https://doi.org/10.1016/j.conbuildmat.2020.121756

Experimental Investigation on Flexural Behaviour of Composite PVC Encased Macro-Synthetic Fibre Reinforced Concrete Walls

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Abstract: Composite PVC encased concrete walls provide substantial advantages in terms of structural strength and durability enhancement, ultraviolet radiation and pest infestation resistance, design flexibility, ease of construction and excellent resistance to impact. In this study, the effects of using macro-synthetic fibre reinforced concrete on flexural behaviour of composite PVC encased walls in comparison with composite PVC encased walls filled with conventional plain concrete and reinforced concrete have been experimentally investigated. Fifteen composite PVC encased concrete wall specimens were cast and tested using three-point bending test. Based on the load-deflection curves resulting from the three-point bending tests, flexural parameters including ultimate loads, ultimate flexural strengths, stiffness and flexural rigidity values for cracked and uncracked conditions 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 this study, it has become apparent that using BarChip 48 macro-synthetic fibre reinforced concrete in composite PVC encased walls instead of plain concrete can lead to 43.5% flexural strength improvement and 25% stiffness enhancement at the age of 28 days. Based on the experimental measurements and theoretical comparison in this study, it has been concluded that composite PVC encased walls filled with BarChip 48 macro-synthetic fibre reinforced concrete, without steel reinforcement, are deemed suitable for sway-prevented structures such as retaining walls. If using steel reinforcement in composite PVC encased retaining walls is not an option due to high-risk of steel corrosion in harsh environment; it is highly recommended that the retaining walls to be filled with macro-synthetic fibre reinforced concrete instead of plain concrete to ensure the safety and structural integrity of this type of sway-prevented structures.

Keywords: *Composite PVC encased concrete walls, Flexural behaviour, Flexural rigidity, Stiffness, Macro-synthetic fibre reinforced concrete*

1. Introduction

Over the past decade, Polyvinyl Chloride (PVC) stay-in-place formwork has become a popular alternative for conventional formwork in the concrete construction industry due to its relatively lower cost of construction and ease of assembly [1]. 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 (Figure 1) [2]. 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 with no need for steel reinforcement in some cases,

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except for steel dowels, which are necessary to anchor the wall to the concrete foundation [3]. Composite PVC encased reinforced concrete walls also exhibit better fire resistance performance compared to conventional reinforced concrete walls with traditional removable formwork [4].

Several researchers [1, 3, 5, 6] have studied structural behaviour of Composite PVC encased concrete walls under different load conditions. Regarding flexural behaviour of composite PVC encased concrete walls, which is the focus of the current study, Kuder et al. 2009 [2] experimentally investigated the flexural performance of PVC-encased systems by testing reinforced concrete beams with and without the PVC components. The results of their investigations revealed that the PVC encasement increases the moment capacity and toughness of concrete specimens. In addition, they pointed out that composites containing more PVC stay-in-place formwork in the tension regions will have a higher moment capacity. Wahab & Soudki (2013) [7] carried a comprehensive experimental study to compare the flexural behaviour of PVC encased concrete walls with conventional concrete walls. They pointed out that the PVC stay-in-place system contributed to enhancing the ductility of the wall system with an increase in ultimate deflection between 2.5% and 134% over the conventional concrete walls. In addition, the increase in the ultimate flexural capacity due to the PVC stay-in-place system ranged from 17.4% to 37.7% compared to the conventional concrete walls tested. Scott et al. (2016) [8] carried out flexural tests on eighteen walls with and without PVC encasement in order to understand the polymer's contribution to flexural capacity. The outcomes of their study revealed that PVC encasement improved the flexural capacity and ductility of the tested reinforced concrete walls. They also noticed that the improvement in the flexural capacity reduced as either the reinforcement ratio or the wall thickness increased.

One of the main factors concerning durability and service life of retaining walls is corrosion of steel bars especially when exposed to harsh environment [9]. The use of macro-synthetic fibre-reinforced concrete, as non-corrosive material, in composite PVC encased walls with no steel reinforcement can potentially solve the corrosion related problems. This can reduce the maintenance cost and increase the service life of the retaining walls. Several researchers

[3,7] have pointed out that composite PVC encased concrete walls can function as retaining walls and foundation walls with no need for steel reinforcement. Therefore, in this study, the suitability of the tested composite PVC encased concrete walls (Flex-Plain and Flex-BarChip specimens) for being used without steel reinforcement in sway-prevented structures such as retaining walls has been examined.

Abdulla (2017) [10], in a comprehensive study on PVC encased reinforced concrete members, pointed out that more practical work, laboratory and field tests, and detailed information from analytical and experimental studies will be required for developing appropriate design guidelines for composite PVC encased reinforced concrete members. In addition, structural material properties and characteristics significantly influence the performance of structural members [11, 12]. As a result, the experimental testing program in this study has aimed to investigate the effects of using macro-synthetic fibre reinforced concrete (BarChip 48 macro-synthetic reinforcement system) on flexural behaviour of composite PVC encased walls in comparison with composite PVC encased walls filled with conventional plain concrete and reinforced concrete. In addition, suitability of utilising composite PVC encased macro-synthetic fibre reinforced concrete walls, with no steel bar reinforcement, in sway-prevented structures such as retaining walls has been examined and discussed in Section 5 of this study.

2. Employed Materials

2.1. 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. Details and dimensions of those panels are shown in Figure 2 [13]. As plan layout of 275mm Dincel structural walling panels shows in Figure 3, any length of wall at 275mm increments can be created by using 275mm Dincel panels. 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 [14] specifications. As illustrated in Figure 4, tensile tests were conducted by applying a constant rate of 0.083 mm/s according to ASTM D638 [14] and the resulted average ultimate tensile strength, Young’s modulus of elasticity, and Poison’s ratio were

determined and presented in Table 1. Stress-strain curve of the tested PVC material has also been obtained and plotted in Figure 5.

2.2.Macro-synthetic Fibre Reinforcement

BarChip 48 macro-synthetic fibres (Figure 6) 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 [15]. 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 [15]. Table 2 summarises the characteristics of BarChip 48 macro-synthetic fibres provided by the manufacturer.

3. Experimental Testing Program

3.1.Test Specimens

Fifteen composite PVC encased concrete wall specimens were cast and tested at the UTS Tech Lab. The first of its type in Australia, UTS Tech Lab is a new-generation facility with 9000 m^2 facility that is designed to bring university and industry together to innovate and disrupt traditional university approaches to research [16]. All fifteen composite PVC encased concrete walls were prepared, poured with concrete that has compressive strength of 32 MPa at the curing age of 28 days and 200mm slump. The concrete mix proportions for cement, sand, coarse aggregates and water are 1, 2.5, 4.0, and 0.66, respectively. The test specimens have been cured on site at UTS Tech Lab by Dincel technicians and the entire process has been overseen and reviewed by UTS staff prior, during and post pour. All reinforcement details, mix designs and mix properties were reviewed and approved by suitably qualified UTS staff. As illustrated in Figure 7, the test specimens have been made of three 275mm Dincel panels with overall dimensions of 825mm wide × 3300 mm long (3m clear span). Concrete compression cylinders were taken from the fresh concrete mix and tested to measure the concrete strength at the ages of 24 hours and 28 days to determine the concrete properties throughout curing strength predictions and validation of the concrete mechanical properties.

