Centre of Excellence in Engineered Fibre Composites (CEEFC)

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-Commercial-in-Confidence-

Report on "Investigation on the flexural and compressive behaviour of Diamond Grid"

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1 Executive Summary

Diamond Grid International Pty Ltd and the Centre of Excellence in Engineered Fibre Composites (CEEFC) at the University of Southern Queensland (USQ) are in research collaboration to investigate the mechanical and structural performance of the Diamond Grid as an effective system for soil stabilisation and paving grids. This project report has been prepared covering the experimental testing and evaluation of the mechanical properties of Diamond Grid and its component materials in order to evaluate the performance and quality of this technology. The testing was conducted at CEEFC at USQ following the approved standards or equivalent and witnessed by appropriate personnel.

2 Introduction

Diamond Grid International Pty Ltd has developed a Diamond Grid product made from recycled high density polypropylene plastic materials. The grids are connected to each other by the integral, self-locking and snap-fit clips. This technology is anticipated to provide an effective and economical alternative for pathways in the mining, construction and in driveways. This report covers the physical and mechanical testing conducted to demonstrate the performance quality of the Diamond Grid and evaluation for the approval of different industries to use in actual applications.

3 Methods

This section details the flexural and compressive tests conducted to evaluate the mechanical properties of the Diamond Grid. The size of one diamond grid is approximately 2062 mm^2 and 40 mm deep with a wall thickness of 3 mm. The details of the specimens tested are provided in the table below.

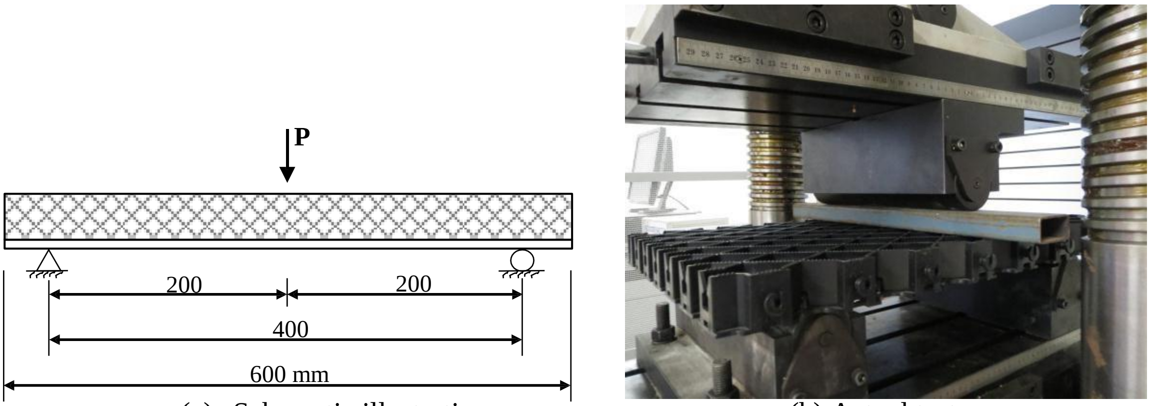
Table 1. Details of test specimens

Type of test	No. of samples	Dimensions (mm)		
		length	width	height
Flexural	5	600	400	40
Flexure at joints	5	600	400	40
Compression*	5	225	170	40

**Diamond shape*

3.1 Bending strength

The bending strength of the Diamond Grid was determined by testing the product up to failure under a 3-point static bending test. The grid is simply supported with a test span of 400 mm (overall length of 600 mm) and a width of 400 mm. Figure 1 shows the test set-up for the bending strength and modulus test. Similarly, the strength of the Diamond Grid loaded at the joint was tested under bending as shown in Figure 2. The concentrated load was applied to the midspan of the Diamond Grid at a rate of 5 mm/min using the SANS hydraulic testing machine. The vertical displacement was measured at midspan and a steel plate was provided over the loading point to prevent premature indentation failure. The applied load and displacement were recorded and obtained.



