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# Mineral wool waste-based geopolymers

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**Abstract.** Mineral wools –a general term for stone wool and glass wool– are the most common building insulation materials in the world. The annual amount of mineral wool waste generated in Europe totaled 2.3 Mt in 2010 – including wastes from the mineral wool production and from the construction and demolition industry. Unfortunately, mineral wools are often considered unrecyclable due to their fibrous nature and low density. Thus, the utilisation of post-consumer mineral wool waste in different applications remains low.

Mineral wools have a great potential as geopolymer precursors as they have suitable chemical and mineralogical compositions. As geopolymers can provide significant CO<sub>2</sub> emission reductions compared to traditional Portland cement concretes, using mineral wool waste as geopolymer precursor would be an attractive utilisation path. Here, we show that mineral wool waste can be geopolymerised to form sustainable cements with good mechanical properties. Geopolymerisation of mineral wool waste therefore offers an attractive route for waste valorisation and production of low-CO<sub>2</sub> cements.

## 1. Introduction

Mineral wools, including stone and glass wools, are the most common insulating materials in the world. The production volumes are estimated to be 2/3 of stone wool (SW) and 1/3 of glass wool (GW), whereas slag wool is no longer produced in significant volume [1]. Although mineral wool production creates waste and by-products, including mineral wool offcuts, the main mineral wool waste stream is generated by building construction and demolition (C&D) industry. In 2010, the total volume of mineral wool waste produced in the 27 European Union countries was 2.3 million tons, and it is expected to rise to 2.5 million tons annually by 2020 [2].

Unfortunately, mineral wool waste is often considered unrecyclable. The main current practice is to landfill this waste which causes high costs for the C&D industry as well as for mineral wool producers. Utilising mineral wool waste as a source material for alkali-activated binders, often called as geopolymers, prevents the landfilling costs and can provide an avenue for an additional profits for C&D and mineral wool manufacturing companies.

Geopolymers can be produced from a wide range of aluminosilicate precursors, the most common ones being ground granulated blast furnace slag (GGBFS) and coal fly ash. As many industrial side streams can be used as geopolymer precursor, and geopolymer production can provide CO<sub>2</sub> emission reductions as much as 80% compared to Portland cement concretes [3], geopolymers are considered to be important part of the current and future toolkit of sustainable cementing binder systems.



Mineral wools have favourable chemical composition and mineralogy for geopolymer precursor. They are completely X-ray amorphous which increases their reactivity and they have a high Si content which is the main structural component of the binder. Further appealing characteristic of mineral wool waste is its high specific surface area which further increases the reactivity. [4,5]

The present study investigates the suitability of mineral wool waste for geopolymer precursor. The objective was to identify if both old mineral wool waste collected from building demolition sites and new mineral wool collected from building construction sites can be used as geopolymer precursor. The development of compressive strength is measured during the first 28 days of hardening. Furthermore, the freeze-thaw durability of the developed binders are determined. This will provide valuable information to improve the utilisation potential of mineral wool waste as geopolymer precursor.

## 2. Experimentations

### 2.1. Materials

Mineral wool waste samples were separated from C&D waste piles manually (Figure 1). In total, four samples were collected: 1) stone wool from construction site (SW\_new); 2) stone wool from demolition site (SW\_old); 3) glass wool from construction site (GW\_new); and 4) glass wool from demolition site (GW\_old). The installation dates of the old mineral wools from demolition sites are not known exactly, but they are expected to be from the 1970s or 1980s. The chemical compositions of the samples are presented in Table 1. In addition to the major oxides given in Table 1, glass wool contains typically ~2-4 wt.% B<sub>2</sub>O<sub>3</sub> which is not quantifiable with the XRF technique used here. Both stone wools and both glass wool have chemical composition close to each other, which is important as the chemistry dictates the formation of the binder gels. Stone wool samples have a lower content of organic resin than glass wool samples, depicted by the loss-on-ignition at 550°C.



Figure 1. Mineral wool samples were collected manually from demolition and construction sites.

Table 1. Chemical composition and loss-on-ignition (LOI) of the mineral wool samples.

	SW_new	SW_old	GW_new	GW_old
CaO, [%]	18.2	16.6	7.9	7.3
SiO <sub>2</sub> , [%]	39.4	44.1	61.3	61.9
Al <sub>2</sub> O <sub>3</sub> , [%]	15.9	14.3	2.0	3.3
Fe <sub>2</sub> O <sub>3</sub> , [%]	9.8	5.5	1.4	1.2
Na <sub>2</sub> O, [%]	1.3	1.2	16.3	16.0
K <sub>2</sub> O, [%]	0.5	0.3	1.0	0.8
MgO, [%]	11.4	14.7	2.0	2.9
P <sub>2</sub> O <sub>5</sub> , [%]	0.1	0.0	0.2	0.0
TiO <sub>2</sub> , [%]	1.0	0.2	0.1	0.0
SO <sub>3</sub> , [%]	0.1	0.0	2.0	0.3
Cl, [%]	0.0	0.0	0.1	0.1
LOI 550°C	4.3	2.6	9.4	8.8

## 2.2. Methods

Prior to the alkali activation mineral wool waste samples were milled with a ball mill for 3 hours. Milled mineral wool was added continuously to potassium silicate solution (SiO<sub>2</sub>/K<sub>2</sub>O molar modulus of 3.4 and water content of 55.3 wt.%) according to Table 2. The amount of mineral wool was adjusted so that suitable workability was achieved. Mixing was done with an IKA Eurostar 20N-mixer at 200 rpm with 8 minutes mixing time. Samples were cast into 2x2x8 cm<sup>3</sup> plywood molds and cured at 23°C until testing.

