Influence of Weathering Conditions on TRC Sandwich Renovation Panels

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Abstract. Using large lightweight prefabricated sandwich panels for the renovation of existing dwellings facilitates the installation process and reduces the renovation time to a few days. To guarantee the performance of the panels during their entire life span it is necessary to evaluate their behaviour on the long term. During their life span the facade panels are exposed to weather conditions such as wind, snow, rain, etc. To simulate these effects 8 sandwich beams, with a span of 2.2 m were fabricated and loaded until failure, after being subjected to repeated mechanical loading and/or and heat-rain cycles. The latter were done in a climate chamber according to ETAG004.

The results of this study show that repeated loading reduces the initial stiffness of the panels up to 40%. Durability tests (heat-rain cycles) did not influence the stiffness noticeably but led to a decrease of about 30% in ultimate strength when compared to a non-aged panel.

Keywords: Repeated loading · Durability loading · Heat-rain cycles · Bending test

1 Introduction

The increasing energy and insulation regulations created a strong need for low-energy building solutions, not only for new buildings but also for the renovation of existing dwellings. Other than for new buildings, the inconvenience for the current residents needs to be limited. In an ideal situation dwellings must be renovated in a couple of days. To fulfil this need the authors propose a composite sandwich panel façade system. Sandwich panels are composed out of two thin and stiff face-elements, interconnected through a lightweight (insulating) core. They are generally characterized by a high bending stiffness and strength in comparison with their relatively low self-weight. Using prefabricated sandwich panels with the dimensions of one floor enables us to limit the renovation time to a strict minimum, namely two or three days.

Nowadays a lot of research is performed on lightweight wall systems using different materials. Not only steel and aluminum (Pokharel 2003) but also sandwich faces made of wood have been investigated (WTCB 2011). Besides these traditional building materials also the use of composite materials have gained a lot of interest in the current context.

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Composites are characterized by a high structural capacity to weight-ratio. Composites with a cementitious matrix are preferred to polymer composites because of their excellent fire resistance. The possibility of using cementitious composites to fabricate sandwich elements has already been demonstrated by several authors (Shams et al. 2015; Colombo et al. 2015a, b).

In practice, the façade panels are exposed to varying weathering conditions like wind, rain, freeze, etc. To guarantee the structural performance of these panels during their lifetime the behaviour of the panels under these conditions needs to be verified. In the past some work has been done on the durability of cementitious composites. In her work Cuypers performed freeze-thaw (FT) and heat-rain (HR) cycles on textile reinforced concrete (TRC) (Cuypers et al. 2006). The main conclusion of her research was that the stiffness was not influenced by the environmental loading. Other similar experiments point out that accelerated ageing of TRC has an important impact on the tensile capacity and cracking strength (Colombo et al. 2015a, b; Williams Portal et al. 2015). More work needs to be performed to confirm these tendencies.

To the author's knowledge no work has been performed on the effect of accelerated ageing on sandwich elements cladded with TRC. This paper is a first feed to fill this gap. It describes the experimental work done on sandwich beams, where the influence of heat-rain cycles on these specimens is quantified experimentally. In total eight beams are fabricated and tested. To quantify the effect of the durability cycles, two specimens in the virgin and six in the aged state are tested. To induce the effect of wind loading a repeated loading was applied on six specimens. These specimens were loaded ten times up to their cracked state. Afterwards these six specimens were put in the climate chamber and were subjected to 80 HR cycles. Finally all specimens were loaded up to failure by a four-point bending test.

2 Experimental Program

2.1 Specimen Geometry

The specimens have a total length of 2.60 m. They are composed of a 200 mm thick insulation core and 3 mm thick TRC skins, made of a premix mortar and a glass fibre textile reinforcing grid. The sandwich beams were fabricated by applying one skin per beam at the time by hand lay-up. For four beams the textile reinforcing grid was glued on the insulating core. Afterwards the mortar was poured onto the core. For the other four beams the textile mat was pushed into the fresh poured mortar. Afterwards the skin was covered to prevent early evaporation of the water. After one day the beam was turned upside down and the other skin was applied in the same way. The beams were stored 28 days to cure the skins. An overview of all the specimens can be found in Table 1.