(a) Schematic illustration (b) Actual test

Figure 1. Flexural test of Diamond Grid

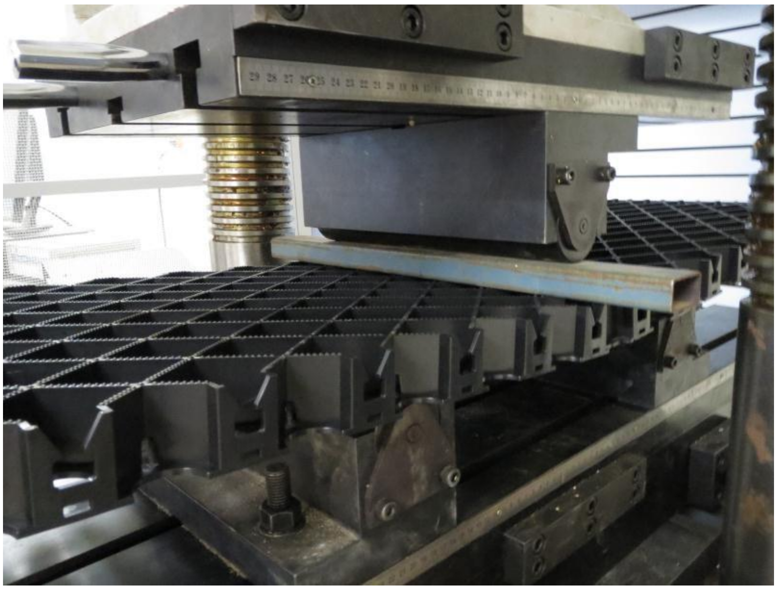


Figure 2. Flexural test at joints

3.2 Compressive strength test

The compressive strength test was performed by loading the specimen in compression through the thickness direction as shown in Figure 3. A 9 grid specimen (area of about 18,562.5 mm^2) was cut from the Diamond Grid and tested under compression. The load was applied at a rate of 3 mm/min using the SANS hydraulic testing machine.

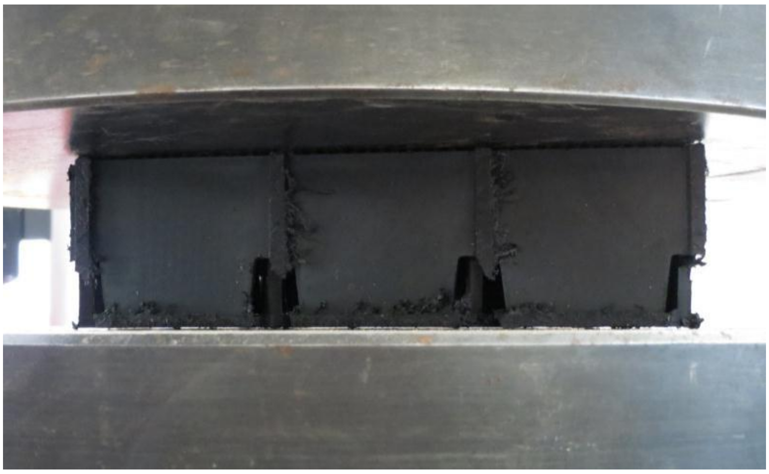


Figure 3. Compression test of Diamond Grid

4 Results and Observations

4.1 Summary of test

A summary of the test results including the average value and the standard deviation for the strength properties of the Diamond Grid are summarised in Table 2. The tests show consistent results as the variation among the measured properties is only at a maximum of 4.2% indicating that the product is manufactured consistently and behaved reliably under applied loading.

Table 2. Strength properties of the Diamond Grid

Specimen	Flexure (N)		Compression (N)
	Without joint	With joint	
1	1,587.9	492.7	64,631.6
2	1,617.2	469.7	62,709.8
3	1,573.8	477.4	63,520.9
4	1,544.5	463.3	65,036.4
5	1,566.2	464.2	69,766.2
Average	1,577.9	473.4	65,133.0
Std. deviation	27.0	12.1	2,747.6
COV (%)	1.7	2.6	4.2

4.2 Flexural test of Diamond Grid

4.1.1 Load and deflection behaviour

Figure 4 shows the load and midspan deflection behaviour of the Diamond Grid under 3-point static bending. In the graph, F designates to the specimen tested under flexure while numbers 1-5 indicate the replicate number of the specimen. All specimens exhibited almost similar load deflection behaviour. The midspan deflection increased linearly with the applied load up to around 1200 N. After this load, deformation was observed in the grid in the compression side (top) which results in a slight decrease in stiffness of the Diamond Grid. The specimen continued to carry load up to tensile failure of the Diamond Grid (at the bottom) at an average applied load of 1570 N. An increase in deformation was then observed even with the reduction in the applied load.

