REACTION TO FIRE PROPERTIES OF WOOD WASTE-BASED GEOPOLYMER PANELS

Nataša Knez (1), Friderik Knez (1), Vilma Ducman (1), Sergio Tamburini (2), Marco Natali (2), Adriana Bernardi (3)

(1) ZAG - Slovenian National Building and Civil Engineering Institute, Slovenia

(2) CNR-ICMATE – National Research Council, Institute of Condensed Matter Chemistry and Technologies for Energy, Italy

(3) CNR-ISAC – National Research Council, Institute of Atmospheric Sciences and Climate, Italy

Abstract

Wood waste, possibly originating from deconstruction of buildings is processed to obtain fine fractions which are further embedded into innovative high performance prefabricated geopolymeric panels, intended to be used as façade panels or internal lining. For these uses reaction to fire (RtF) is one of the most important characteristics. Inside the EU InnoWEE project (Innovative pre-fabricated components including different waste construction materials reducing building energy and minimizing environmental impacts) this aspect is studied on the innovative panels. As the material's basis is inorganic there is a possibility of compliance to high demanding reaction to fire classes (non-combustible materials). Furthermore as there are different variants of the material that may also include CDW wood chips, it is important to understand how the variable content of wood chips influences critical parameters for the RtF. Different variants of CDW geopolymers based panels were assessed with respect to the reaction to fire, using cone calorimeter. Results have shown that CDW panels containing 20% of wood comply to the A2 class and are suitable for all uses, with respect to fire. Higher wood content (maximum 50% of wood chips) yields hardly combustible materials.

1. Introduction

Materials made of construction and demolition waste (CDW), used as raw materials, wood from deconstructed buildings being one of such raw materials, can be attractive from different points of view – use of waste is beneficial for the environment, products can be less expensive, and produced with less energy consumption. Such products can also be visually appealing [1], [2].

The proposed application of the CDW within this project is implementation of inorganic (i.e. concrete, ceramics, glass) or organic (i.e. wood) part of CDW into geopolymer (alkali activated) panels for cladding of internal walls and façade cladding. Geopolymers or alkali activated materials are inorganic polymers obtained from reaction of an aluminosilicate with an alkaline solution [3, 4].

But before one can start with massive production also regulatory requirements should be addressed [5, 6]. Among these one of the main concerns is fire safety in buildings. Geopolymers with inorganic components are significant substitute for concrete where spalling in case of fire can be problematic. For this reason many studies have been done on fire resistance [7, 8, 9] or elevated temperature [10, 11] properties of geopolymers. Yet such analyses do not provide an adequate assessment of fire related risks in facades, where many fire events have proven the issue to be of paramount importance. In fact to address issue of fire spread or fire growth one should consider reaction to fire properties of the exposed materials. Reaction to fire is usually much less of concern when geopolymers are considered, since inorganic materials are deemed to be essentially non-combustible. Only materials with non-negligible amount of organic components need to be tested. Geopolymer products, based on wood may contain substantial percentage of wood and are interesting materials for building industry due to their environmental footprint. Some research has also been done on such geopolymers, addressing reaction to fire characteristics [5], but to a lesser extent as in the case of fire resistance of geopolymers.

In our study reaction to fire of geopolymer products containing waste wood was addressed. Reaction to fire is the most relevant fire related property for several applications in the inside of a building but also in facades. For reaction to fire of façade claddings a common EU large scale test method is also being prepared. However such method is not feasible for early development of the material due to quantity of the tested material needed, to perform one test. Therefor used method (ISO 5660-1, the cone calorimeter method) serves as currently the best available small scale method, yielding relevant results with respect to the reaction to fire. In laboratory production of the material there were only small samples available for testing, so small scale tests for reaction to fire classification estimation were used.

2. Reaction to fire classification

Reaction to fire (RtF) in the European union is classified according to the standard EN 13501-1 in classes A1 and A2, representing non-combustible materials, classes B and C representing materials that are hard to ignite, and classes D and E representing easily ignitable materials.

Some materials in general do not have any organic additives or their organic content is very low (less than 1% in weight). In case of fire such materials do not add any energy to the fire or their influence is negligible. Such materials are considered non-combustible based on their low organic content alone. Materials with higher organic content must be tested to determine their RtF class. If the organic content is sufficiently low the RtF class of such materials is A1 or A2. There is usually no limitation for the use of such materials from fire safety point of view. Materials that have minor influence to the fire growth are classified B. Their use is allowed in most cases, but it may be limited when used as façade cladding.

