Durability assessment of geopolymer façade panels based on CDW

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Abstract

As part of the InnoWEE project (2016-2020) (*Innovative pre-fabricated components including different waste construction materials reducing building energy and minimising environmental impacts*) construction and demolition waste (CDW) was processed into fine fractions which were then embedded into innovative high performance prefabricated geopolymeric panels. The CDW fractions consisted of brick, concrete and mortar, and wooden chips. Fly ash, slag and metakaolin were used as a binder and were activated by a mixture of K-silicate and KOH. Optimized compositions were defined and panels were produced in sizes of 50 cm × 50 cm intended for bonded contact (similar to ETICS) or 60 cm · 60 cm for ventilated façades. One type of panel was produced using mainly inorganic CDW (ground bricks and concrete), and were designated as high density geopolymer panels (HDG). A second type was made of at least 40% of wooden chip CDW and were designated as wood-based geopolymer panels (WGP). The durability of both types of panels was assessed according to the provisions of ETAG 004 and relevant standards for façade systems or wall cladding, including freeze – thaw resistance, impact resistance, bond strength, water vapour permeability, and capillary water uptake. Results showed that the performance of such panels is suitable for use as façade cladding.

1. Introduction

CDW constitutes a major solid waste stream in the world, most of which is sent to landfill[1], which has increased the need for effective recycling methods. Proper management of CDW and recycled materials can have major benefits in terms of sustainability and quality of life and can also provide benefits for the construction and recycling industry. Aggregates are the main products of CDW recycling, where about "90 % of the recycled aggregates are used directly in construction works as structural material, and the rest are used to manufacture other construction products" [2]. One potential use of CDW is in geopolymer technology (often also used as a synonym for alkali activated materials – AAM [3]). Geopolymers are inorganic polymers obtained from the reaction of an aluminosilicate powder with an aqueous alkaline solution [3]. The source of aluminosilicate material can be metakaolin, blast furnace slag, fly ash or other suitable waste material. The aluminosilicates are activated by an alkali hydroxide/alkali silicate solution. Depending on the raw material used and processing conditions, geopolymers can exhibit a wide variety of properties and characteristics including high compressive strength, low shrinkage, short setting time andgood resistance to chemicals. They are mechanically stable up to 1000-1200°C and are intrinsically non-flammable.

Research regarding the use of CDW as either (partially) reactive material or a (nearly) inert filler in geopolymer technology has indicated that CDW is compatible with geopolymer binders [4]. This technology could therefore present an interesting option to recycle CDW (brick, concrete, tiles and mortar) into prefabricated building products. The main environmental benefit of such technology is a lower CO_2 emission of such material compared to cement-based concrete, which is even further decreased by the application of recycled (CDW) aggregates instead of virgin ones. A successful application of ground waste concrete [5], brick, and ceramic [6, 7] have been reported.

The goal of the InnoWEE project is to develop different panels based on CDW through the application of geopolymer technology, to be used either as façade panels, similar to the ETICS- External Thermal Insulation System (contact façade), or for a ventilated facade. Some of the panels were made from wood waste (wood geopolymer panels - WGP), others from inorganic CDW (high density geopolymer panels – HDG). A mixture of alkali-activated blast furnace slag and metakaolin was used as the geopolymer binder. Since there are no specific standards for testing geopolymer-based panels, the provisions from the standards for cement-bonded particle boards or other building elements were applied for the wood-based panels (WGP), and the provisions from ETAG were followed for HDG panels in order to determine their properties and durability. ETICS panels have been designed to relatively easily separate HDG from expanded polystrene (EPS), while the recycling of HDG geopolymer to produce new geopolymer or concrete materials is a work in progress and part of the wider research regarding recycling of geopolymer waste products [8, 9].

2. Experimental

2.1 Materials

Two types of panels were developed, ETICS-like panels and wood-geopolymer panels to be used as a component of ventilated façade panels (Figure 1).