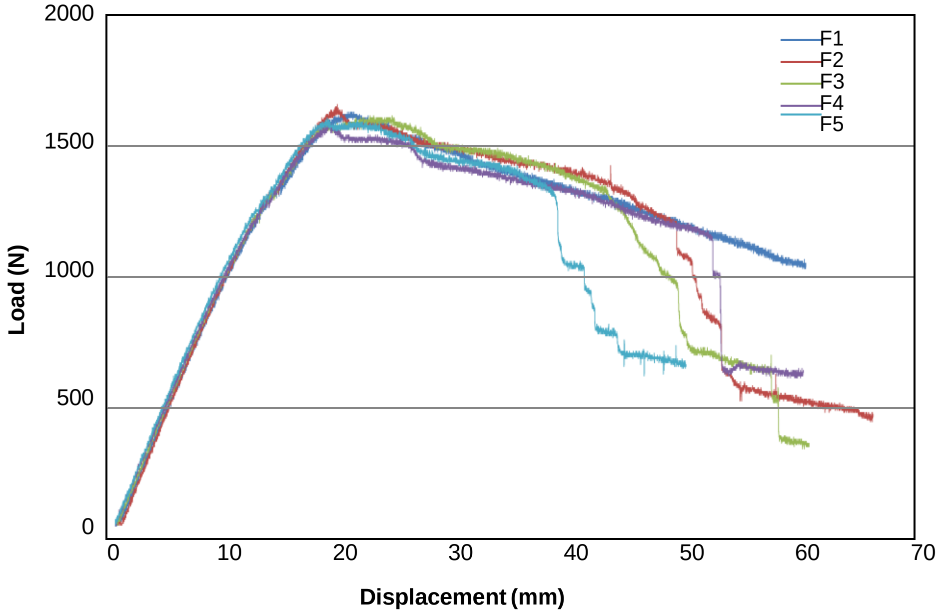


Figure 4. Load deflection behaviour under flexure

4.1.2 Failure behaviour

Deformation of the grid in compression (top) was observed at a load of around 1200 N as shown in 5. The specimen then continued to carry load but showed significant amount of deformation as shown in Figure 6. The Diamond Grid then failed due to tensile failure at the bottom of the specimen as shown in Figure 7.

Figure 5. Deformation of the grid in compression

Figure 6. Deflection of the grid

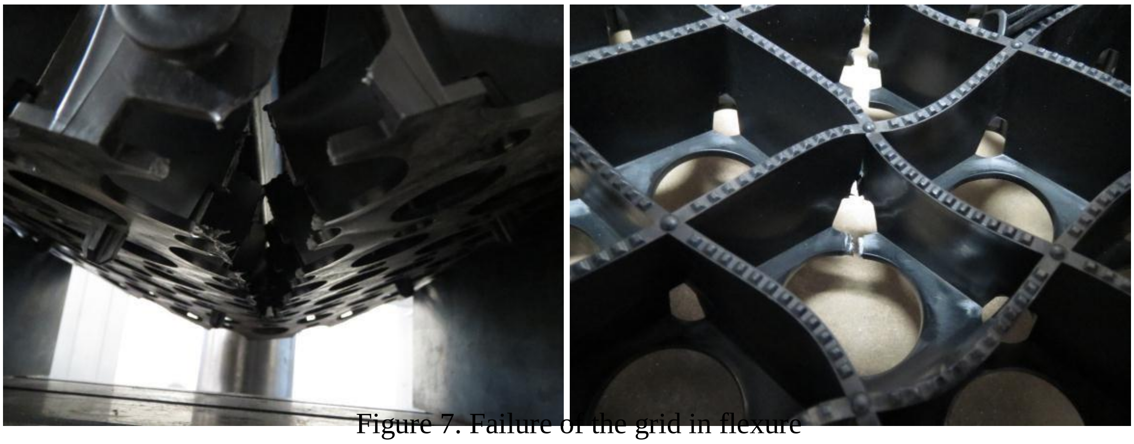


Figure 7. Failure of the grid in flexure

4.2 Flexural test of Diamond Grid at joints

4.2.1 Load and deflection behaviour

Figure 8 shows the load and midspan deflection behaviour of the Diamond Grid tested at the joints under 3-point static bending. In the graph, FJ designates to the specimen tested at the joints under flexure while numbers 1-5 indicate the replicate number of the specimen. An almost linear elastic behaviour was observed up to an applied load of 470 N. After this load, all the joints failed which resulted in the decrease in the load capacity and increase in the deformation of the Diamond Grid.