2.2 Materials

2.2.1 Expanded Polystyrene (EPS)

For the insulating core EPS, or Styrofoam, was used. Styrofoam was preferred above other insulating materials because of its low cost. It is also characterised by a low density

Table 1. Overview specimens.

Specimen	Location reinforcement	Cyclic loading	Heat-Rain cycles	Label		
1	Glued on insulation	No	No	Virgin	GI	
2	Embedded in mortar	No	No	Virgin	GM	
3	Glued on insulation	Yes	No	Cyclic	GI	
4	Embedded in mortar	Yes	No	Cyclic	GM	
5	Glued on insulation	Yes	Yes	Degra	GI	A
6	Glued on insulation	Yes	Yes	Degra	GI	B
7	Embedded in mortar	Yes	Yes	Degra	GM	A
8	Embedded in mortar	Yes	Yes	Degra	GM	B

Table 2. Properties EPS 200 (Kemisol 2017).

Density kg/m^3	E-modulus MPa	Bending strength kPa
20	10	250

(15–20 kg/m^3). These characteristics compensate the less performant mechanical properties of Styrofoam (Davies 2008). The properties of the used Styrofoam, EPS 200 are listed in Table 2.

2.2.2 TRC

Like mentioned before the TRC is composed of a premix mortar and an AR-glass textile grid. The mortar used in this research is a commercially available mortar (Pagel 2017). In practice this shrinkage free mortar is used in applications where the thickness of the elements needs to be reduced, for example for structural repair work. Only water needs to be added to the mortar. After 5 min of mixing it stays workable for about 1 h. The properties of the mortar can be found in Table 3.

Table 3. Properties mortar (Pagel 2017).

Density kg/m^3	E-modulus GPa	Bending strength MPa	Grain size mm
2200	>25	>8	0–1

To reinforce the mortar matrix a commercially available textile grid is used (Knauf 2017). The grid is made of AR-glass fibres. The properties of the grid can be found in Table 4.

To identify the structural properties of the resulting TRC, three uniaxial tensile tests are performed. The tests are performed on an Instron tensile bench 5885 according to RILEM TC 232-TDT (Brameshuber et al. 2016). The specimen geometry and test set-up can be seen on Fig. 1. The measured stress-strain curve is plotted on Fig. 2. An initial E-modulus of 30 GPa is obtained. The cracking strength of the matrix equals 4 MPa. All three specimens failed in the same way, namely by fibre fracture near the clamps.

Table 4. Properties AR-glass textile grid (Knauf 2017).

Density kg/m^2	Tensile strength N/50 mm	Mesh size mm
200	2500	5 × 5

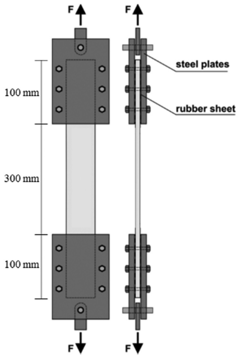

Fig. 1. Tensile test set-up.

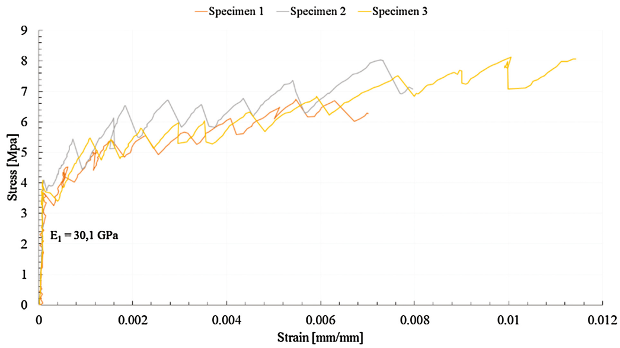

Fig. 2. Stress-Strain curve of TRC, with an effective fibre volume fraction of 0.58%.

2.3 Durability Study

Since we are dealing with innovative building concepts no standard design rules exists. However some available guidelines for European technical approval (ETAG) are applicable for our application, i.e. ETAG 004 (External thermal insulation composite systems with rendering) and ETAG 17 (Veture kits – prefabricated for external wall insulation). Besides requirements for the mechanical resistance and stability both guidelines also prescribe measures for the durability.

