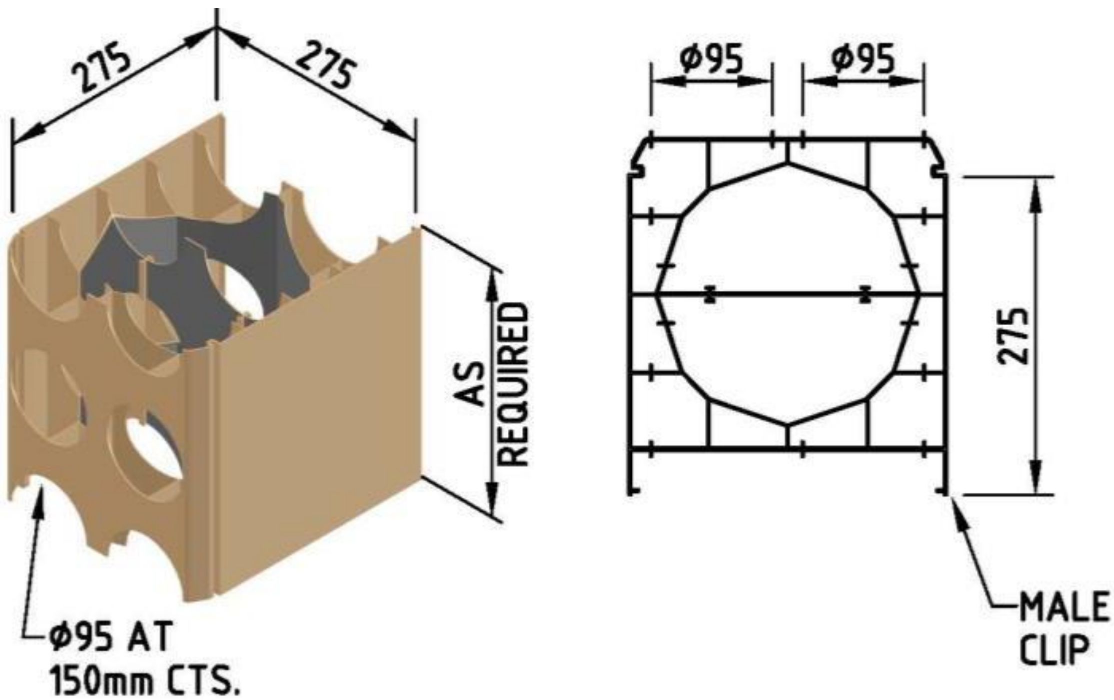


Figure 1: Typical dimensions of 275mm Dincel structural walling panels [23]