For classification of the tested material for classes A2 or B, testing according to EN 13823 (Single burning item test, SBI) should be performed. These measurements require larger samples (2,25 m^2), which were in our case not available due to early development phase of the material. Instead, small scale test (ISO 5660-1, cone calorimeter) has been done and the results extrapolated using dedicated software (Conetools, Fire Testing Technology, based on [12]) to calculate needed parameters for the RtF classification.

It should be noted that the SBI and the cone calorimeter method do not distinguish between non-combustible and hard to ignite materials of class B. The results rather represent the contribution of the material to the fire growth. Materials in both classes do not contribute to the fire growth in its first stage. The basic comparison between the SBI test method and the cone calorimeter test method is shown in table 1.

Some criteria parameters cannot be simulated from cone calorimeter test results: lateral flame spread, smoke release and incidence of flaming droplets. Therefor full classification based on cone calorimeter measurement is not possible.

Table 1: Comparison between mid-scale and small scale test

		
	EN 13823 (SBI)	**ISO 5660-1 (Cone calorimeter)**
Ignition source	propane burner 30 kW	electrical heater incident heat flux 50 kW/m^2, spark induced ignition
Specimen positioning	Vertical	Horizontal
Specimen dimensions	corner: (0,5 m + 1 m) × 1,5 m	0,1 m × 0,1 m

3. Samples

Wood chips were obtained from unpainted construction wood waste from e.g. pallets, scaffolding boards, cable drums, crates, etc. using a wood shredder. Chips of length below approximately 5 cm and width below 5 mm were obtained by sieving. Wood chips were mixed with geopolymer reagents including Na-silicate and metakaolin and processed into wood-geopolymer panels (WGP) using a hydraulic press, applying appropriate pressure in the range of about 1 MPa to 2 MPa. Curing was done at ambient temperature. The procedure is developed in frames of the InnoWEE H2020 project and is patent pending.

Table 2: Test specimens

Specimen	**Wood quantity**	**Slag added**	**Pressure applied**	**Mass [g]**	**Thickness [mm]**
WGP 30 %	30%	Yes	High	200,29	14,8
WGP 40 %	40%	No	Low	150,25	14,8
WGP 50 %	50%	Yes	High	117,07	11,6

During the development of the product various formulations and preparation techniques have been considered of which selected i.e. most promising were subjected to fire testing.

For fire testing three different samples of geopolymer were selected with 30%, 40% and 50% by weight of wood fragments each. In two samples also ground blast furnace slag was added. Three different round specimens of 130 mm diameter have been prepared (Table 2).

4. Test methods

For different RtF class according to EN 13501-1 different test methods are required. The target class for the new materials was A2 or B, therefor tests according to EN ISO 1716 (bomb calorimetry) and EN 13823 (SBI) are required, and for classification B tests according to EN 13823 and EN ISO 11925-2 (attack with small flame impingement) are required. However due to small amount of available samples, compared to the needed quantity for the full testing programme, we have modified the test programme while still ensuring relevant information on possible class of the materials. Most relevant: the cone calorimeter to simulate SBI and bomb calorimetry were done.

4.1 Bomb calorimetry

Calorific value of three different specimens was measured with bomb calorimeter (Figure 1). The measurement serves to determine gross calorific potential (PCS) of the burnt substance. The method is basic method for distinguishing between non-combustible and combustible materials. If the PCS value is less than 2,0 MJ/kg or less than 3,0 MJ/kg the material may comply to the requirements for non-combustible materials of class A1 or A2 respectively. The test was made according to testing method EN ISO 1716:2010.

4.2 Cone calorimeter

The cone calorimeter method (ISO 5660-1) is a bench-top method with testing done on relatively small samples. It provides the data on the characterization of burning process of the burnt sample; heat release rate and smoke production rate. The results obtained on the cone calorimeter can be extrapolated to the medium scale, using appropriate software tools.

In the experiment we used the incident heat flux of 50 kW/m^2 and open air (approx. 21% oxygen) conditions.

