23rd Australasian Conference on the Mechanics of Structures and Materials

2014

Structural performance of composite panels filled with light-weight crumb rubber concrete

X Ma
University of South Australia

J E. Mills
University of South Australia

Publication details

Ma, X, Mills, JE 2014, 'Structural performance of composite panels filled with light-weight crumb rubber concrete', in ST Smith (ed.), *23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, vol. II, Byron Bay, NSW, 9-12 December, Southern Cross University, Lismore, NSW, pp. 669-674. ISBN: 9780994152008.

23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)
Byron Bay, Australia, 9-12 December 2014, S.T. Smith (Ed.)

STRUCTURAL PERFORMANCE OF COMPOSITE PANELS FILLED WITH LIGHT-WEIGHT CRUMB RUBBER CONCRETE

X. Ma*
School of Natural and Built Environments, University of South Australia
Mawson Lakes, SA, 5095, Australia. xing.ma@unisa.edu.au (Corresponding Author)

J.E. Mills
School of Natural and Built Environments, University of South Australia
Mawson Lakes, SA, 5095, Australia. julie.mills@unisa.edu.au

ABSTRACT

Crumb Rubber Concrete (CRC) first appeared in the 1990s, where crumbed rubber made from waste tyres was used as a partial aggregate replacement in paving concrete. CRC has better acoustic insulation, higher toughness, better impact resistance and reduced shrinkage and cracking when compared with traditional concrete. However, due to the weak interfacial bonds between the cement paste and tyre rubber, there is a reduction in compressive strength of concrete manufactured with rubber aggregates, which has to date limited the application of CRC in structural engineering. This paper addresses one of the potential structural applications of CRC for wall panel construction. An innovative composite panel with external steel skin filled internally with light-weight CRC has been designed, constructed and tested. Because of the reversible elasticity properties of rubber materials and the significantly increased damping properties, the new composite CRC panel is expected to have potential advantages in structures sensitive to vibration and impact. In this research, the static moment capacity and compression capacity of the CRC composite panel was tested. As a second step in the study, windborne debris impact tests were carried out to calibrate the impact capacity of the CRC panel. The test results verify that the newly developed CRC panel exhibits superior dynamic performance without any significant loss in static load-carrying capacities when compared with traditional lightweight composite panels.

KEYWORDS

Crumb rubber concrete, light-weight concrete, composite panel, static performance, impact resistance.

INTRODUCTION

Offsite construction describes the increasingly common practice of assembling components of a structure in a factory or other manufacturing site, and transporting complete assemblies or sub-assemblies to the construction site where the structure is to be located. The term is used to distinguish this process from the more conventional construction practice (onsite construction) of transporting the basic materials to the construction site where all assembly is carried out. Compared with the traditional construction method, the advantages of offsite construction are obvious: (1) reduced need for formwork, shuttering and scaffolding; (2) reduced construction time; (3) better quality control; (4) less weather dependent; (5) less construction waste or easier to recycle.

Currently, the most widely-used offsite construction form in building and civil engineering field is the use of prefabricated concrete and prefabricated steel sections in structures. But for steel structures, there are some key challenges - buckling phenomena, especially for thin-walled steel sections, reduce the load-carrying capacity of structural members; and large quantities of secondary members for wall cladding and roofing are required. Therefore prefabricated concrete structures are sometimes more popular in modern construction industries. On the other hand, in prefabricated concrete structure systems, transportation costs may be higher for large volume prefabricated sections than for the materials of which they are made, which can often be packed more efficiently; and large prefabricated sections require heavy-duty cranes and precision measurement and handling to place them in position.

To avoid the disadvantages from both prefabricated steel structures and concrete structures, a third structural system is proposed in the CSA (Composite Structural Assemblies) system. The research objective is to develop building elements with performance superior to existing building elements, based on the use of high strength light gauge steel in combination with other light-weight materials. In this study, expanded polystyrene (EPS) foamed concrete was employed to reduce structural self-weight and the experimental work on related composite wall panel systems (Figure 1) is reported here.

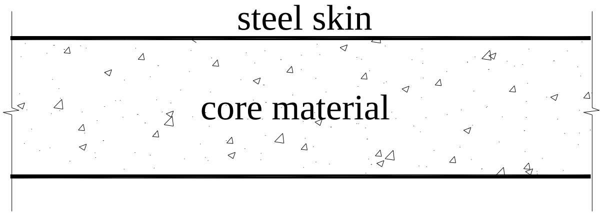


Figure 1. CSA panel system concept

The expected advantages of the composite panel system include: high load-carrying capacity; light-weight; good thermal/acoustic insulation.