3.2. Test Procedure

The experimental testing program has aimed to investigate the effects of using macro-synthetic fibre reinforced concrete (BarChip 48 macro-synthetic reinforcement system) on flexural behaviour of composite PVC encased walls in comparison with composite PVC encased walls filled with conventional plain concrete and reinforced concrete. To achieve this goal, flexural testing was conducted on the test specimens, which were cast with plain concrete, reinforced concrete and BarChip fibre reinforced concrete, respectively, and tested at the age of 28 days with the following details:

- Three composite PVC encased concrete wall specimens, named *Flex-BarChip*, with concrete reinforced with 5kg/m^3 of BarChip 48 macro-synthetic fibres and no steel bar reinforcement;
- Three composite PVC encased concrete wall specimens, named *Flex-Plain*, with plain concrete; and
- Three composite PVC encased concrete wall specimens, named *Flex-Reo*, with reinforced concrete (N16@275mm normal ductility class deformed reinforcing bars grade D500N according to AS3600-2018 [17]).

It should be noted that three samples were tested for each different test detail for statistical analysis purposes. In order to investigate the flexural behaviour of Dincel panels filled with BarChip 48 at the early age of 24 hours, when the backfilling of the retaining walls may potentially start, six test specimens (three samples for each test detail) were cast and tested 24 hours after pouring the concrete with the following details:

- Three composite PVC encased concrete wall specimens, named *Flex-BarChip*, with concrete reinforced with 5kg/m^3 of BarChip 48 macro-synthetic fibres and no steel bar reinforcement; and
- Three composite PVC encased concrete wall specimens, named *Flex-Plain*, with plain concrete.

For flexural testing, three-point bending test on a three-metre span was chosen, with the load point at 3rd span (Figure 7) in order to apply a load that conservatively resembled the pressure applied to a propped cantilever such as basement retaining walls. As illustrated in Figure 8, the supports and the load point used in the test configuration represented a simply supported beam to provide the maximum bending moment and shear force at one-third of the span. The load was applied using a hydraulic actuator (MTS 201.35 fatigue rated actuator and controlled using a PID controller (MTS Flex Test 60) in stroke control. The test load was applied with a suitably stiff spreader beam to distribute the load across the full width of the three modules. Laser displacement sensors were positioned at one-third and half of the span length on the underside of the test specimens to monitor displacement throughout the whole tests (Figure 9), with all the sensors and actuator properties (force and stroke) recorded for post processing purposes using the computerised controller system shown in Figure 10. Loading was applied until the maximum bending moment capacity of the specimens had been reached. Figure 11 shows one of the BarChip 48 fibre reinforced concrete failed samples from both sides after reaching the maximum bending moment capacity. The test setup and loading rates of the tests were derived in a way that satisfies the requirements of AS3600-2018 [17].

4. Results and Discussion

4.1. Load-deflection Curves

The load-deflection curves for all the test specimens have been obtained and plotted in Figures 12 to 16. Figures 12 and 13 show the load-deflection curves for Flex-Plain specimens (specimens filled with plain concrete) and Flex-BarChip specimens (specimens filled with BarChip 48 macro-synthetic fibre reinforced concrete) at the age of 24 hours, respectively, when the backfilling of the retaining walls may potentially start. Figures 14 to 16 respectively illustrate the load-deflections curves for Flex-Plain specimens (specimens filled with plain concrete), Flex-BarChip specimens (specimens filled with BarChip 48 macro-synthetic fibre reinforced concrete) and Flex-Reo specimens (specimens filled with reinforced concrete with N16@275mm normal ductility class deformed reinforcing bars) at the age of 28 days when the concrete has reached the intended strength of 32 MPa.

In order to compare and interpret the results properly, the average load-deflection curves for Figures 12 to 16 have been developed and presented in Figures 17 and 18. Figure 17 compares Flex-BarChip and Flex-Plain average load-deflection curves at the age of 24 hours while Figure 18 presents a comparison between Flex-BarChip, Flex-Plain and Flex-Reo average load-deflection curves at the age of 28 days.

4.2. Flexural Strength

4.2.1. Flexural Strength at the Age of 24 Hours

Since several construction companies (e.g. Dincel Construction) commence backfilling their retaining walls with compacted material after 24 hours [13], it is important to understand the flexural behaviour and strength of the retaining walls at this early age, in particular the ones without the steel reinforcement. Therefore, this study has only tested the two cases of Flex-BarChip and Flex-Plain specimens at the age of 24 hours. Based the average results presented in Figure 17, the average ultimate loads, P_u, (the maximum load that the specimens can tolerate before breaking) and the average modulus of rupture values (ultimate flexural strength), M_u, have been determined and tabulated in Table 3. Comparing the curves in Figure 17 and the results in Table 3, it can be seen that the ultimate load (63 *kN*) and the modulus of rupture value (42 *kN.m*) of Flex-BarChip specimens are 23.5% larger than the corresponding values (51 *kN* and 34 *kN.m*) obtained from the Flex-Plain specimens. Therefore, it is understood that using BarChip 48 macro-synthetic fibre reinforced concrete instead of plain concrete in the tested specimens can increase the flexural strength by 23.5% at the early age of 24 hours.

4.2.2. Flexural Strength at the Age of 28 Days

In order to investigate the flexural strength of the test specimens at the age of 28 days, the average ultimate loads and the average modulus of rupture values (ultimate flexural strength) have been extracted from Figure 18 and summarised in Table 4. Comparing the average curves in Figure 18 and the determined values in Table 4, it is noted that the ultimate load (89 *kN*) and the modulus of rupture value (59.3 *kN.m*) of Flex-BarChip specimens have increased by 43.5% compared to the corresponding values of 62 *kN* and 41.3 *kN.m* determined from the Flex-Plain specimens after 28 days, respectively. 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 leads to 43.5% flexural strength enhancement at the age of 28 days. It should be noted that this increase is 20% more than what has been observed at the age of 24 hours showing that the flexural strength improves over time. In addition, comparison between the three groups of the tested specimens in Figure 18 and Table 4 has revealed that the flexural strength of Flex-Plain specimens (62 *kN*) is

33% of the flexural strength of Flex-Reo specimens (186 *kN*) while Flex-BarChip specimens (89 *kN*) have achieved almost 50% of the flexural strength of the Flex-Reo specimens. It is an important observation that shows employing BarChip 48 macro-synthetic fibre reinforcement in composite PVC encased walls can produce half of the flexural strength achieved by a fully reinforced composite PVC encased walls while only one third of this capacity can be reached by using conventional plain concrete.