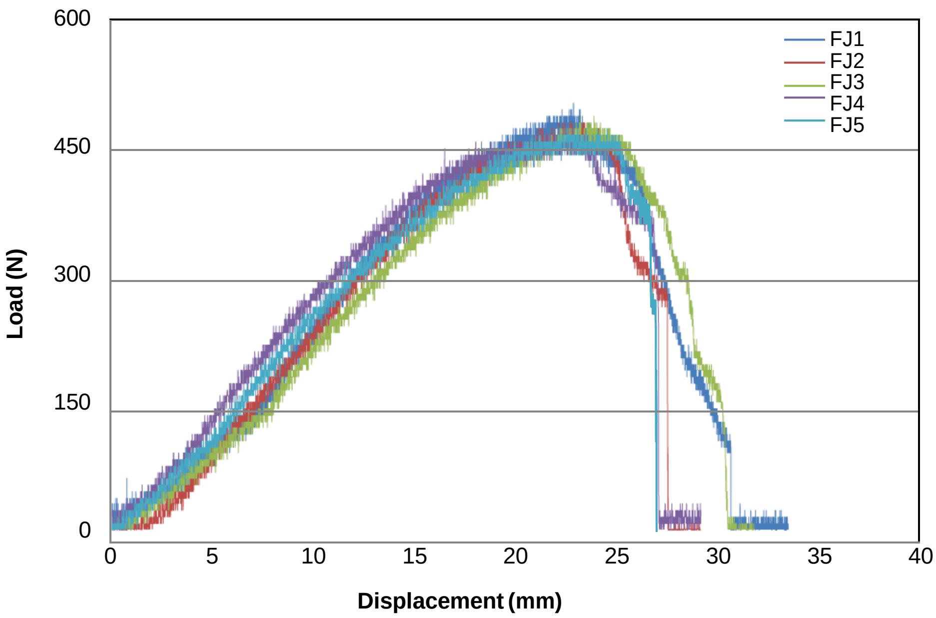


Figure 8. Load deflection behaviour under flexure of Diamond Grid with joints

4.2.2 Failure behaviour

Large deformation of the Diamond Grid was observed during the application of the load as shown in Figure 9. This is due to the opening of the gap between the two connected mats as shown in Figure 10. All the joints then simultaneously failed at an average applied load of 473 N as shown in Figure 11.