HD geopolymer binder was prepared using different combinations of metakaolin, ground blast furnace slag, fly ash, KOH, K-silicate, and CDW was used as an aggregate. The CDW was a blend of fired clay brick and concrete aggregates below 2 mm in size and was incorporated at a level of 50 % by weight. Details of the formulations have been published elsewhere [10]. The HD binder was used to cast an 8 mm thick geopolymer layer on top of expanded polystyrene (EPS) plates to form ETICS panels as follows: HD binder was cast into a casting box of size 50 cm × 50 cm. A vibration table was used to spread the binder evenly inside the box. A mortar reinforcing mesh with 1 cm mesh openings was then inserted and further vibration applied to submerge the mesh. A 2 cm thick EPS plate was then pressed on top and the casting box closed with a rigid cover plate. Curing was done in a sealed bag under saturated humidity conditions at 50°C for 12 h. After demoulding the panel was stored in a sealed bag at ambient temperature for a further 5 days to reduce the risk of drying shrinkage cracking. A second EPS plate 6 cm thick was then glued to the back of the first EPS plate to yield a final EPS thickness of 8 cm as required by the final ETICS panel design.

The WG binder was prepared by mixing metakaolin, ground blast furnace slag and Na-silicate with woodchips below a few cm in size from unpainted crushed wood construction waste (pallets, scaffolding boards, cable drums, crates). The wooden chips were incorporated at a level of 40-50 % by weight for different applications (indoor, outdoor). Wood-geopolymer panels of ca. 60 cm × 60 cm in size with a thickness of 15-18 mm were prepared using a hydraulic press to compress the WGP binder inside a suitable casting box. Panels were cured under compression for 1 day at ambient temperature. Demoulded panels were then dried slowly clamped between two wooden plates to avoid warping and then finally dried free-standing vertically.

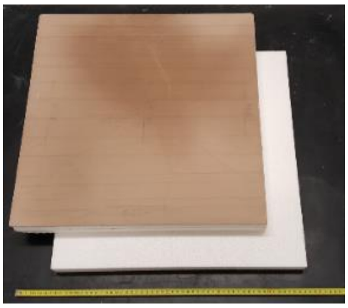
(a)  (b)  (c) 

Figure 1: InnoWEE products. a) ETICS-like panel prototype 50×50 cm with 8 cm thick EPS, (b) WGP 60×60 cm and 15 mm thick for backside reinforcement of ventilated façade panels, (c) ventilated façade panel.

2.2 Methods

The provisions from the standards intended for wood-based panels (EN 310, EN 321) were applied for testing the WGP, and provisions from the European Technical Assessment Guide (ETAG 004) were followed for the ETICS-like panels.

The service life of the developed ETICS-like panels and WGP depend on their resistance to climatic conditions, so the following characteristics were tested on the ETICS-like panels:

- capillary water absorption test, according to standard ETAG 004 (HDG layer),
- water vapour permeability, according to standard ETAG 004 (HDG layer),
- impact resistance, according to standard ISO 7892 (composite),
- bond strength, according to standard EN 1542 (composite),
- freeze–thaw behaviour, according to standard ETAG 004 (composite),
- freezing in the presence of de-icing salt resistance. according to standard SIST 1026 (HDG layer).

For WGP the following characteristics were determined:

- bending strength and modulus of elasticity in bending after 50 cycles of freezing and thawing, according to standards EN 1328 and EN 310,

- humidity cycling test and tensile strength perpendicular to the plane of the board, according to standards EN 321 and EN 319,
- freezing in the presence of de-icing salt resistance, according to standard SIST 1026.

Since the samples were made in the laboratory, some adjustments were made to the dimensions required in the standard procedure.

3. Results and discussion

The façade products developed were investigated according to the standards mentioned above.

3.1 Evaluation of ETICS-like panels

Table 1: Results of the investigation of selected ETICS-like panels

	Standard	**ETICS-like**
Capillary water uptake (on HDG layer) ($kg/m^2\ h^{0.5}$)	ETAG 004	0.38
Coefficient of water vapour diffusion resistance-⌠ (on HDG layer)	ETAG 004	97.2
Impact resistance	ISO 7892	Zone II
Bond strength between base coat and insulation product (N/mm^2)	EN 1542	0.26
Freeze-thaw behaviour (after 30 cycles)	ETAG 004	no visible changes
Freezing in the presence of de-icing salts resistance (on HDG layer) (mg/mm^2)	SIST 1026	3.08

As seen in Table 1 the capillary water uptake for the HDG layer was 0.38 $kg/m^2\ h^{0,5}$, which indicates that the value meets requirements, when compared to the requirement for similar products e.g. repair mortars for which it should be below 0.5 $kg/m^2\ h^{0.5}$.