4.2.3. Stiffness and Flexural Rigidity at the Age of 28 Days

In order to develop a better understanding of the flexural performance of the tested specimens at the age of 28 days, in addition to flexural strength, flexural rigidity (EI) and stiffness (K) values for cracked and un-cracked conditions considering tension stiffening effect have been determined based on the load-deflection curves presented in Figure 18. As shown in Figures 19 to 21, when the applied force P is plotted against the displacement δ, straight lines can be fitted in both elastic and cracking stages. The gradient of these lines can estimate the stiffness values for the specimens in un-cracked, effective and fully cracked conditions [18, 19]. In Figures 20 and 21, where BarChip48 and steel reinforcement were used in the concrete to provide resistance against tensile stresses, tension stiffening effects are generated due to the bond between the reinforcement and concrete [19,20]. Those effects have been taken into account in determining the stiffness of Flex-BarChip and Flex-Reo specimens and the corresponding un-cracked, effective and fully cracked stiffness values have been estimated and tabulated in Table 5. For Flex-Plain specimens shown in Figure 19, the stiffness values were only determined in un-cracked and fully cracked phases (Table 5) since there is no tension stiffening effects observed. As reflected in Figures 19 to 21, in all the tested specimens, a sudden drop occurs in section stiffness when the first crack appears that correlates very well with previous studies in this area [18, 19]. According to the method used by [21, 22], using the estimated stiffness values, flexural rigidity values in un-cracked, effective and fully cracked conditions for the tested specimens have been calculated and summarised in Table 6. As the results in Tables 5 and 6 indicate, Flex-Plain, Flex-Reo and Flex-BarChip specimens have similar stiffness and flexural rigidity of 21500 *N/mm* and 9555×10^9 $N.mm^2$, respectively in elastic (un-cracked) stage which corresponds well with the previous studies [20, 22]. However, the fully cracked stiffness (1750 *N/mm*) and flexural rigidity (777×10^9 *N.mm*^{2}) values of Flex-BarChip specimens are 25% higher than the corresponding values determined from Flex-Plain specimens (1400 *N/mm* and 622×10^9 *N.mm*^{2}) after 28 days. Thus, it can be understood that using BarChip 48 macro-synthetic fibre reinforced concrete instead of plain concrete in composite PVC encased walls can result in noticeable improvement in stiffness and flexural rigidity at the age of 28 days. These findings correlate well with Camille et al. (2019) [23] study which indicates that experimental results demonstrated that the fibres provide a bridging effect that characteristically reducing the crack propagation. In addition, it has been observed that Flex-BarChip specimens have achieved 44% of the stiffness and flexural rigidity of Flex-Reo specimens while Flex-Plain specimens obtained 34% of those. It clearly indicates that using BarChip 48 macro-synthetic fibre reinforcement in composite PVC encased walls can produce nearly half of the flexural rigidity and stiffness achieved by a fully reinforced composite PVC encased walls while only about one third of those values can be reached by using conventional unreinforced concrete. Furthermore, it has been noted in Tables 5 and 6 that the cracked and effective stiffness and flexural rigidity values are slightly different. Those minor differences observed between the effective and fully cracked stiffness and flexural rigidity values are attributed to the tension stiffening effects caused by the bond between the reinforcement and concrete [18,19].

5. Suitability of Using Unreinforced PVC Encased Walls as Sway-prevented Structures

Several researchers [4, 6] have pointed out that composite PVC encased concrete walls can function as retaining walls and foundation walls with no need for steel reinforcement, except for steel dowels, which are conventionally used to anchor the wall to the concrete foundation. Therefore, in this study, the suitability of the tested composite PVC encased concrete walls (Flex-Plain and Flex-BarChip specimens) for being used without steel reinforcement in sway-prevented structures such as retaining walls has been examined. To achieve this goal, a conventional reinforced concrete retaining wall with the height of 3m that has been designed according to AS3600-2018 [17] to safely function as a retaining wall has been selected as the base for assessing suitability of the tested specimens. The selected retaining wall has 275 mm thickness, the same thickness as the tested specimens, and is poured with concrete with the compressive strength of 32 MPa at 28 days. The required p=0.25% reinforcement as per Clause 11.7.1.a of AS3600-2018 [17] for concrete walls with normal ductility class deformed reinforcing bars grade D500N, has been adopted for this concrete retaining wall and the ultimate flexural strength of this wall has been estimated according to Clause 8.1.5 of AS 3600-2018 [17].

The ultimate flexural strength (M_u) of the tested Flex-Plain specimens (specimens filled with plain concrete) and Flex-BarChip specimens (specimens filled with BarChip 48 macro-synthetic fibre reinforced concrete) have been compared with the ultimate flexural strength of the described conventional reinforce concrete retaining wall at the age of 28 days. The calculated ultimate flexural strength of the conventional reinforced retaining wall as well as the measured ultimate flexural strength values for Flex-Plain and Flex-BarChip specimens from Table 4 are presented in Table 7 for comparison purposes. Comparison between the results in Table 7 shows that the flexural strength (M_u) of the tested Flex-Plain specimens is 41.3 *kN.m* which is 30 % lower than the flexural strength of the conventional reinforced concrete retaining walls (57.9 *kN.m*) while the flexural strength of the tested Flex-BarChip specimens is 59.3 *kN.m* that is 2.4 % more than the flexural strength of the conventional reinforced walls. The relatively higher flexural capacity of composite PVC encased walls filled with BarChip 48 macro-synthetic fibre reinforced concrete without steel reinforcement bars compared to the base reinforced concrete walls makes this type of PVC encased walls also a suitable option to be used as retaining walls. As a result, it can be concluded that since 275 Dincel structural walling panels filled with BarChip 48 fibre reinforcement without steel bar reinforcement exhibit more flexural capacity than conventional reinforced concrete retaining walls (that can safely function as a retaining wall), this type of wall can be deemed suitable for being used as sway-prevented structures such as retaining walls.

If using steel reinforcement in the composite PVC encased retaining walls is not an option due to high-risk of steel corrosion in harsh environment; it is highly recommended that the retaining walls to be filled with macro-synthetic fibre reinforced concrete instead of plain concrete to ensure the safety and structural integrity of this type of sway-prevented structures.

6. Conclusions and Recommendations

In this study, the effects of using macro-synthetic fibre reinforced concrete, instead of conventional concrete, on flexural behaviour of composite PVC encased walls have been experimentally investigated. Fifteen composite PVC encased concrete wall specimens were cast and tested using three-point bending test in the UTS Tech Lab. Based on the load-deflection curves obtained from the three-point bending tests, flexural parameters including ultimate load, ultimate flexural strength, stiffness and flexural rigidity for cracked and un-cracked conditions 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 using BarChip 48 macro-synthetic fibre reinforced concrete in composite PVC encased walls instead of plain concrete can lead to 43.5% flexural strength improvement and 25% stiffness enhancement at the age of 28 days. As a result, in can be concluded that composite PVC encased macro-synthetic fibre reinforced concrete walls can noticeably exhibit higher flexural strength, flexural rigidity and stiffness compared to composite PVC encased walls filled with plain concrete. It is also understood that using BarChip 48 macro-synthetic fibre reinforcement in composite PVC encased walls can produce nearly half of the flexural strength, flexural rigidity and stiffness achieved by fully reinforced composite PVC encased walls while only about one third of those flexural behaviour values can be reached by using conventional plain concrete in composite PVC encased walls.

Comparison between the results in Table 7 shows that the flexural strength (M_u) of the tested Flex-Plain specimens is 41.3 *kN.m* which is 30 % lower than the flexural strength of the conventional reinforced concrete retaining walls (57.9 *kN.m*) while the flexural strength of the tested Flex-BarChip specimens is 59.3 *kN.m* that is 2.4 % more than the flexural strength of the conventional reinforced walls. Therefore, based on the experimental measurements and theoretical comparison in this study, it has become apparent that composite PVC encased walls filled with BarChip 48, without steel reinforcement, can exhibit 2.4 % more flexural capacity than conventional reinforced concrete walls, designed in accordance with AS3600-2018 to function safely as retaining wall. As a result, this type of composite PVC encased wall is deemed suitable for sway-prevented structures such as retaining walls. If using steel reinforcement in composite PVC encased retaining walls is not an option due to high-risk of steel corrosion in harsh environment; it is highly recommended that the retaining walls to be filled with macro-synthetic fibre reinforced concrete instead of plain concrete to ensure the safety and structural integrity of this type of sway-prevented structures.