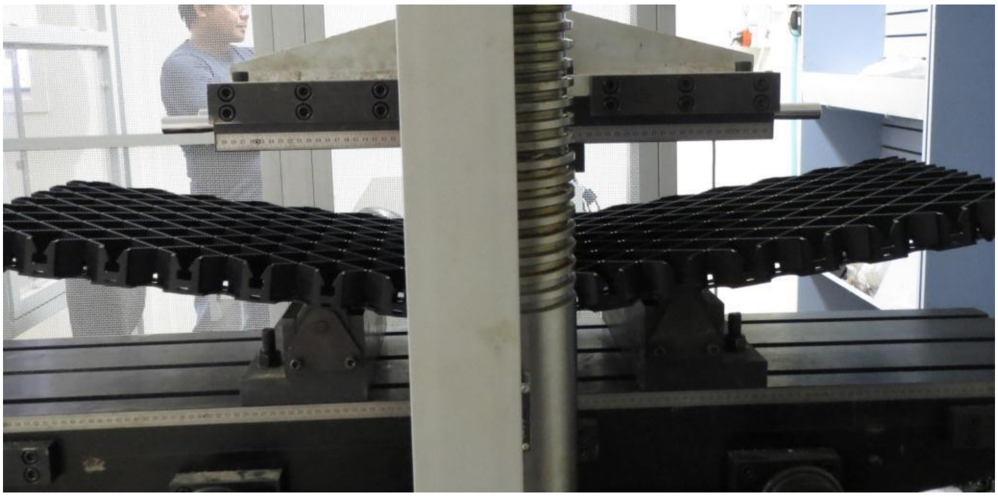


Figure 9. Deformation of the Diamond Grid loaded at joints

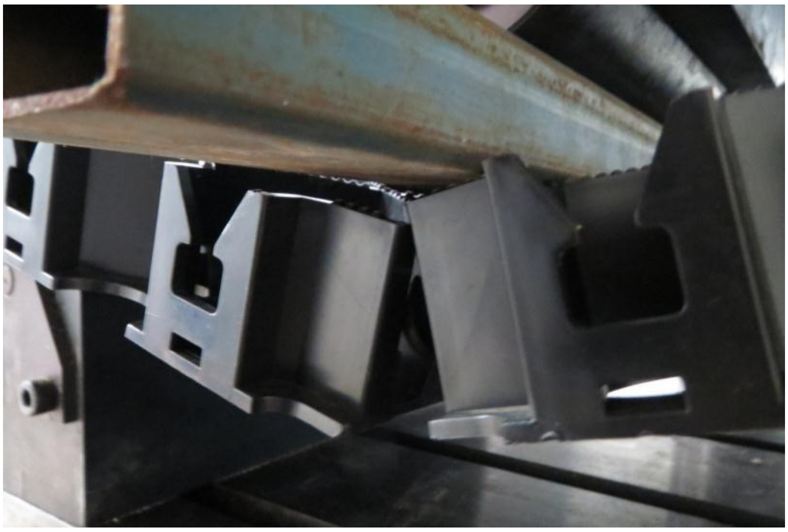


Figure 10. Opening at the joints

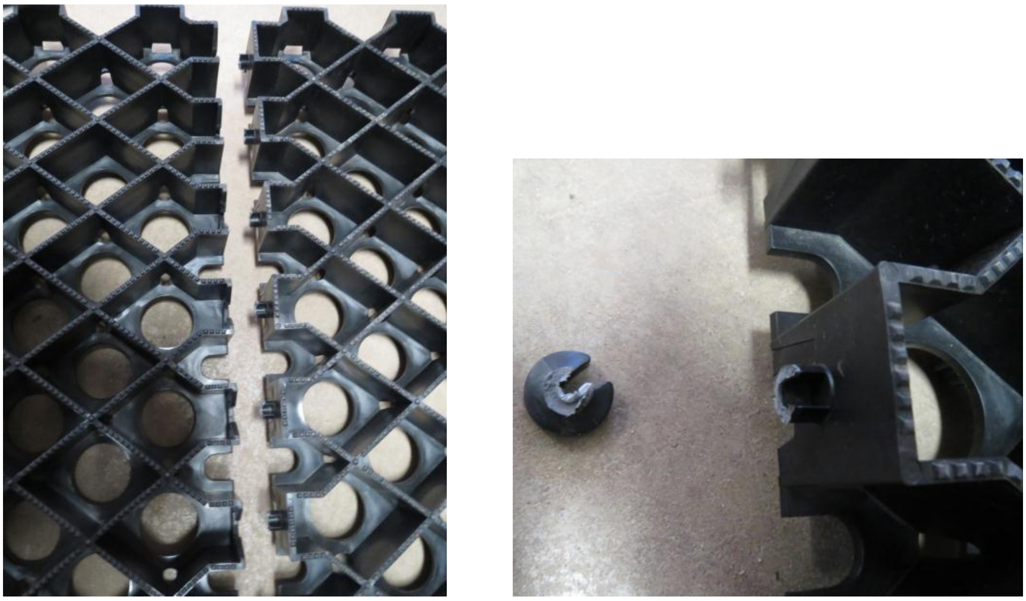


Figure 11. Failure of the joints

4.3 Compressive test

4.2.1 Load and deformation behaviour

Figure 12 shows the load and deformation of the Diamond Grid tested under compression. In the graph, C designates to the specimen tested under compression while numbers 1-5 indicate the replicate number of the specimen. An almost linear elastic behaviour was observed up to an applied load of around 6200 N. After this load, buckling of the walls and opening of the edges of the grid were observed which reduces the load capacity and increased the deformation of the specimen.