Figure 1: Bomb calorimeter for testing according to EN ISO 1716 (left) and test apparatus for testing according to ISO 5660-1 (right)

5. Results and discussion

5.1 Bomb calorimetry

Test results have shown that none of the test specimens could be classified A2 (Figure 3). From test results for the three specimens the results have been extrapolated. It has been estimated that for the A2 class the amount of wood chips in the product could be up to 20% in weight. For the extrapolation linear regression was used.

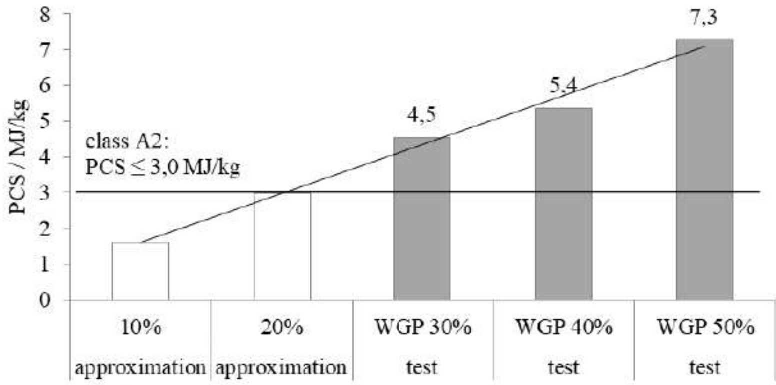

Figure 2: Results of calorimetry measurement (solid grey columns) with estimated values for smaller wood content (grey bordered columns).

5.2 Cone calorimeter

The three test specimens were exposed to 50 kW/m^2 of heat flux. Sparker was placed above the tested specimens to ignite the gases, evaporating from the sample due to the heat flux. In all three specimens the flame faded out in few seconds after ignition. Later in specimens with 40% and 50% of wood content an auto ignition due to the surface temperature of the test specimen occurred after 5 and 12 minutes respectively. In specimen with 40% of wood content flame persisted for more than 8 minutes and in specimen with 50% of wood content the flame lasted for one minute and a half. Specimens were tested for about 25 minutes each.

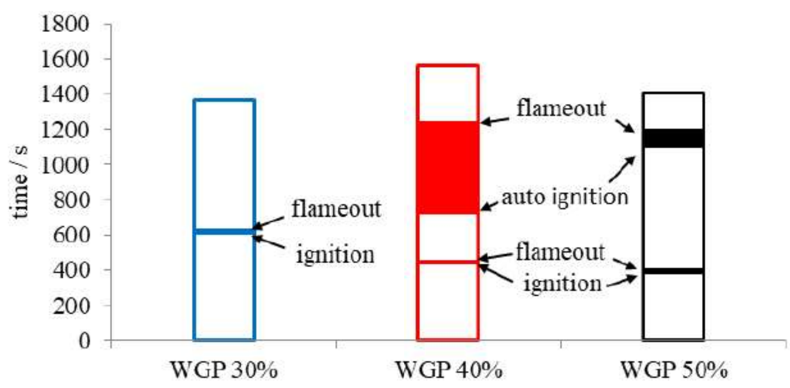

Figure 3: Test results of testing according to ISO 5660-1 (cone calorimeter): test duration (column height) with occurrence of flames (filled parts of columns)

In all three specimens release of smoke was observed. Intense smoke release started first in specimen with the highest amount of wood and latest in specimen with the lowest amount of wood which was expected. In specimen with 40% of wood particles auto ignition occurred almost immediately after intense smoke release, indication of the incomplete combustion, started (Figure 6) and with complete combustion the smoke release decreased. With ignition rapid increase of heat release was noticed (Figure 5). In specimen with 50% of wood chips auto ignition was also noticed, but flame duration was short and no evident increase of heat release was observed.