Since understanding the creep and creep recovery properties of composite structural members is important to portray a clear and realistic picture of the long-term flexural behaviour of those members [24, 25], the authors of this paper are planning to experimentally investigate the long-term creep behaviour of this type of walls, caused by non-linear, inelastic and time-dependent nature of the concrete. The experimental outcomes will be published in the subsequent papers of the authors.

Acknowledgment

The authors would like to thank Dincel Construction System and BarChip Australia companies for funding this research project (Funding Number: PRO19-7845).

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Figure 1: An overview of composite PVC encased concrete walls

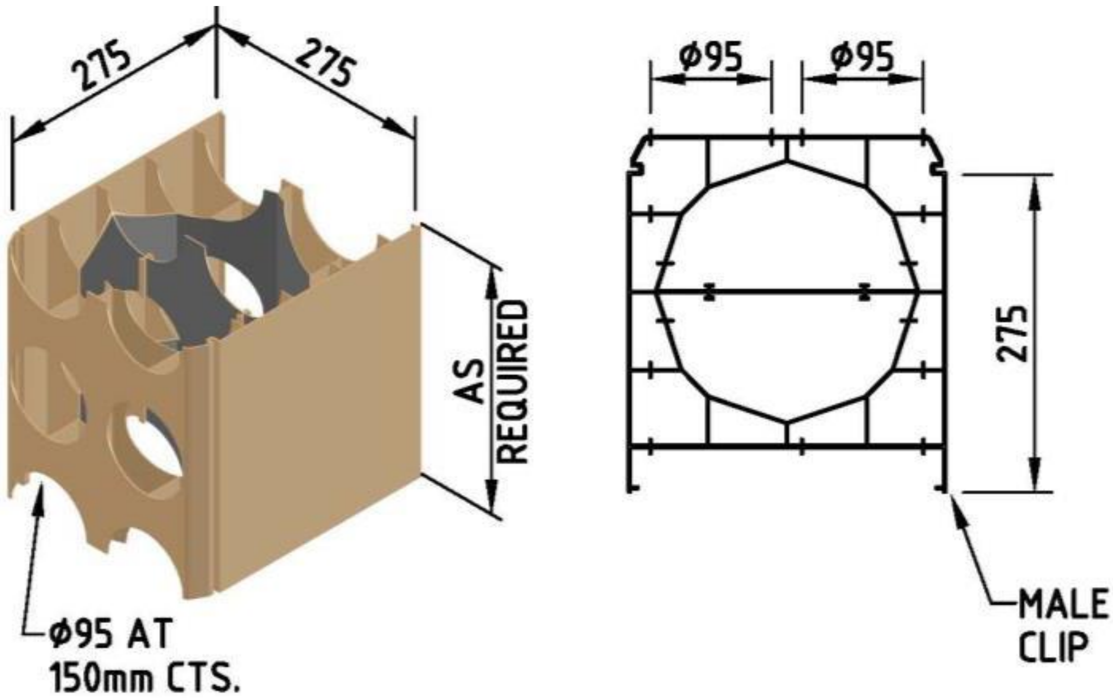

Figure 2: Details and dimensions of 275mm Dincel structural walling panels [13]