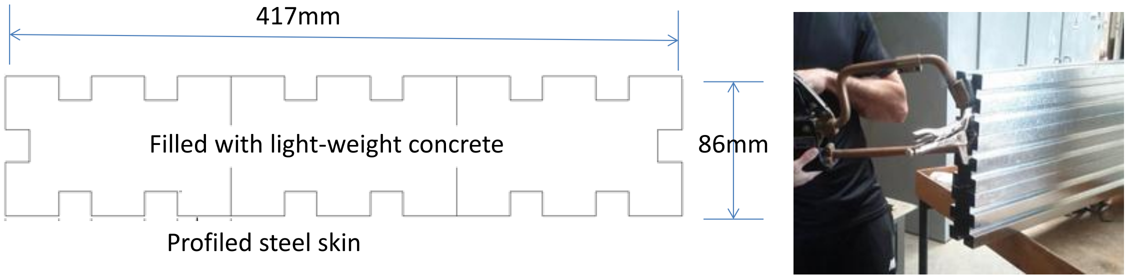
Sine 2006 approximately 50 million tyres per year reach the end of their life in Australia but currently only 30% are recycled (Hyder 2012). Apart from the disposal costs of the un-recycled tyres, waste tyres can be a source of health and environmental problems and constitute a big loss of valuable resources. Since the 1990s, researchers have proposed to use crumbed rubber made from waste tyres as a partial replacement for conventional aggregate in concrete used in paving construction (Eldin & Senouci 1992). This new type of concrete is named Crumb Rubber Concrete (CRC). CRC has better acoustic insulation, higher toughness, better impact resistance and reduced shrinkage and cracking when compared with traditional concrete (Pacheco-Torgal 2012). Because of the reversible elasticity properties of rubber materials and the significantly increased damping properties, CRC could have potential advantages in structures sensitive to vibration and impact, i.e. uses beyond road pavements. However, due to the weak interfacial bonds between cement paste and tyre rubber, there is a reduction in compressive strength of concrete manufactured with rubber aggregates, which has to date limited the application of CRC in structural engineering.

This paper addresses some preliminary research on the potential structural application of CRC in CSA panels. The structural performance of traditional light-weight CSA panel and rubberized light-weight CSA panels has been investigated experimentally. The final results showed that the rubberized light-weight CSA panel achieved higher sectional compressive strength, moment capacity and superior impact resistance even with lighter self-weight than the comparison panel.

EXPERIMENTAL STUDY

Composite Panel Specimens

The 1000mm-long composite panels in this study had a cross section of 417mm*86mm (Figure 2a) and were composed of profiled steel skin filled with light-weight concrete. The corrugation is employed to improve the skin buckling performance by avoiding contact buckling before yielding. To keep steel sections as a single system, two adjacent steel sections are connected through welding points(Figure 2b). Two types of concrete were used as filler materials: traditional EPS foamed concrete and rubberized EPS foamed concrete with 10% replacement of sand aggregate by volume with crumb rubber. The steel skin was produced by Lysaght Bluescope with thickness of 0.8mm and yielding strength of 400MPa.



(a) Panel Section (b) Welding between two steel sections

Figure 2. Steel sheeting in composite panels

Concrete

Concrete mixtures are shown in Table 1.

Table 1. Light-weight concrete mixture per litre

Mix	Cement (kg)	Sand (kg)	Water (L)	EPS bead (L)	Rubber (g)	Plasticizer (mL)
Non-Rubberised	0.45	0.85	0.175	0.7	0	2.9
Rubberised	0.45	0.77	0.175	0.7	27.5	2.9

The average dry density of the non-rubberized EPS concrete and rubberized EPS concrete was 1417kg/m^3 and 1383kg/m^3, respectively indicating that replacing sand aggregate with rubber particles slightly reduced the concrete density. The crumb rubber particles size used were 0.15-2.36mm.

Compressive Test and Bending Test

Compressive tests on three specimens including 2 rubberized composite panels and 1 non-rubberized panel were conducted (Figure 3). A concentric load was applied directly to the panel. Because the panel was quite short, with a length to thickness ratio of 12, global buckling behaviour was not significant and the compressive tests provided the section capacity for the specimen.