In this paper we focus on the hygrothermal behaviour, in particular the behaviour under HR cycles. In total 80 cycles are applied. Each cycle comprises three phases. First the specimen is heated to 70 °C (rise for 1 h) and maintained at a temperature of 70 °C and a relative humidity of 10 to 30% for 2 h. Afterwards water (15 °C) is sprayed for 1 h with an amount of 1 l/m^2/min. Last phase is a drainage of 2 h. Thus, in total one cycle takes 6 h, which leads to a total elapsed time of 480 h for the experiment. According to the guidelines no visible damage should occur during, nor after completion of the cycles.

The cycles are performed in a self-built climate chamber. As can be seen on Fig. 3 the desired temperature profile is approximated in an accurate way. For the cooling of the specimens more power is required. Nevertheless the specimens are aged in a sufficient way.

In reality the panels are also subjected to the wind, which is equivalent to a cyclic flexural loading of the panels. This results in crack formation in the TRC skins. To induce these cracks in the experiments a cyclic loading was applied on the specimens. This loading was performed by using a four-point bending test (Fig. 4). To have crack

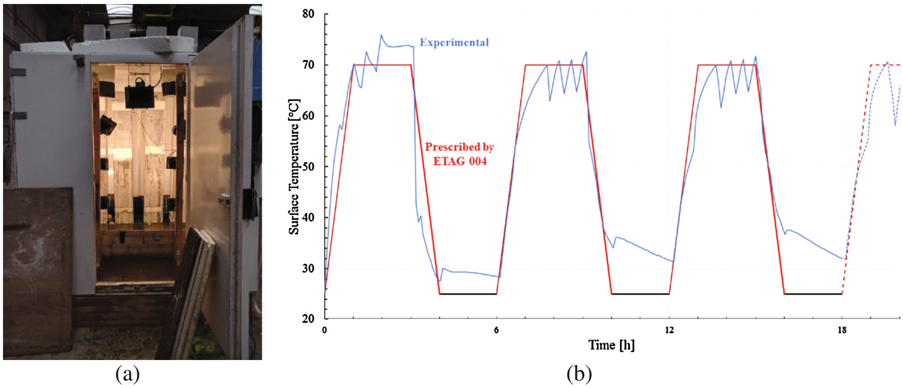

Fig. 3. (a) Self-built climate chamber (b) The desired temperature profile, as prescribed by ETAG004 is approximated in an accurate way.

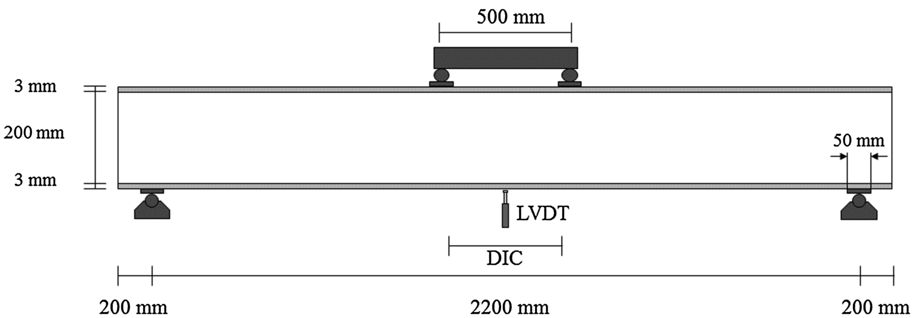

Fig. 4. Schematic overview of four-point bending test.

formation in the lower skin (loaded in tension) a stress higher than the cracking/bending strength of the matrix needs to be attained (Fig. 2). Preliminary calculations showed that a midspan deflection of 10 mm was needed to have a crack formation. The beams were loaded displacement controlled from 0 to 10 mm, and afterwards completely unloaded. This loading-unloading procedure was repeated ten times per beam.