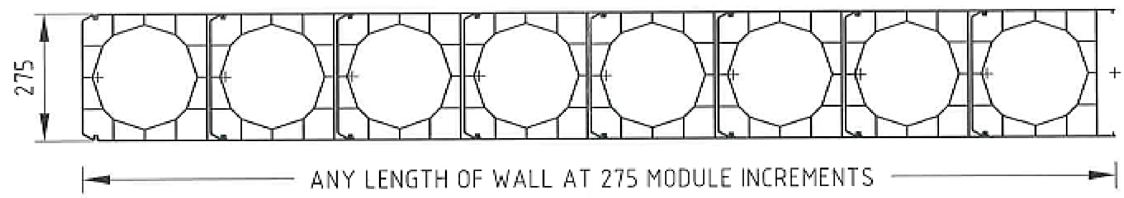

Figure 3: Plan layout of 275mm Dincel structural walling panels

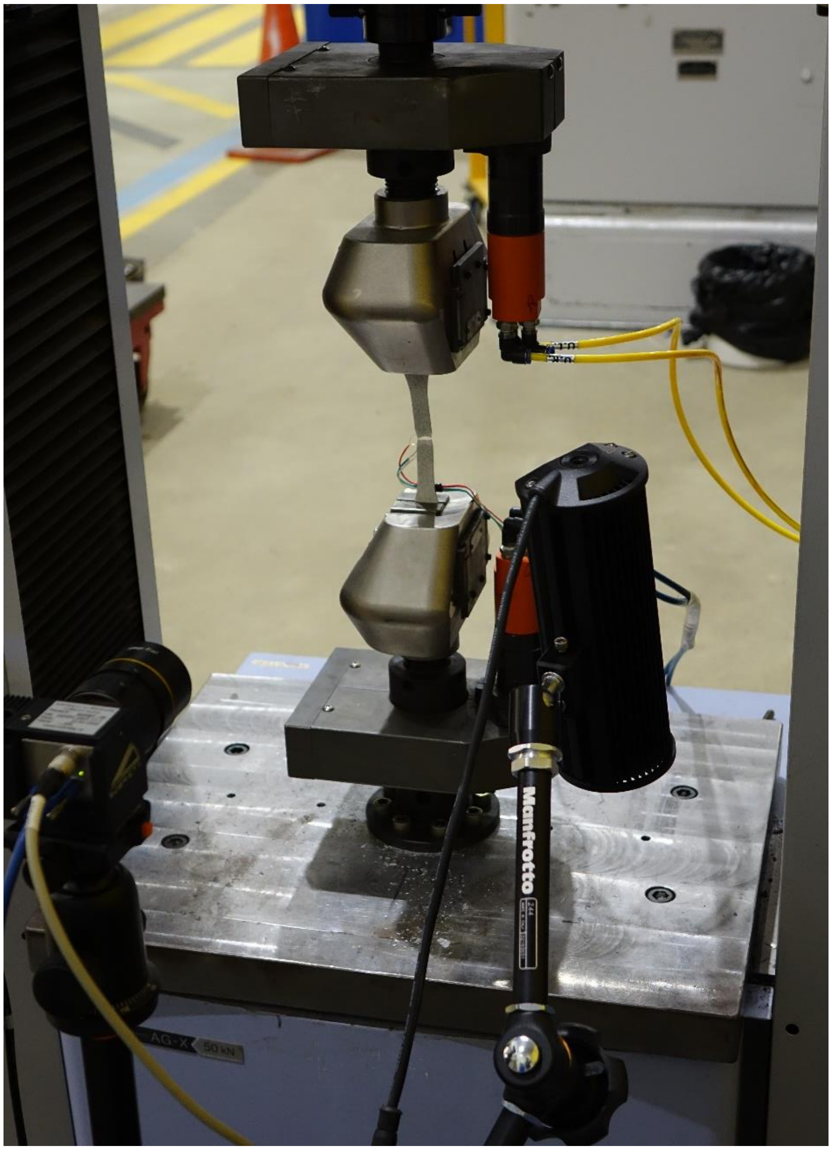

Figure 4: Tensile tests on PVC dog-bone coupon specimens according to ASTM D638

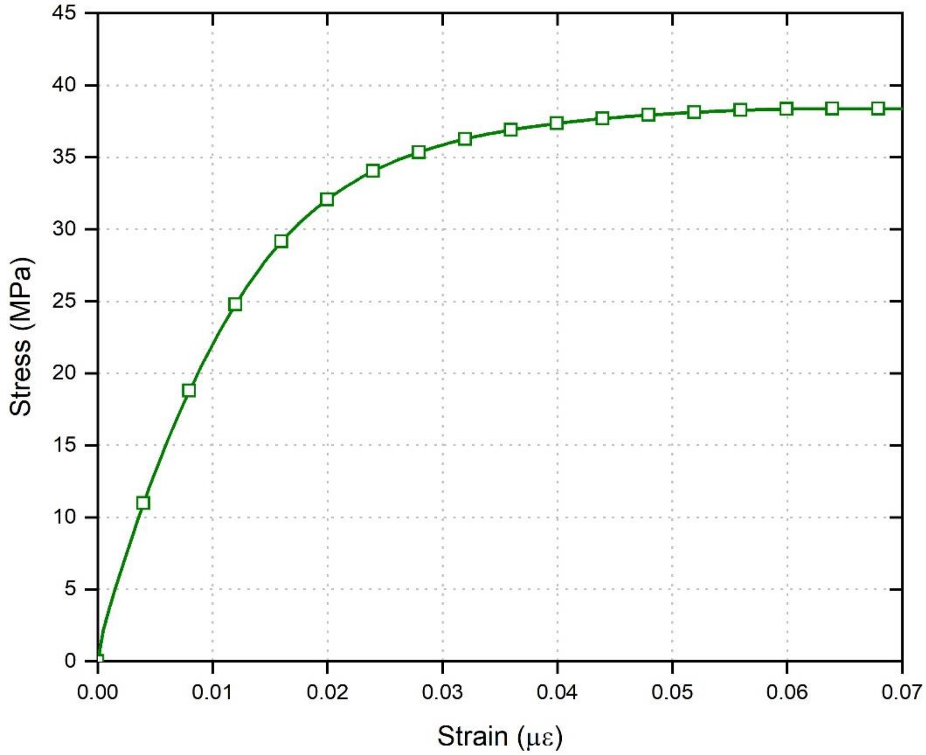

Figure 5: Stress-strain curve of the tested PVC encasing material

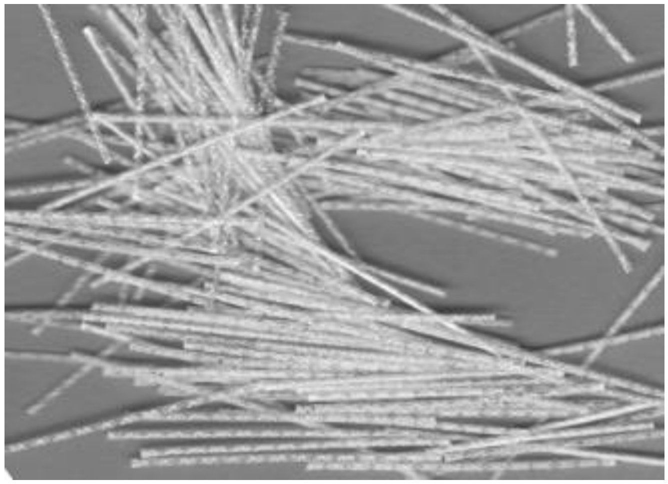

Figure 6: BarChip 48 macro-synthetic fibre concrete reinforcement [15]

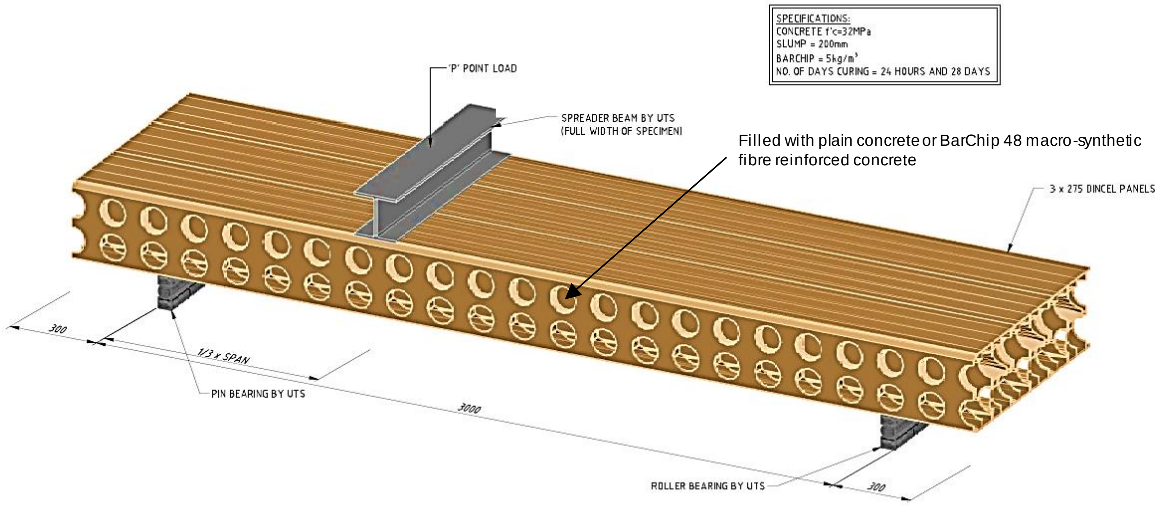

Figure 7: Overall view and dimensions of the test specimens

Figure 8: An overview of the three-point bending test configuration

Figure 9: One of the laser displacement sensors under its protective stand

(a) **(b)**

Figure 10: Controller system used for recording and post processing purposes; a) Front view, b) Rear view

(a) **(b)**

Figure 11: Failure of one of the BarChip 48 fibre reinforced concrete specimens after reaching the maximum bending moment capacity; a) Front side cracks, b) Underside cracks

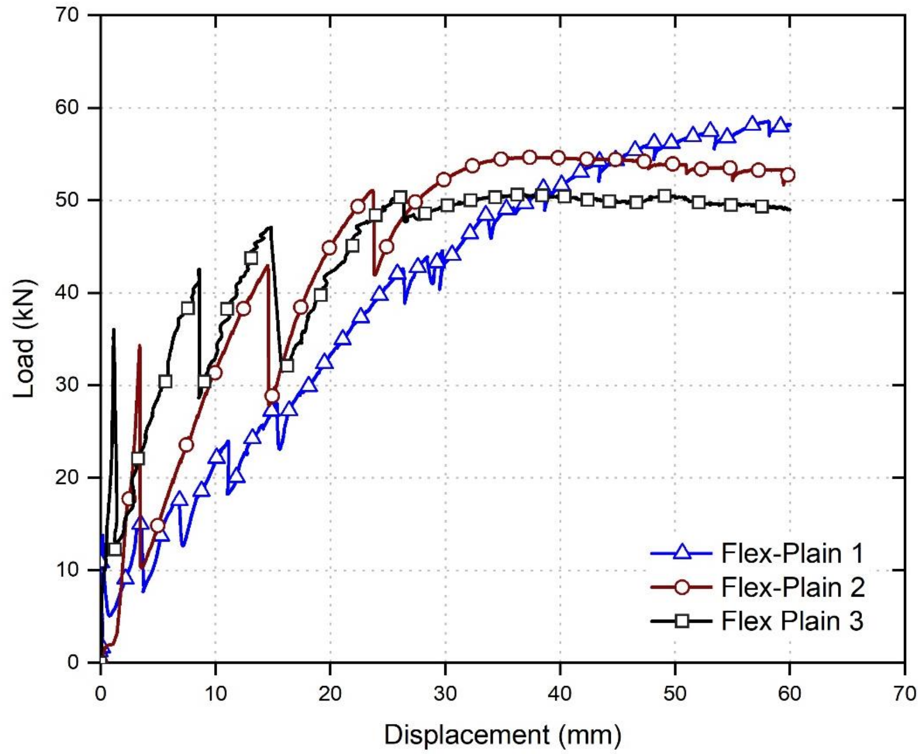

Figure 12: Load-deflection curves for Flex-Plain specimens (specimens filled with plain concrete) at the age of 24 hours