Figure 3. Compressive test set up

Four point bending tests were also conducted (Figure 4). A load spreader was placed on the top two rollers to evenly distribute the load. Load was then continuously applied until failure was observed.

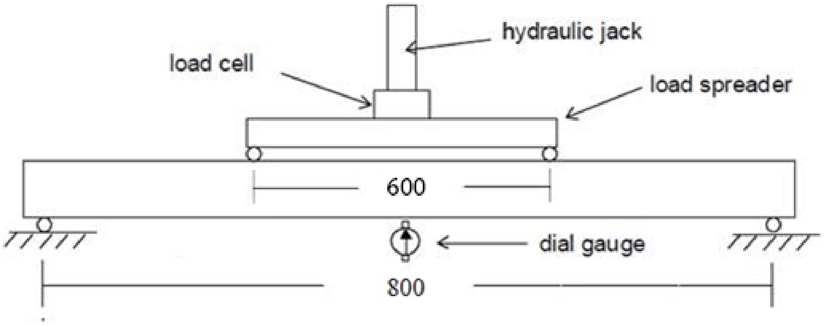


Figure 4. Flexural test set up

Impact Test

Impact testing was conducted using the rig shown in Figure 5. Before the commencement of the impact testing, the sensors were checked for consistency and accuracy, by using a simple pendulum test setup. A pendulum (preferably a spherical bolt with little air resistance) is dropped from a known height. The calculated velocity is compared to the measured velocity from the sensors. Once the sensors are calibrated, the rig can then be set up to begin the impact testing. The composite panel was placed on its side in a horizontal position directly in front of the mouth of the cannon. The cannon was positioned to shoot a 4kg timber block directly in the middle of the composite panel. With the doors of the lab locked and all observers standing behind the protection screen, the cannon pressure was raised to 650kPa causing the wood speed of approximately 31m/s. This wind speed would be an appropriate design speed for small buildings in most of Australia designated as region A in the wind loading code (Standards Australia, 2011). After impact, the composite panels were removed from the device and observed.

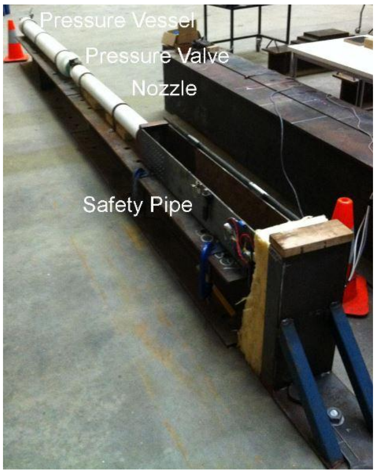


Figure 5. Impact test set up

The wind loading code for Australia and New Zealand AS/NZS 1170.2 (Standards Australia, 2011) specifies whether a specimen passes or fails such an impact test as follows:

- If timber member did not penetrate and no obvious aperture is present → Pass
- If test specimen stops member but is left with an aperture smaller than 5000mm^2 → Pass
- If test specimen stops member but is left with an aperture greater than 5000mm^2 → Fail
- If test specimen stops timber member but member is visible from the inside (i.e. protruding through test specimen) → Fail

RESULTS AND DISCUSSIONS

Concrete Cylinder Tests

The 28 day cylinder compressive test showed that the rubberized concrete had an average compressive strength of 11.6 MPa, slightly higher than non-rubberized concrete which was 10.9 MPa. These results were different from normal weight concrete where rubberized concrete is usually slightly weaker than traditional concrete.

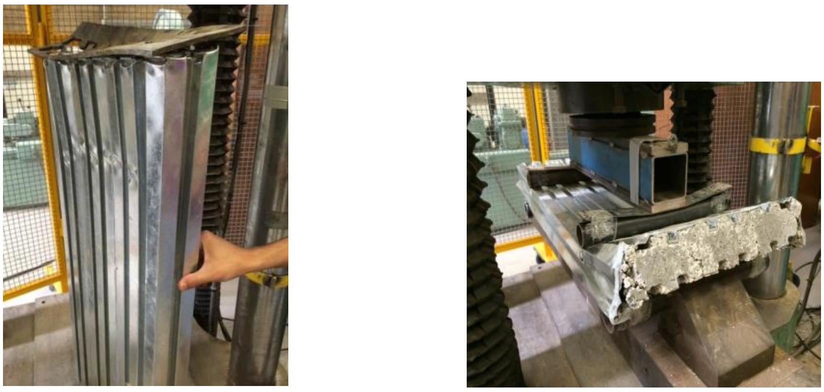
(a) Rubberized (b) Non-rubberized

Figure 6. Failure modes of light-weight concrete cylinders

Static Panel Tests

The two rubberized panels reached their compressive capacity at 320kN and 422kN respectively. The non-rubberized panel reached its capacity at 307 kN. No severe delamination of the steel skin occurred in either panel. All the failure modes for the three panels were quite similar: skin buckling at the top of the panels (Figure 7a).