Furthermore, the coefficient of water vapour diffusion resistance was 97.2 for the HDG layer. There are no requirements for facades regarding water vapour permeability, but outdoor materials differ significantly. The structure of glass is completely impervious, for instance, whereas bricks are more permeable and concrete has a value between 18 and 84.

Results showed that the impact resistance of ETICS-like panels was in accordance with the explanation given in the provisions of the ETAG 004 for façade panels classified to zone II. This is a zone liable to impacts from thrown or kicked objects, but in public locations where the height of the ETICS will limit the size of the impact, or at lower levels where access to the building is primarily to those with some incentive to exercise care.

The bond strength between the HDG layer and the EPS was 0.26 MPa. For comparison, according to ETAG 004, the bond strength between an external layer (mortar) and insulation should be min. 0.08 MPa.

After the 30 cycles of testing freeze-thaw behaviour of ETICS-like panels there were no visible changes on the surface of the composites, indicating that the material is suitable for areas with seasonal freezing. But due to the high loss of mass after only 5 cycles of freeze-thaw and de-icing salt resistance, i.e. 3 mg/mm^2, the material should not be used in areas where salt is present. According to the standard for cement-based concrete the permitted value limit after 10 or 25 cycles is 0.4 mg/mm^2.

3.2 Evaluation of wood - based geopolymer panels (WGP)

The results of testing two different WGP are presented in Table 2.

Table 2: Results of the investigated WGP

	Standard	**WGP-40***	**WGP-50***
Bending strength before exposure to freeze-thaw cycling (MPa)	EN 1328, EN 310	5.46	4.32
Bending strength after 50 cycles of freezing and thawing (MPa)	EN 1328, EN 310	3.46	2.07
Modulus of elasticity in bending before exposure to freeze-thaw cycling (N/mm^2)	EN 1328, EN 310	2017.1	1382.9
Modulus of elasticity in bending after 50 cycles of freezing and thawing (N/mm^2)	EN 1328, EN 310	1111.7	499.3
Tensile strength perpendicular to the plane of the board before exposure to freeze-thaw cycling (MPa)	EN 321	0.66	0.56
Tensile strength perpendicular to the plane of the board after 3 cycles of freezing and drying at 70°C (MPa)	EN 321	0.28	0.19
Freezing in the presence of de-icing salts resistance after 25 cycles (mg/mm^2)	SIST 1026	0.11	0.12

*WGP-40 means 40% of wood waste, WG-50 represents 50 % of wood waste within the geopolymer matrix.

For both boards the bending strength and modulus of elasticity in bending was significantly lower after 50 cycles of freezing, than before exposure to freezing. Results showed that the bending strength of WGP-40 was 60 % higher than that of WGP-50. (Table 2) After the freezing test, the bending strength of both samples decreased - WGP-40 by 36 %WGP-40, and WGP-50 by 52%.

Similarly, the modulus of elasticity in bending for the WGP-40 sample is approximately 30% higher than the WGP-50. After exposure to freezing and thawing, the modulus of elasticity in bending also decreased significantly in both samples. After 3 cycles of hygro-thermal exposure the tensile strength decreased in both samples (Figure 2), in the case of WGP-40 by 56 % and in the case of WGP-50 by 66%.

After 25 cycles of the freeze-thaw and de-icing salt resistance test neither type of WGD panel exceeded the prescribed average basic limit value for concrete, which is 0.20 mg/mm^2. The WGP-40 exhibited better performancei.e. higher resistance to freeze-thaw cycles than the WGP-50. In both cases, the investigated products swelled during the test.

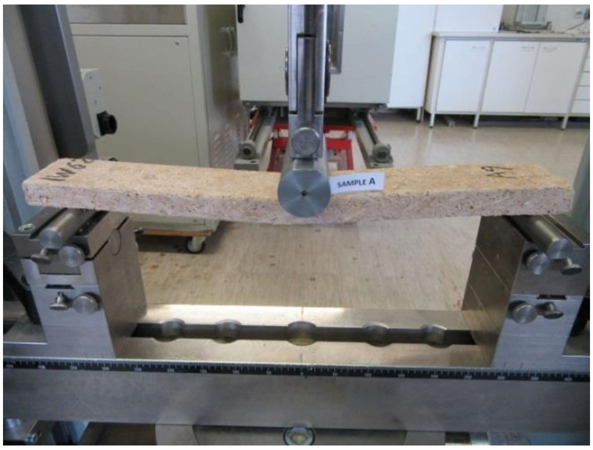


Figure 2: Determination of tensile strength of WGP.