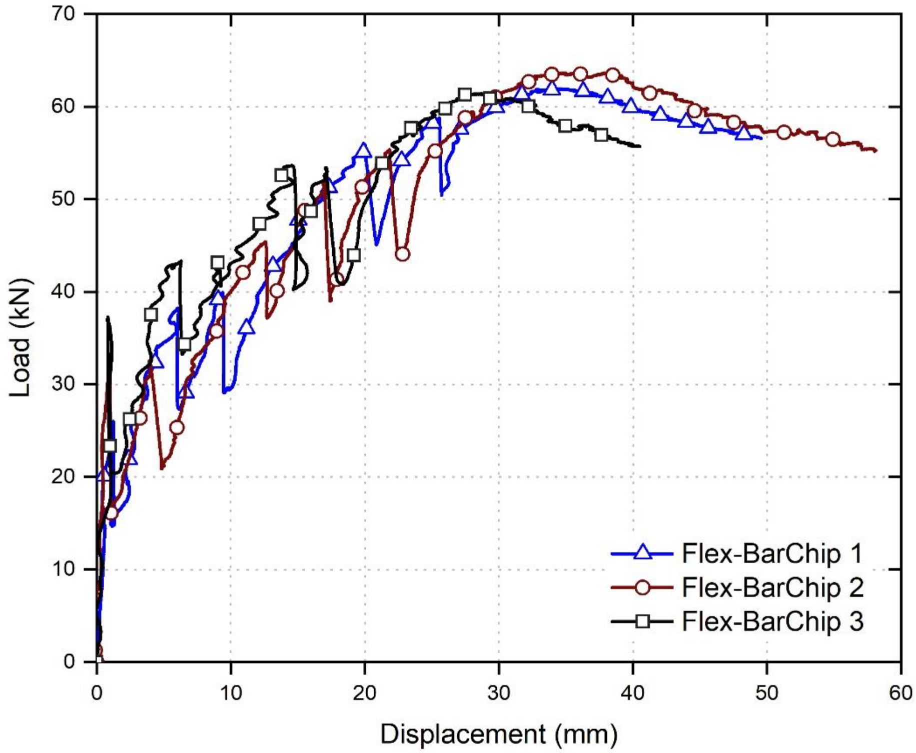

Figure 13: Load-deflection curves for Flex-BarChip specimens (specimens filled with BarChip 48 macro-synthetic fibre reinforced concrete) at the age of 24 hours

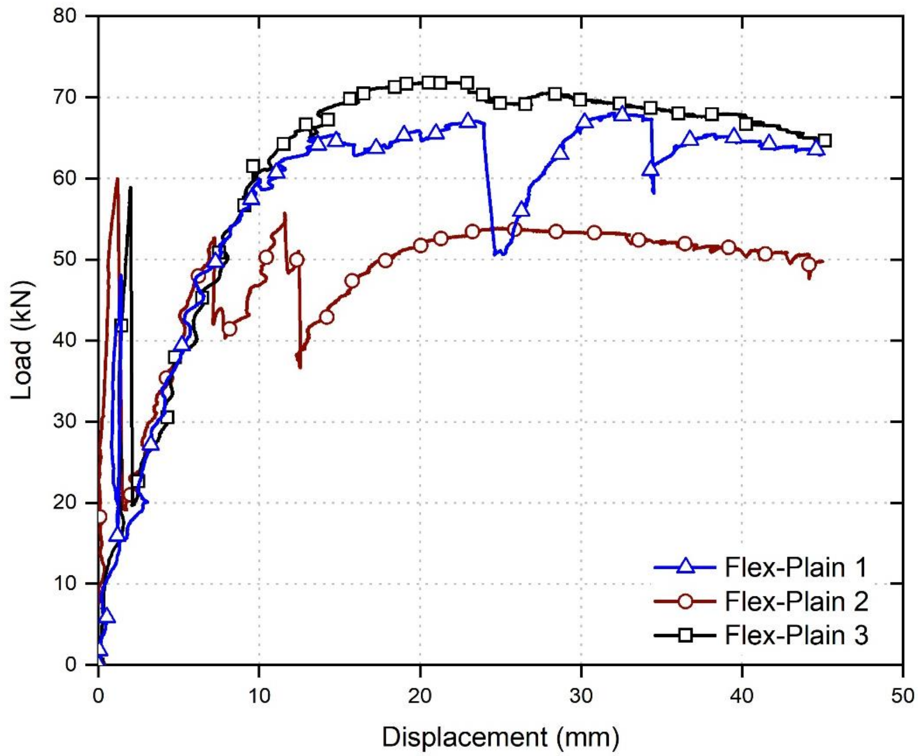

Figure 14: Load-deflection curves for Flex-Plain specimens (specimens filled with plain concrete) at the age of 28 days

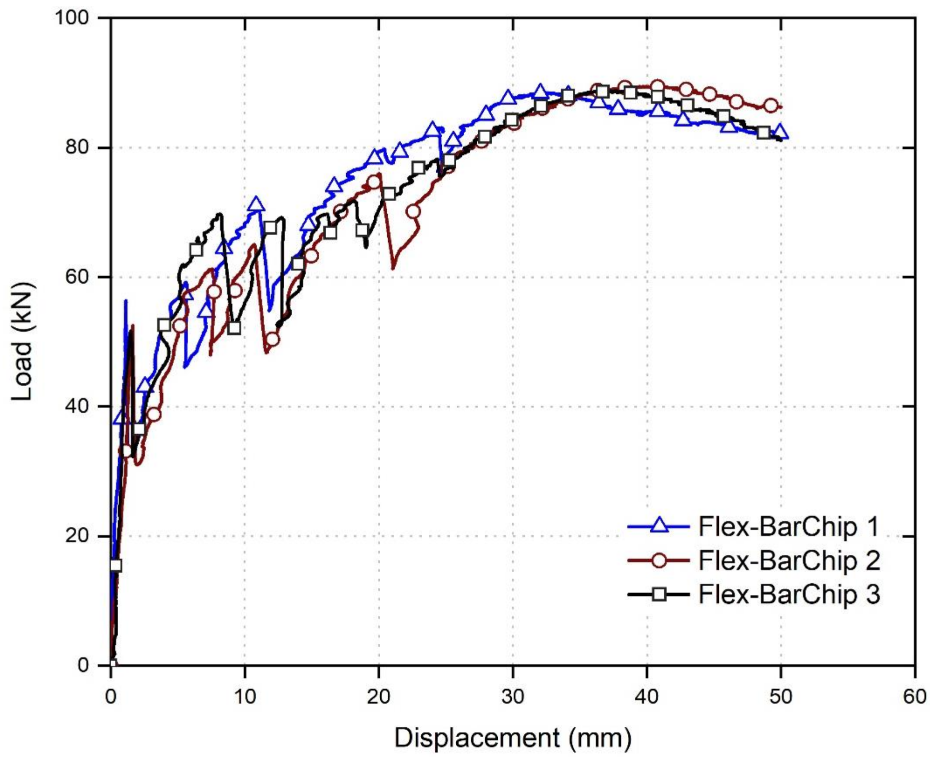

Figure 15: Load-deflection curves for Flex-BarChip specimens (specimens filled with BarChip 48 macro-synthetic fibre reinforced concrete) at the age of 28 days