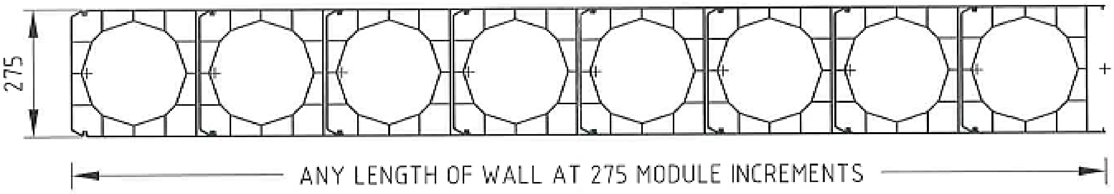


Figure 2: Typical plan layout of 275mm Dincel structural walling panels

Figure 3: Typical use of closed tie reinforcement within Dincel panels

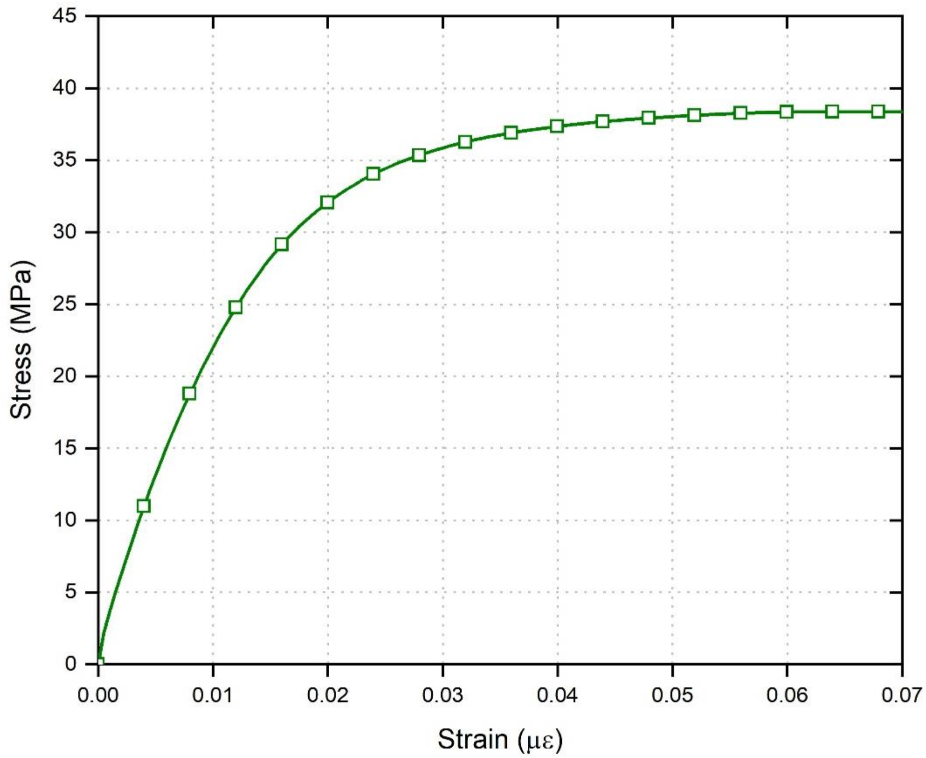


Figure 4: Stress-strain curve of the tested PVC encasing material

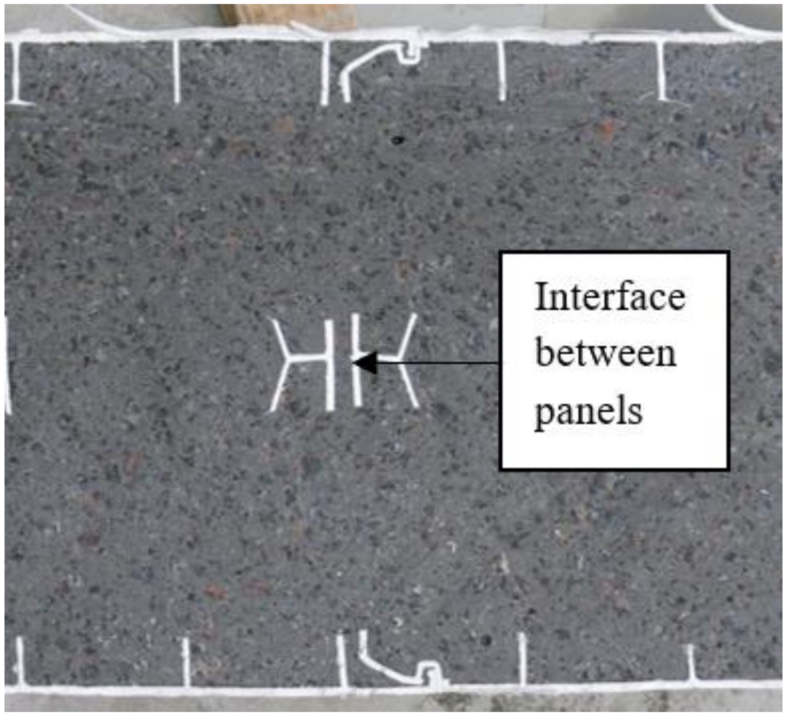