For flexural tests, the moment capacities at the peak loads were 8kN-m and 6.3kN-m for the rubberized panel and non-rubberized panel, respectively. Both failure modes were bending and local crush at the loading points (Figure 7b). Steel-concrete delamination between steel and the separating between the two steel sheeting occur during both compressive test and bending test (Figure 7). From theoretical point, the weak composite action between the main structural components will inevitably reduce member load-bearing capacity and needs to be improved in future study.

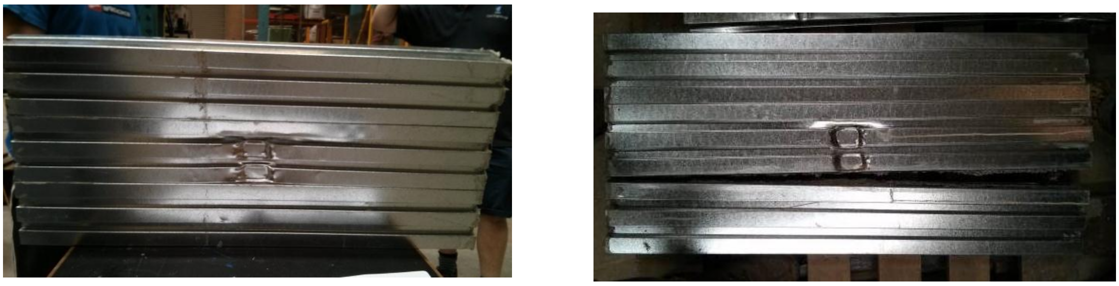


(a) Compressive tests (b) Bending tests

Figure 7. Failure mode of composite panel

Impact Test

Both rubberized panels passed their impact tests. There was large permanent deformation at the impacting point without any penetration or aperture through the steel and a large crack was observed at the top and bottom (Figure 8a). By comparison, the non-rubberized panel failed its impact test, with a connection failure on the front and rear of the panel occurring and as a result the panel was split into two parts (Figure 8b).



(a) Rubberized panel (b) Non-rubberized panel

Figure 8. Composite panels after impact test

CONCLUSIONS AND FUTURE RESEARCH PLAN

This paper has presented a preliminary experimental study on thin-skinned composite panels. Two types of light-weight concrete were employed: the EPS concrete and the rubberized EPS concrete. Compared with the traditional EPS concrete, the rubberized EPS concrete had a higher strength even with a slightly lower density. The static tests verified the higher compressive and bending capacity of the composite panel with rubberized concrete. The impact test also showed that the rubberized panel had superior impact resistance to the traditional EPS concrete.

Further work will be undertaken to repeat these tests with a range of rubber replacement percentages. Computer modelling of the panels will be carried out with more detailed material properties such as steel and concrete stress-strain relationship and material impact resistance. Structural performance of these types of panels under static and impact loads will be researched in more details and compared with numerical study.

ACKNOWLEDGMENTS

The experimental work was conducted in two honours projects in 2013. The authors acknowledge the contribution from the following University of South Australia undergraduate civil engineering students: Chris Baird, Fezulla Dzeladini, Huw Hillman, Jad Daet, Constantinos Morias, Yuan Chang Wang, Wei Lip Beh and Abdullah Tawfiq Abdul Rahman.

REFERENCES

Eldin, N. and Senouci, A. (1992) “Engineering Properties of rubberized concrete”, *Canadian Journal of Civil Engineering*, Vol. 19, No. 5, pp. 912-923.

Hyder 2012, *'Study into domestic and international fate of end-of-life tyres – Final Report'*, Hyder Consulting Pty Ltd.

Pacheco-Torgal, F., Ding, L. and Jalali, S. (2012) “Properties and durability of concrete containing polymeric wastes (tyre rubber and polyethylene terephthalate bottles): An overview”, *Construction and Building Materials*, Vol. 30, pp. 714-724.

Standards Australia (2011) *Structural design actions - wind actions, AS/NZS 1170.2: 2011,* Standards Australia.