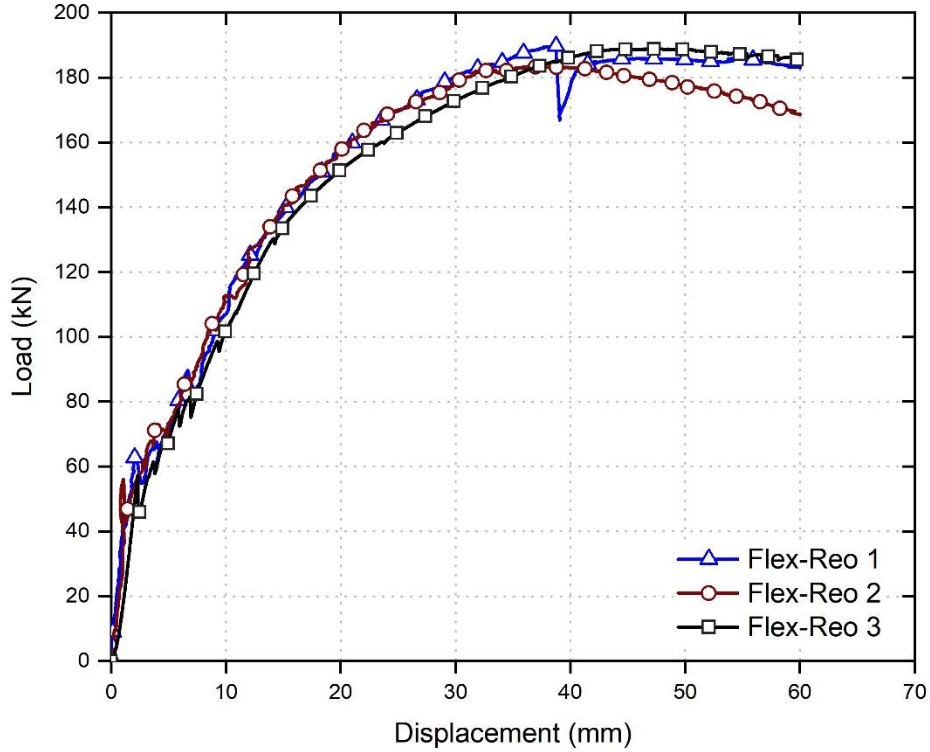

Figure 16: Load-deflection curves for Flex-Reo specimens (specimens filled with reinforced concrete N16@275mm) at the age of 28 days

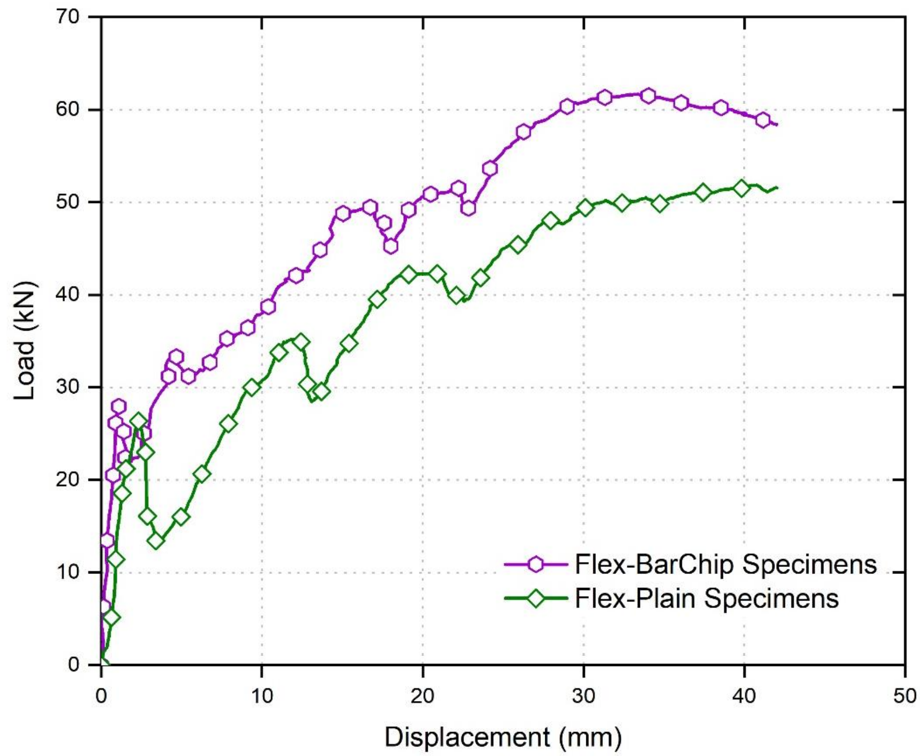

Figure 17: Comparison between Flex-BarChip and Flex-Plain average load-deflection curves at the age of 24 hours

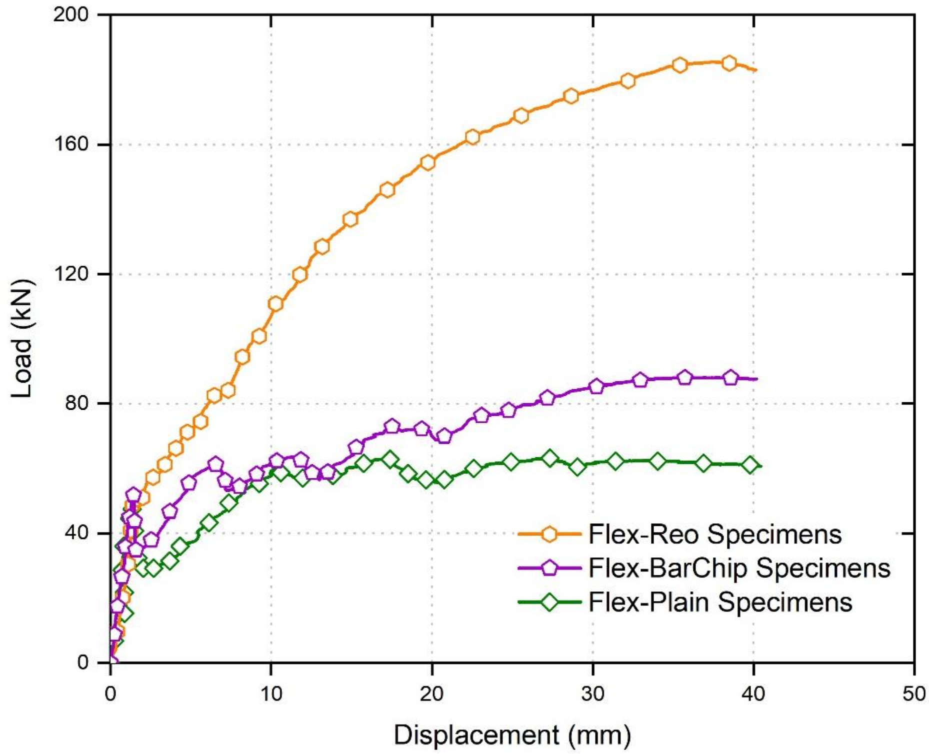

Figure 18: Comparison between Flex-BarChip, Flex-Plain and Flex-Reo average load-deflection curves at the age of 28 days