2.4 Bending Test Set-up

After completion of both cyclic and durability loading all eight specimens are loaded up to failure by means of a four-point bending test (Fig. 4). The tests are performed on an Intron test bench 5885. The tests are displacement controlled with a rate of 1 mm/min. During the tests displacements at mid span are recorded with a LVDT (Linear Variable Differential Transducer). On the lower face DIC (Digital Image Correlation) (Sutton et al. 2009) was used which enables us to measure crack widths.

3 Results and Discussion

ETAG004 prescribes that no visible damage should occur by applying HR cycles. This requirement is fulfilled for the tested specimens. From the load-displacement curve (Fig. 5) one can conclude that the place of the textile grid has a substantial influence on

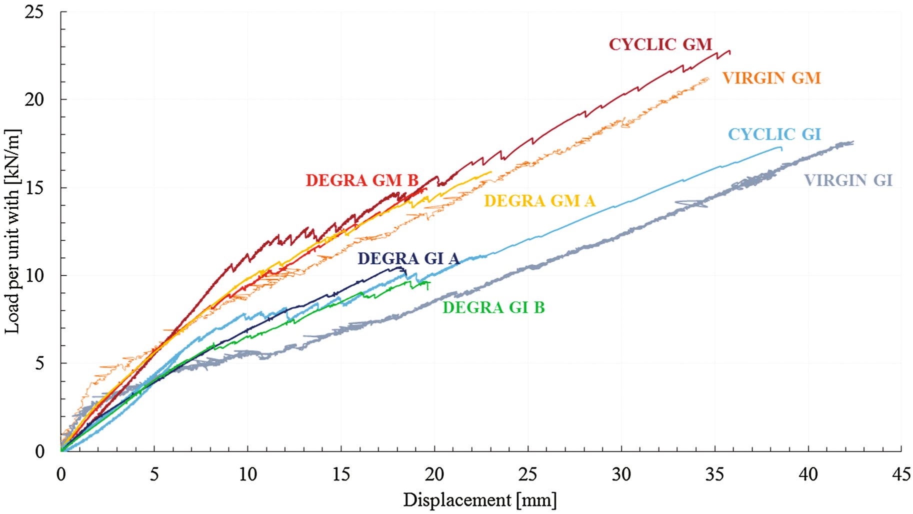

Fig. 5. The load-displacement curves of all specimens reveal that the location of the textile reinforcing grid has a large influence on the structural behaviour.

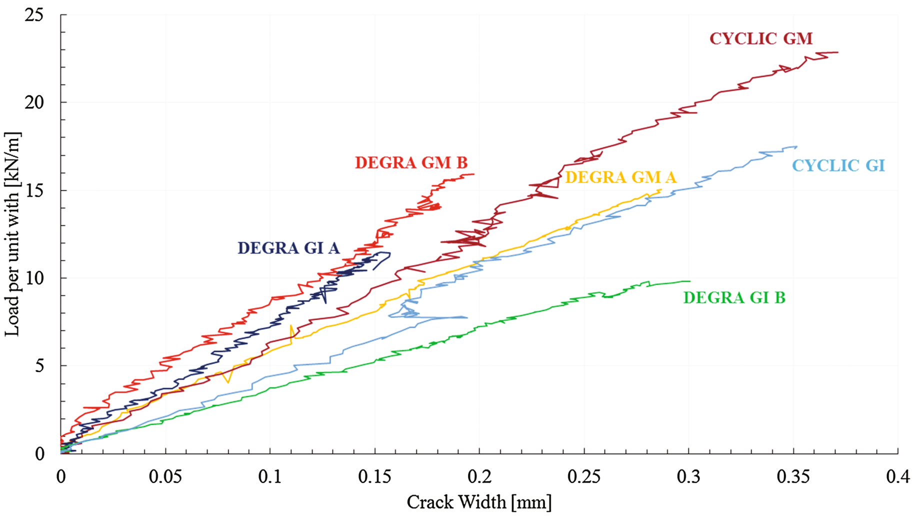

Fig. 6. Larger cracks appear for beams where the reinforcing grid is glued to the insulation core.