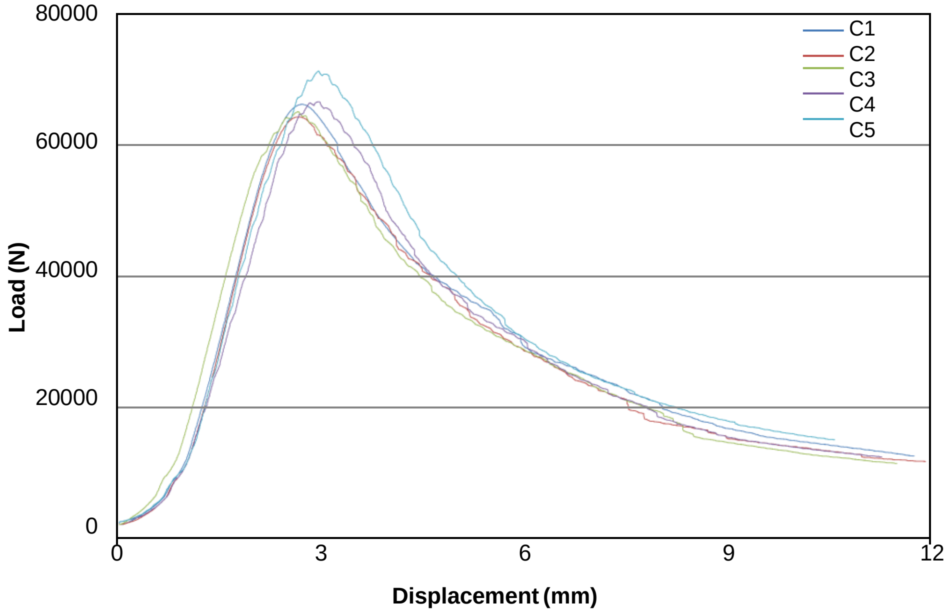
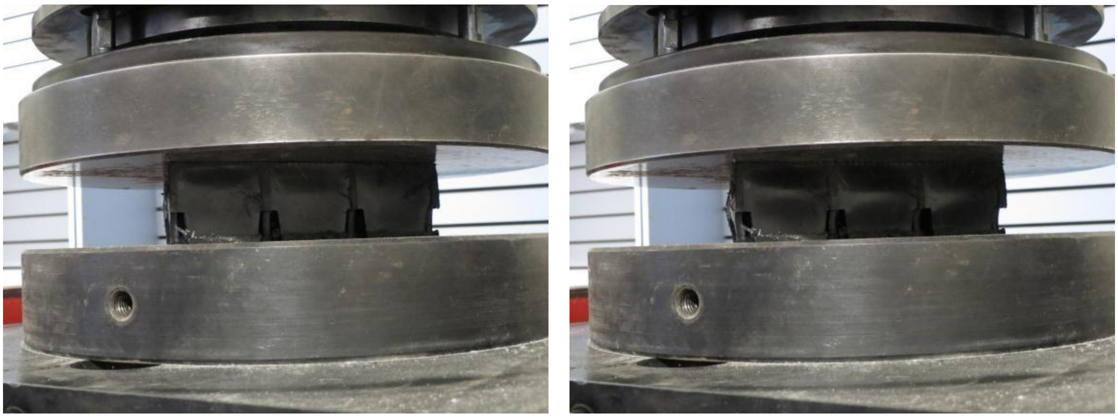


Figure 12. Load deflection behaviour under flexure

4.2.2 Failure behaviour

Figure 13 shows the progression of deformation and failure of the Diamond Grid under compression. As can be seen from the figures, the specimen is deformed by buckling of the walls and opening of the grid at the corners. The opening of the grids initiated from the bottom cut-off sections of the walls. Further, material failure was observed at the buckled grid on the tensile side of the wall. After removing the applied load, the grids did not return to its original shape due to the buckled walls.