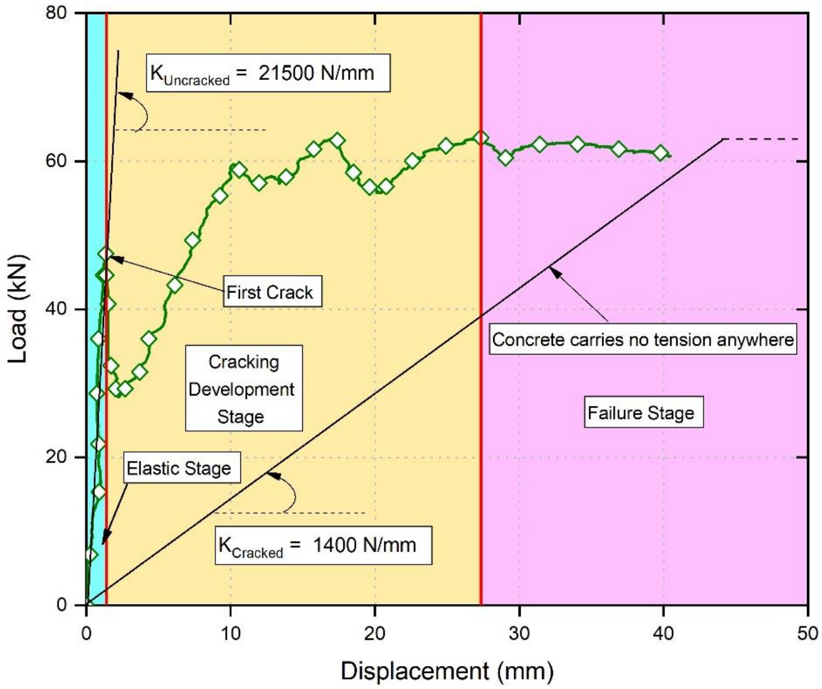

Figure 19: Stiffness calculation for Flex-Plain specimens

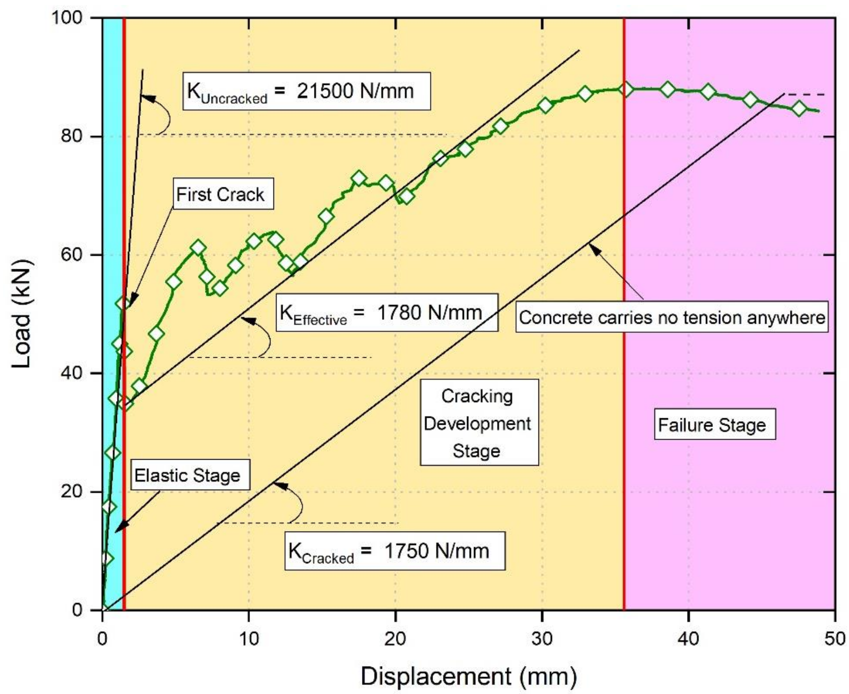

Figure 20: Stiffness calculation for Flex-BarChip specimens

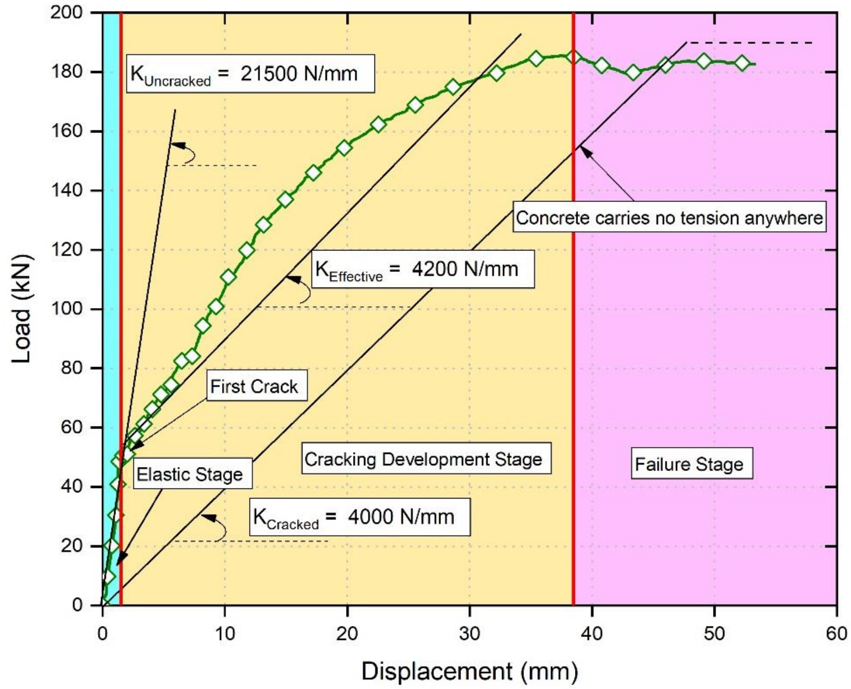

Figure 21: Stiffness calculation for Flex-Reo specimens

Table 1: 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 2: 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 3: Ultimate loads and module of rupture values for tested specimens at the age of 24 hours

	Flex-Plain	Flex-BarChip
Ultimate Load P_u (kN)	51	63
Modulus of Rupture M_u ($kN.M$)	34	42

Table 4: Ultimate loads and module of rupture values for tested specimens at the age of 28 days as well as the empty cell

	Flex-Plain	Flex-BarChip	Flex-Reo
Ultimate Load P_u (kN)	62	89	186
Modulus of Rupture M_u ($kN.M$)	41.3	59.3	123

Table 5: Un-cracked, effective, and cracked stiffness values for the tested specimens

	Flex-Plain	Flex-BarChip	Flex-Reo
Uncracked Stiffness (*N/mm*)	21500	21500	21500
Effective Stiffness (*N/mm*)	N/A	1780	4200
Fully Cracked Stiffness (*N/mm*)	1400	1750	4000

Table 6: Un-cracked, effective, and cracked flexural rigidity values for the tested specimens

	Flex-Plain	Flex-BarChip	Flex-Reo
Uncracked Flexural Rigidity ($N.mm^2$)	9555×10^9	9555×10^9	9555×10^9
Effective Flexural Rigidity ($N.mm^2$)	N/A	791×10^9	1866×10^9
Fully Cracked Flexural Rigidity ($N.mm^2$)	622×10^9	777×10^9	1777×10^9

Table 7: Comparison between the ultimate flexural strength values

	Tested Specimens Filled with Plain Concrete	Conventional Reinforced Wall (with p=0.25% reinforcement as per AS3600 11.7.1.a [17])	Tested Specimens filled with BarChip 48 Fibre Reinforcement
Ultimate Flexural Strength M_u ($kN.M$)	41.3	57.9	59.3