Figure 5 : The interface between panels filled with concrete

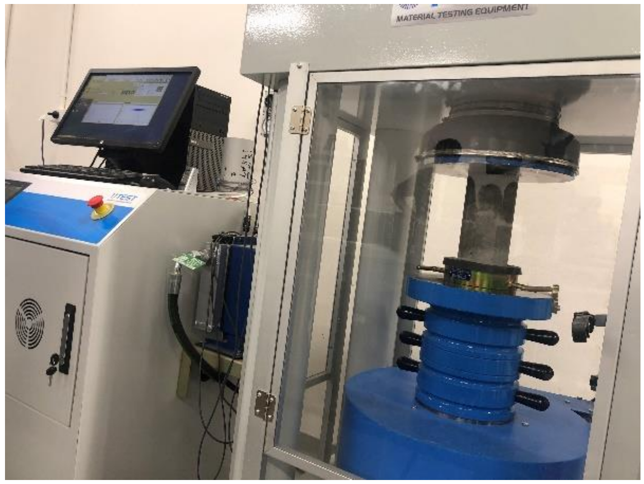


Figure 6: Concrete cylinder compression testing according to ASTM C39/C39M [26] in process at UTS Tech Lab

Figure 7: Dincel panels with shear and longitudinal steel reinforcements (before pouring concrete)

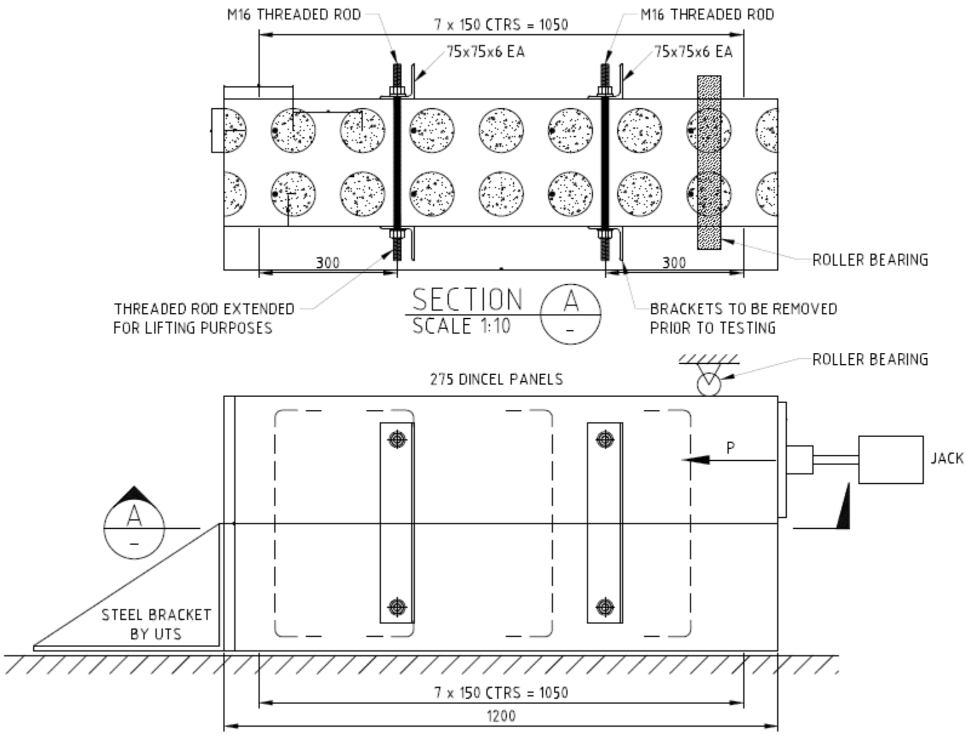
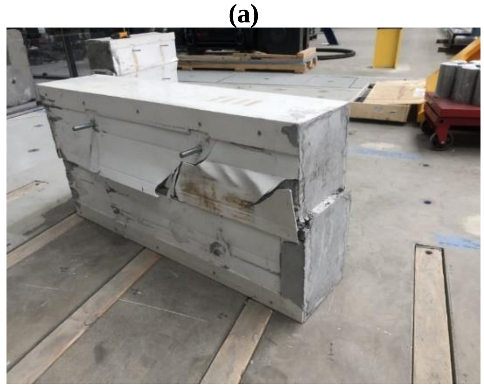