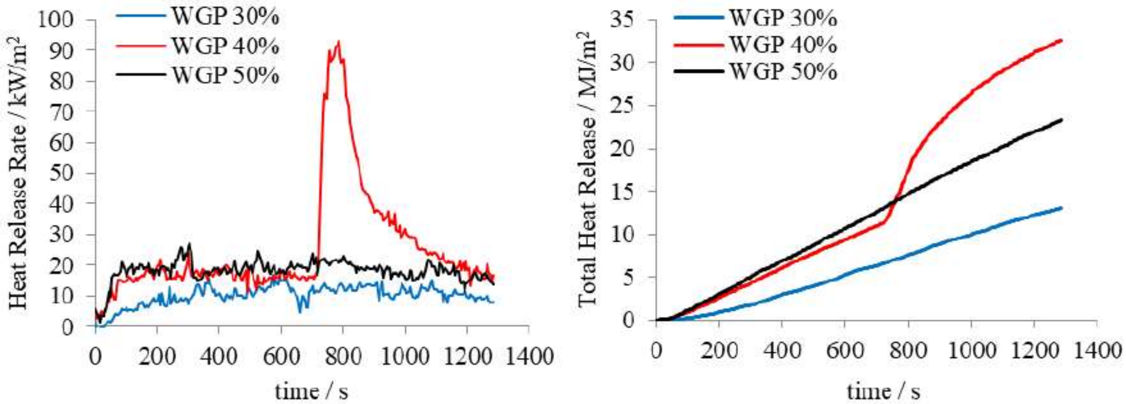

Figure 4: Heat release rate (HRR) and total heat release (integral of HRR) of the three specimens testing according to ISO 5660-1 (cone calorimeter)

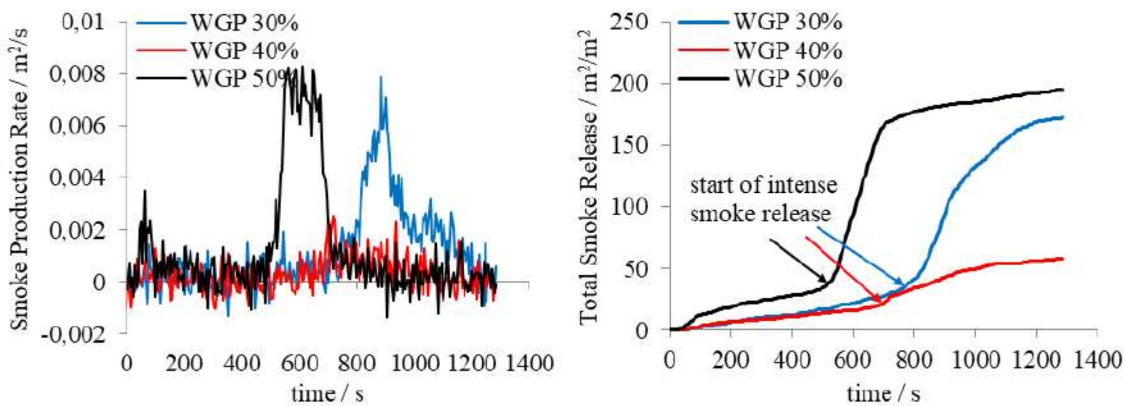

Figure 5: Smoke production rate (SPR) and total smoke release (integral of SPR) of the three specimens testing according to ISO 5660-1 (cone calorimeter)

Different behaviour of the three tested specimens was caused by different wood amount and also some other factors, as follows. Some differences were caused by differences in preparation of the specimens (e.g. added slag, applied pressure) and dimensions (e.g. different thickness). In addition it was noticed that wood chips were notably larger size in specimen with 40% of waste wood content (Figure 7). The main difference in behaviour – auto ignition and long duration of persisting flaming in specimen with 40% of wood content – was likely caused by presence of larger pieces of wood and possibly by lower pressure applied during the production process.

In Figure 6 photos of the three specimens after the test can be seen.

WGP 30%	WGP 40%	WGP 50%

Figure 6: Photos of the three tested materials after the test with cone calorimeter method (ISO 5660-1) at 50 kW/m^2 of heat flux

5.3 Simulation of SBI test parameters

Test results of testing according to ISO 5660-1 were used for simulation of SBI parameters Fire growth rate index (FIGRA) and Total heat release (THR).

Results of the simulation showed that all three products would be classified B according to EN 13501-1. Both SBI parameters were much lower than the limit values of classification criteria. Criteria for SBI parameters are the same for classification A2 and B, but since PCS values of the specimens were too high, class A2 would not be possible to achieve.