4. Conclusions

Two types of panels based on CDW, which were developed in the frame of the InnoWEE project, were assessed with respect to their durability i.e. (a) ETICS-like geopolymer panels (HDG with EPS) and (b) wood-geopolymer panels (WGP) to be used as a component of ventilated façade panels. The panels were investigated according to the provisions of ETAG 004 and relevant standards for façade systems or wall cladding, including freeze–thaw resistance, bond strength, impact resistance, water vapour permeability and capillary water uptake. Capillary water uptake for the HDG layer amounted to 0.38 $kg/m^2\ h^{0.5}$, the impact resistance of the composite of HDG and EPS classified the product for zone II, and the bond strength between the HDG layer and the EPS was 0.26 MPa. HDG layers withstood freezing-thawing (30 cycles) without any visible damage, but loss of mass was recorded after exposure to freezing in the presence of salt (NaCl) after only 5 cycles. In the case of panels with wooden chips, all parameters are more favourable for the sample containing a lower amount of wooden chips, i.e WGP-40 (40% wooden chips). The bending strength of the WGP-40 was 5.5 MPa compared to 4.3 MPa for the WGP-50 (50% wooden chips). The modulus of elasticity in bending was 2017 N/mm^2 for the WGP-40 and 1383 N/mm^2 for the WGP-50. Bending strength decreased significantly after exposure to freeze-thaw cycling in both types of WGP - by 36 % for the WGP-40 and by 52% for the WGP-50. A similar drop was also noticed for the modulus of elasticity. After 3 cycles of hygro-thermal exposure the tensile strength in both samples also decreased, in the case of WGP-40 by 56 % and in the case of WGP-50 by 66%.

Preliminary results showed that the performance of HDG panels could be suitable for use as façade cladding if not exposed to freezing in the presence of salt, whilst WGP panels are more suitable for areas without exposure to water and freezing.

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References

[1] Pacheco-Torgal F., Introduction to the recycling of construction and demolition waste (CDW), Handbook of Recycled Concrete and Demolition Waste, A volume in Woodhead Publishing Series in Civil and Structural Engineering, 2013, 1-6.

[2] Study on data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials, Final Report, 2015, https://www.certifico.com/component/attachments/download/2886, 1.7.2017.

[3] Provis J., Van Deventer J., Alkali Activated Materials: State-of-the-Art Report, RILEM TC 224-AAM (RILEM State-of-the-Art Reports), 2014.

[4] H2020 InnoWEE project: http://innowee.eu/proyect/, 6.7.2018.

[5] Ahmari S., Ren X., Toufigh V., Zhang L., Production of geopolymeric binder from blended waste concrete powder and fly ash, Construction and Building Materials 35 (2012) 718–729.

[6] Komnitsas K., Zaharaki D., Vlachou A., Bartzas G., Galetakis M., Effect of synthesis parameters on the quality of construction and demolition wastes (CDW) geopolymers, Advanced Powder technology 26 (2015) 368-376.

[7] Reig L., Sanz M. A., Borrachero M. V., Monzó J., Soriano L., Payá J., Compressive strength and microstructure of alkali-activated mortars with high ceramic waste content, Ceramics International, 43 (16) (2017) 13622-13634.

[8] Gharzouni A., Vidal L., Essaidi N., Joussein E., Rossignol S., Recycling of geopolymer waste: Influence on geopolymer formation and mechanical properties, Materials and Design 94 (2016) 221–229.

[9] Akbarnezhad A., Huan M., Mesgari S., Castel A., Recycling of geopolymer concrete, Construction and Building Materials 101 (2015) 152–158.

[10] Panizza M., Natali M., Garbin E., Tamburini S., Secco M., Assessment of geopolymers with construction and demolition waste (CDW) aggregates as a building material, Journal of Construction and Building Materials 181 (2018) 119–133.