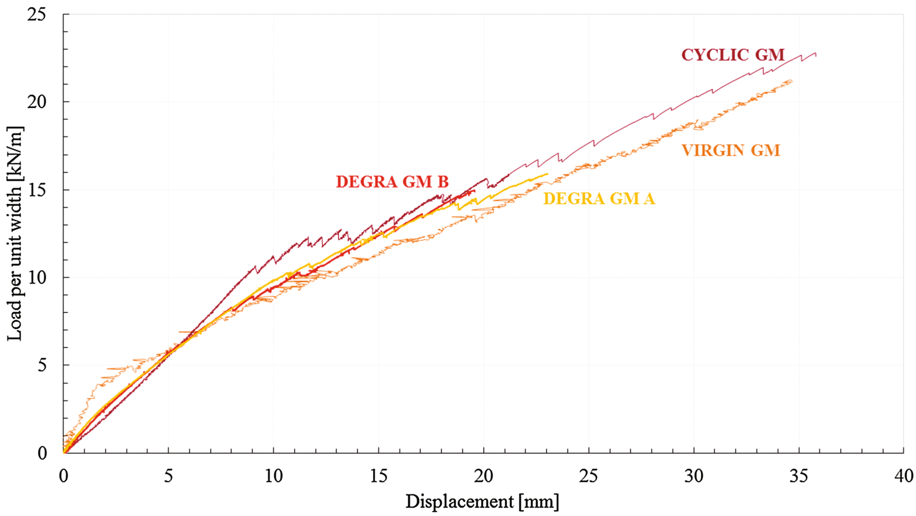

Fig. 7. Both cyclic as environmental loading has an influence not to be neglected.

the mechanical behaviour of the sandwich beams. Beams where the grid is glued on the EPS have a lower initial stiffness and a lower ultimate load.

All beams failed in a similar way, namely tensile rupture of the lower skin. During loading multiple cracks appeared, clearly visible and hearable. Comparing the largest cracks of the specimens the same tendency as for Fig. 4 can be noticed. Generally speaking, beams with the reinforcing grid glued to the EPS core have larger cracks compared to beams with the grid impregnated in the mortar (Fig. 6).

We can state that the reinforcing grid needs to be embedded in the mortar to have a more performant structural behaviour. To have a closer look at the effect of weathering conditions we will focus on these four specimens. From the load-displacement curves on Fig. 7 two major deteriorations can be observed. First of all, applying a cyclic load has a substantial impact on the initial stiffness of the beams, it is reduced with more than 40% (Table 5). Applying heat-rain cycles afterwards results in a slightly enlarged initial stiffness. This could be explained by the autogenous healing of cementitious composites: non reacted cement particles present in the TRC layer could react with the water of the durability cycles. Future tests are necessary to validate this statement.

Table 5. Structural responses of the specimens.

Specimen	Initial stiffness N/mm^2		Ultimate capacity kN/m	
Virgin	1.96		21.13	
Cyclic	1.13	↓ 42.3%	22.72	↑ 7.5%
Degra A	1.49	↓ 24.0%	15.86	↓ 24.9%
Degra B	1.29	↓ 34.2%	14.89	↓ 29.5%

Regarding the ultimate resistance we can observe that the cyclic loading doesn't have any influence. Applying environmental loading (HR cycles) affects the structural capacity: only 70% of the initial capacity remains (Table 5).

4 Conclusion

The authors investigate the possibility to use TRC sandwich panels with the dimensions of one floor for the renovation of existing dwellings. Since these panels will be exposed to weathering conditions, it is crucial to verify their behaviour on the long term. To do so an experimental program was performed to simulate wind (cyclic) loading and weathering conditions (heat-rain cycles).

From the experiments some preliminary conclusions can be drawn. First of all the reinforcing grid needs to be embedded in the mortar. Like this the composite action between grid and mortar is fully exploited, which results in more performant structural properties of the entire sandwich section.

Regarding the influence of the weathering conditions two things can be concluded. Cyclic loading has a negative impact on the initial stiffness, while an environmental loading (heat-rain cycles) reduces the ultimate resistance of the sandwich beams. Future tests are necessary to validate these first results and to identify the underlying processes.

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