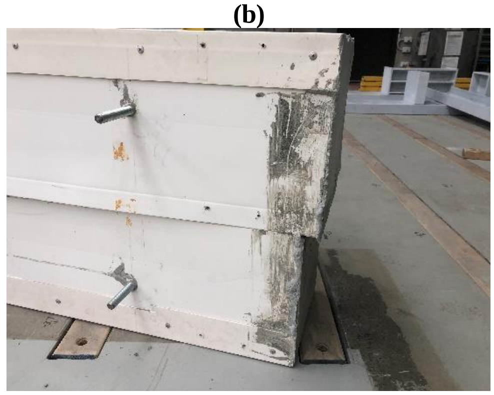
Figure 8: Schematic that test setup and dimensions of the test specimens

Figure 9: An overview of the direct shear test configuration at the Tech Lab

(a)



(b)



(c)

Figure 10: Failure of the test specimens after reaching the maximum shear capacity at the interface of composite PVC encased 275 mm Dincel structural walling panels; a) Shear-Plain specimen; b) Shear-BarChip specimen, c) Shear-Reo specimen

Figure 11: A Shear-BarChip failed interface

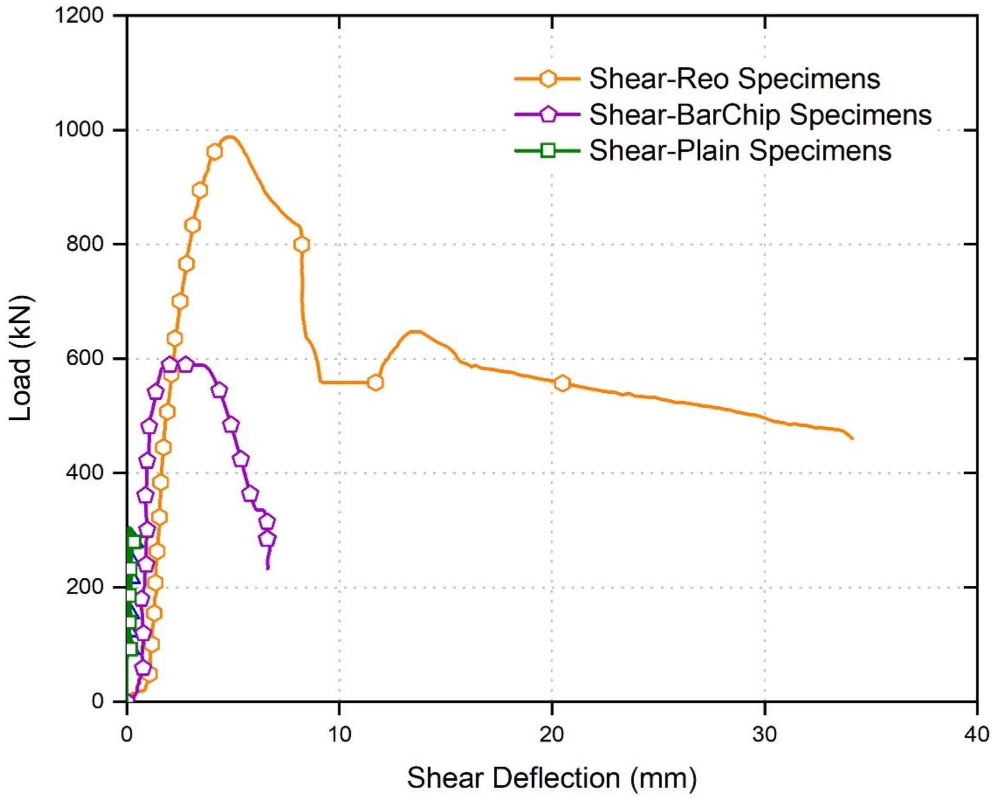


Figure 12: Average load-shear deflection curves obtained from direct shear tests

Table 1: Mechanical properties of tested PVC material [3,4]