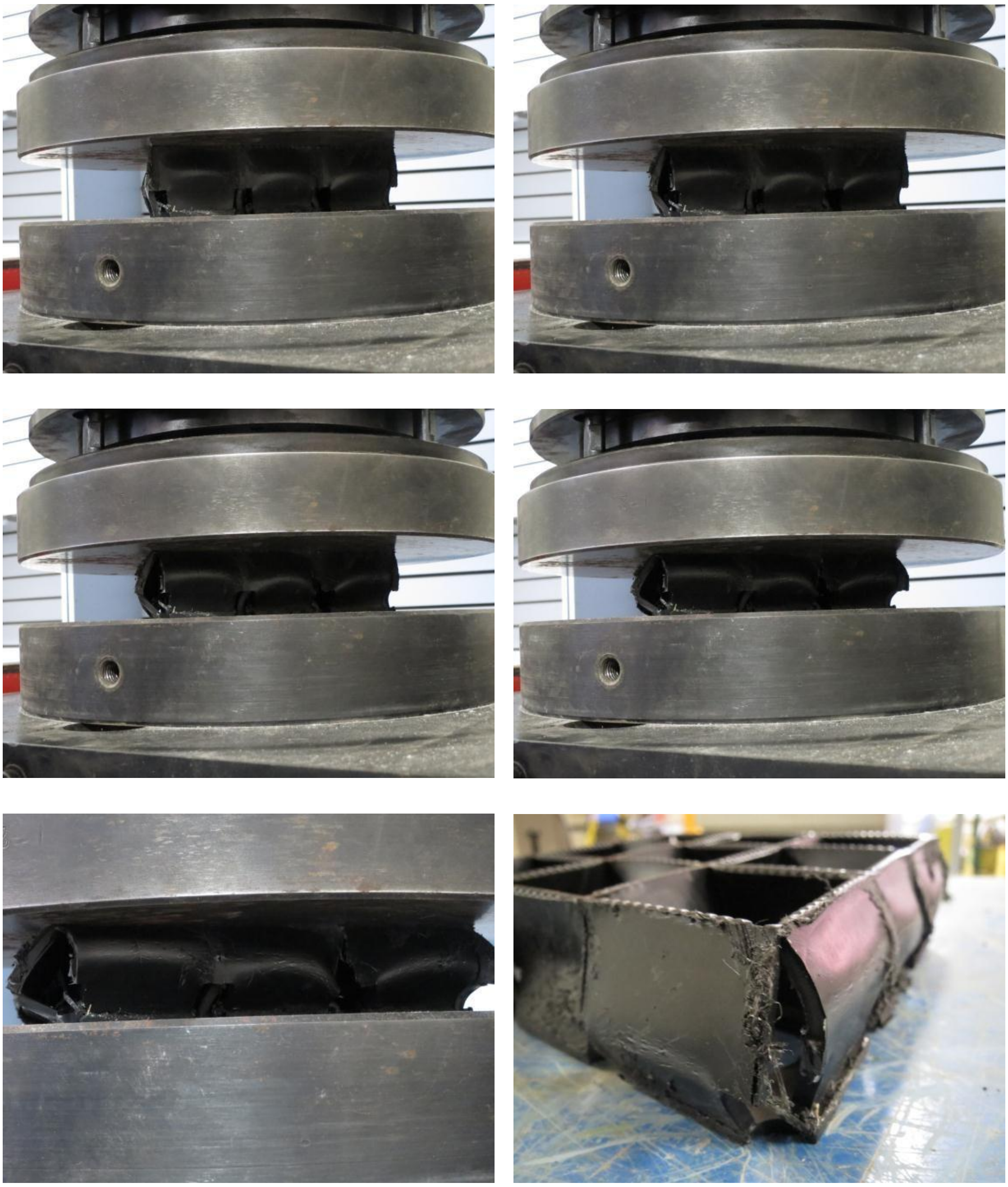


Figure 13. Deformation of the grid in compression

5 Discussion

5.1 Comparison between Diamond Grid loaded at midspan and at joints

Comparison was made on the test results of the flexural behaviour of the Diamond Grid with and without joints. Figure 14 shows the typical load and deflection behaviour of the Diamond Grid under 3-point static bending test. In the figure, F corresponds to the specimen loaded at midspan while FJ corresponds to the specimen loaded at the joint. The results show that specimen F failed at an applied load 3.3 times higher than that of specimen FJ. Specimen F failed at an applied load of around 1,577 N while specimen FJ failed at an applied load of only 473 N. This corresponds to a line load (applied through the width of the Diamond Grid) of 3,942.5 N/m and 1,182.5 N/m, respectively, and a maximum bending moment of 157.8 N-m and 47.3 N-m, respectively. As there are 7 joints connecting the 2 mats of Diamond Grid, each joint can carry a maximum load and bending moment of 67.5 N and 6.76 N-m, respectively. Further, the capacity of the Diamond Grid under uniformly distributed load is calculated to be equal to 9.8 kPa and 2.9 kPa for the specimen loaded at midspan and at the joints, respectively.

Based on the results of the test and assuming that the Diamond Grid has a homogenous rectangular cross section, the maximum flexural stress in tension σ_t when the grid fails can be approximate as:

$$\sigma_t = \frac{My}{I} = \frac{157.8Nm * (40mm/2)(1000mm/m)}{(400mm)(600mm)^3/12} = 0.44kPa$$

Furthermore, specimen F exhibited almost 4 times higher stiffness than that of specimen FJ. This result shows that the joint will be a critical part in the design and optimisation of the Diamond Grid.