Table 3: Simulated SBI parameters

Parameter value	**WGP 30%**	**WGP 40%**	**WGP 50 %**	**Limit value for class A2 and B**
Fire growth rate index ($FIGRA_{0,2MJ}$)	0,2 W/s	1,1 W/s	1,7 W/s	≤ 120 W/s
Total heat release (THR_{600s})	0,01 MJ	0,07 MJ	0,14 MJ	≤ 7,5 MJ

6. Conclusions

Three specimens of geopolymer material based on construction and demolition wood waste material were prepared. Each specimen had different content of CDW wood chips. Reaction to fire classification according to European standard EN 13501-1 for the three specimens was proposed based on small scale reaction to fire tests.

Calorific value for the three specimens has shown approximate linear relationship with wood content in each specimen. It was shown that if less than 20% of wood is embodied in the material the classification A2 according to EN 13501-1 is possible, which is regarded as non-combustible material and has the widest applicability in buildings.

Small scale testing on cone calorimeter has shown that beside wood content also production process and size of wood chips can influence the fire behaviour of specimens. With a help of simulation of cone calorimeter test results SBI parameters for the three specimens were estimated. It has been shown that all specimens would be very likely classified B according to EN 13501-1 which provides somewhat limited but still rather broad possible use in construction. Additional classification (e.g. smoke release and incidence of flaming droplets) are not possible to estimate from cone calorimeter measurement. Overall the use of the new materials under consideration is not significantly limited due to its reaction to fire properties.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723916.

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] Turk, J., Mladenovič, A., Knez, F., Bras, V., Šajna, A., Čopar, A. and Slanc, K., 'Tar-containing reclaimed asphalt - Environmental and cost assessments for two treatment scenarios', *Journal of cleaner production*, **81** (2014).

[3] Alkali Activated Materials: State-of-the-Art Report, RILEM TC 224-AAM (RILEM State-of-the-Art Reports) Edition by John Provis (Editor), Jannie van Deventer (Editor), 2014.

[4] Aziz, I. H., Al Bakri Abdullah, M.M., Cheng Yong, H., Yun Ming, L., Hussin, K., Surleva, A. and Aizat Azimi E., 'Manufacturing parameters influencing fire resistance of geopolymers: A review, J Materials: Design and applications (2016) 1-13.

[5] Morozovs, A., Bukšans, E., Spulle, U. and Tuherm, H., 'Wood-geopolymer composites for enhancement of construction's reaction to fire', in 'Sustainable Use of Local Resources (Entrails of the Earth, Forest, Food and Transport)', Proceedings of National Research programme, New Products and Technologies (NatRes). (Latvian State Institute of Wood Chemistry, Riga, 2013), 107-110.

[6] Berzins, A., Morozovs, A., Gross, U. and Iejavs, J., 'Mechanical Properties of wood-geopolymer Composite', Engineering for rural development, 2017, 1167-1197.

[7] Cheng Yong, H., Yun Ming, L., Al Bakri Abdullah, M.M. and Hussin K., 'Fire Resistant Properties of Geopolymers: A Review', *Key Engineering Materials* **660** (2015) 39-43

[8] Alehyen, S., Zerzouri, M., ELalouani, M., EL Achouri, M. and Taibi, M., 'Porosity and fire resistance of fly ash based geopolymer', *Journal of Materials and Environmental Sciences* **8** (10) (2017) 3676-3689.

[9] Luna-Galiano, Y., Cornejo, A., Leiva, C., Vilches, L.F. and Fernandez-Pereira, C., 'Properties of fly ash and metakaolin based geopolymer panels under fire resistance tests', *Materiales de Construcción* **65** (319) (2015) 1-13.

[10] Sakkas, K., Sofianos, A., Nomikos, P. and Panias, D., 'Behaviour of Passive Fire Protection K-Geopolymer under Successive Severe Fire Incidents', *Materials* **8** (294) (2015) 6096-6104.

[11] Vickers, L., Pan, Z., Tao, Z. and van Riessen, A., '*In situ* Elevated Temperature Testing of Fly Ash Based Geopolymer Composites', *Materials* **9** (445) (2016)

[12] Van Hees, P., Hertzberg, T. and Steen Hansen, A., 'Development of a Screening Method for the SBI and Room Corner using the Cone Calorimeter', Nordtest project 1479-00, SP Fire Technology, SP Report, 2002.