Young's Modulus E (MPa)	Tensile Strength σ_u (MPa)	Poisson's Ratio υ
2609	37.20	0.39

Table 2: Characteristics of BarChip 48 macro-synthetic fibre concrete reinforcement [3,4]

Young's Modulus E (MPa)	Tensile Strength σ_u (MPa)	Length (mm)	Base Material	Anchorage
12000	640	48	Virgin Polypropylene	Continuous Embossing

Table 3: Shear-friction provisions in different design codes

Design Code	Year	Design Expression
CEB-FIP Model Code [17]	1990	$\tau_u = cf_{ctd} + \mu(\sigma_n + \rho f_y) \leq 0.25 f_{cd}$
Eurocode 2 [18]	2004	$\tau_u = cf_{ctd} + \mu\sigma_n + \rho f_y(\mu sin\alpha + cos\alpha) \leq 0.5\nu f_{cd}$
CAN/CSA A23.3 [19]	2004	$\tau_u = \lambda\phi_c(c + \mu(\sigma_n + \rho f_y sin\alpha))cf_{ctd} + \phi_s \rho f_y cos\alpha$
ACI 318 [20]	2008	$\tau_u = \rho f_y(\mu sin\alpha + cos\alpha)$
AS 3600 [21]	2018	$\tau_u = \mu\left(\frac{A_{sf} f_{sy}}{sb_f} + \frac{g_p}{b_f}\right) + k_{co} f'_{ct}$

Table 4: Shear plane surface coefficients [21]

Surface condition of shear plane	Coefficients	
	μ	k_{co}
A smooth surface, as obtained by casting against a form, or finished to a similar standard	0.6	0.1
A surface trowelled or tamped, so that the fines have been brought to the top, but where some small ridges, indentations or undulations have been left; slip-formed and vibro-beam screeded, or produced by some form of extrusion technique	0.6	0.2
A surface deliberately roughened: a) By texturing the concrete to give a pronounced profile; b) By compacting but leaving a rough surface with coarse aggregate protruding but firmly fixed in the matrix c) By spraying when wet, to expose the coarse aggregate without disturbing it	0.7	0.4
Monolithic construction or mechanical shear keys	0.9	0.5

Table 5: Mechanical properties of tested PVC material

Young's Modulus E (MPa)	Tensile Strength σ_u (MPa)	Poisson's Ratio υ
2609	37.20	0.39

Table 6: Characteristics of BarChip 48 macro-synthetic fibre concrete reinforcement

Young's Modulus *E* (*MPa*)	Tensile Strength σ_u (*MPa*)	Length (*mm*)	Base Material	Anchorage
12000	640	48	Virgin Polypropylene	Continuous Embossing

Table 7: Summary of test results for different specimens

Specimen	Average peak shear load (kN)	Shear deflection at peak shear load (mm)	Average interface shear strength (MPa)
Plain Concrete	304	0.10	1.11
BarChip 48 Fibre Reinforced Concrete	589	2	2.14
Steel Reinforced Concrete	988	5	3.60

Table 8: Recommended friction and cohesion coefficients based on experimental study results

Specimen	Friction coefficient (μ)	Cohesion coefficient (k_{co})
Plain Concrete	0.45	0.48
BarChip Fibre Reinforced Concrete	0.45	0.94
Steel Reinforced Concrete	0.45	0.48

Table 9: Comparison between the test results and calculations using proposed coefficients in this study

Specimen	Average peak shear load (kN)	Calculated shear interface capacity using the proposed coefficients (kN)
Plain Concrete	304	300
BarChip 48 Fibre Reinforced Concrete	589	585
Steel Reinforced Concrete	988	939