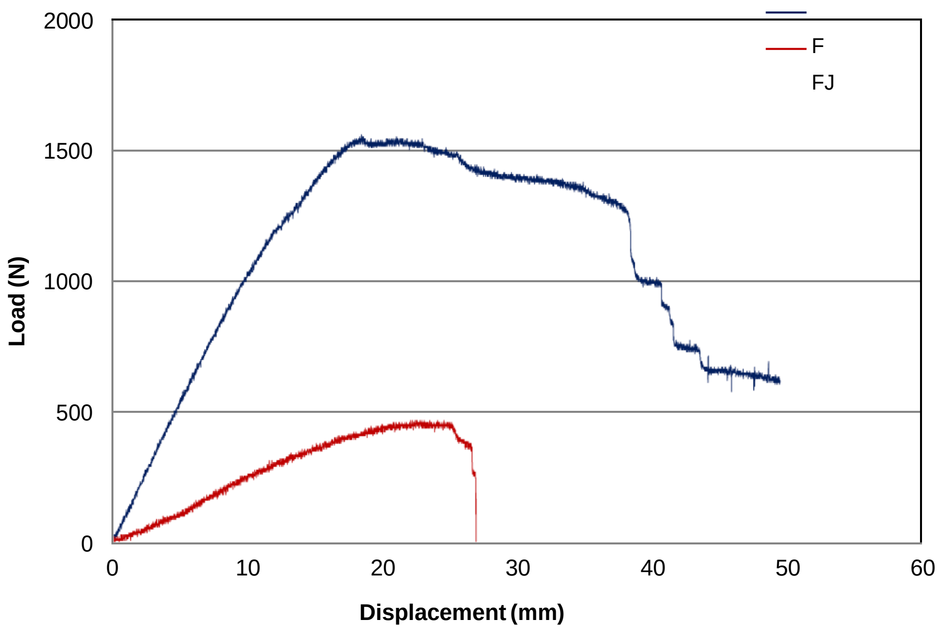


Figure 7. Load-displacement behaviour of Diamond Grid with and without joints

5.2 Crush resistance of the Diamond Grid

The results of the compressive test showed that 9 grids of the unfilled Diamond Grid will fail an average applied load of 65,133 N (6.6 tons). Consequently, this showed that one mat of 400 mm x 600 mm Diamond Grid (98 grids) has a crush resistance of 71.8 ton or around 299.1 ton/m^2. Further, considering only the cross sectional area of the materials in the 9 grids (8 pcs of 140 mm long and 3 mm thick plastics), the maximum compressive σ_c stress in the recycled plastic can be calculated as:

$$\sigma_c = \frac{P}{A} = \frac{65{,}133N}{8(140mm)(30mm)} = 19.4MPa$$

5.3 Summary and recommendations

Table 3 summarises the maximum capacity a Diamond Grid can carry. As observed in the flexural test, deformation of the cells/grids was observed in the compressive region. This can be minimised by either making the wall thickness thicker, modifying the geometry of the grid or filling the cells with gravel. However, the behaviour of such systems should be investigated. Also, the final failure observed for the Diamond Grid loaded at midspan is the tensile failure at the bottom which initiated between the circular cut-outs and propagated towards the edges of the grids. It is anticipated that if the small circular cut-outs at the bottom of the mat as well as the cut-outs at the bottom corners of the walls are not provided, the Diamond Grid will fail at a higher load. Further, buckling of the walls will occur at a higher compressive load as the entire height of the walls is connected to each other.

Based on the characterisation of the properties of the Diamond Grid under flexure and compression, the results indicated that the failure of the Diamond Grid will likely to occur at the joint. This implies that the material strength or the geometry of the joint should be improved to increase the capacity of the Diamond Grid in resisting the applied load.

Table 3. Maximum capacity of Diamond Grid

Properties	Point load	Uniform load	Bending moment	Maximum stress
Flexure at midspan	1577 N	9.8 kPa	157.8 N-m	0.44 kPa
Flexure at joints	473 N	2.9 kPa	47.3 N-m	0.13 kPa
Crush resistance	65,133 N	299.1 ton/m^2	--	19.4 MPa

6 Major findings

The performance behaviour of the Diamond Grid was evaluated under flexural and compressive tests. Based on the results, the following are the major findings of the investigation:

- The Diamond Grid failed at an applied bending moment of 157.8 N-m while each joint resisted an applied bending moment of 6.76 N-m.
- Results of the tests showed that the Diamond Grid will more likely fail at the joint. The flexural strength of the Diamond Grid loaded at the joint is only 30% to that of mats loaded at midspan.
- The crush resistance of the unfilled Diamond Grid is around 299.1 ton/m^2.