Compressive strengths of the samples were determined using a Zwick/Roell Z100 testing machine with loading rate of 1.2 kN/s.

Freeze-thaw durability test was conducted for 4x4x16 cm<sup>3</sup> samples that were cured for 28 days and half immersed in water. Environmental chamber was set to cycle between -15 and +15°C in 6 hour intervals. The duration of the test was 116 cycles in total.

Table 2. Mix designs of the alkali-activated mineral wool samples.

Sample name	SW_new (wt.%)	SW_old (wt.%)	GW_new (wt.%)	GW_old (wt.%)	Alkali activator (wt.%)
SW_new	66				34
SW_old		66			34
GW_new			46		54
GW_old				56	44
SW+GW	16.5	16.5	16.5	16.5	33

## 3. Results

### 3.1. Compressive strength measurements

All alkali-activated mineral wool samples achieved compressive strength between 25–45 MPa which is acceptable for many construction applications (Figure 2). Stone wool showed faster hardening compared to glass wool. The compressive strength of alkali-activated stone wool samples were 15–20 MPa already after 1 day curing and resulted in 44 MPa and 36 MPa for new and old stone wool, respectively, after 28 days. Glass wool samples were still soft after 3 day curing, but achieved 27–34 MPa compressive strength after 28 days. Compressive strength development of the mix of all mineral wools (SW+GW) was slower than that of stone wool samples, but faster than that of glass wool samples, thus both precursors affect the hardening process.

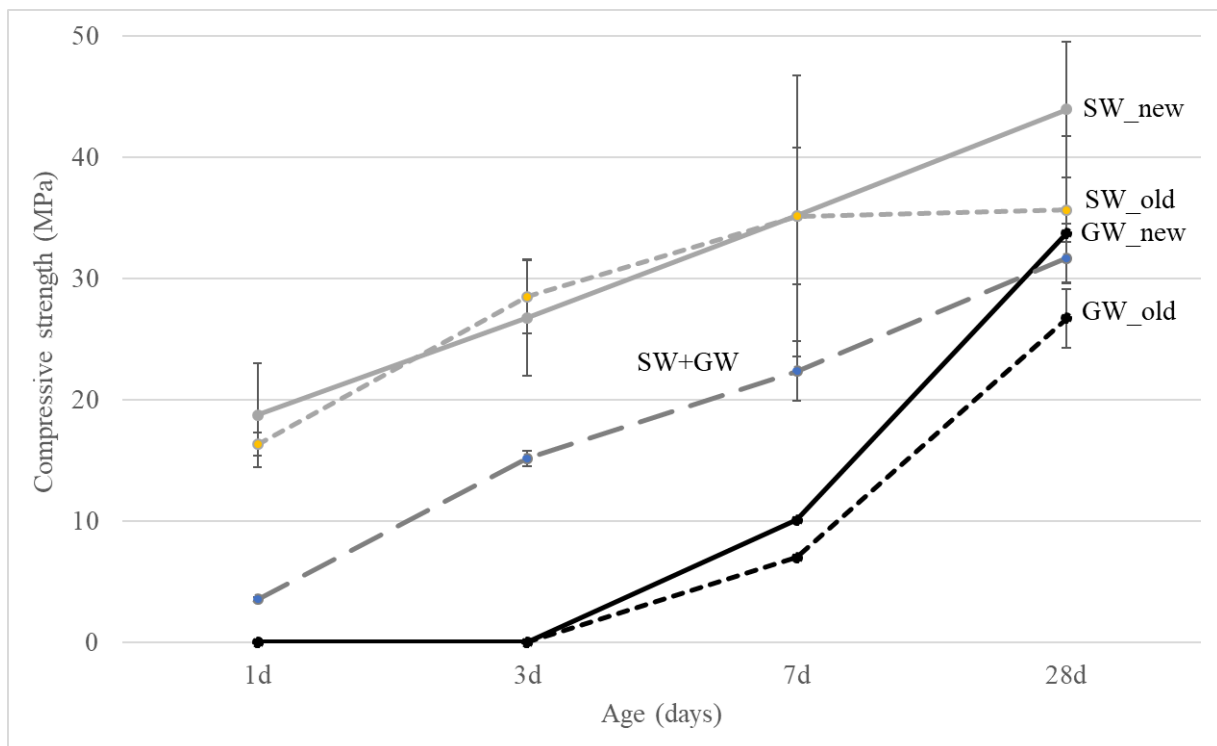


Figure 2. Compressive strengths of alkali-activated mineral wool samples.

### 3.2. Freeze-thaw-durability

The samples that contained stone wool showed excellent durability under the aggressive freeze-thaw test conditions (Figure 3). In contrast, the sample containing only glass wool (GW\_new) disintegrated during the test. This is possibly due to formation of water-soluble binder gel in alkali-activated glass wool, which is observed in the geopolymerization studies with everyday waste glasses that have similar chemistry as glass wool [6,7]. Binder gel lacking hydrolytic stability can disintegrate during the freeze-thaw test as the samples are half immersed under water. However, co-binder that provides additional Ca or Al to the binder system can create water-insoluble gels, thus improving the hydrolytic stability of the binder [6,8–10]. This is demonstrated by the sample containing both stone wool and glass wool (SW+GW) as this sample showed greatly improved durability compared to glass wool-only sample. Stone wool contains both Ca and Al (Table 1) which can take part in the binder gel formation. However, confirmation of this would require further investigation.

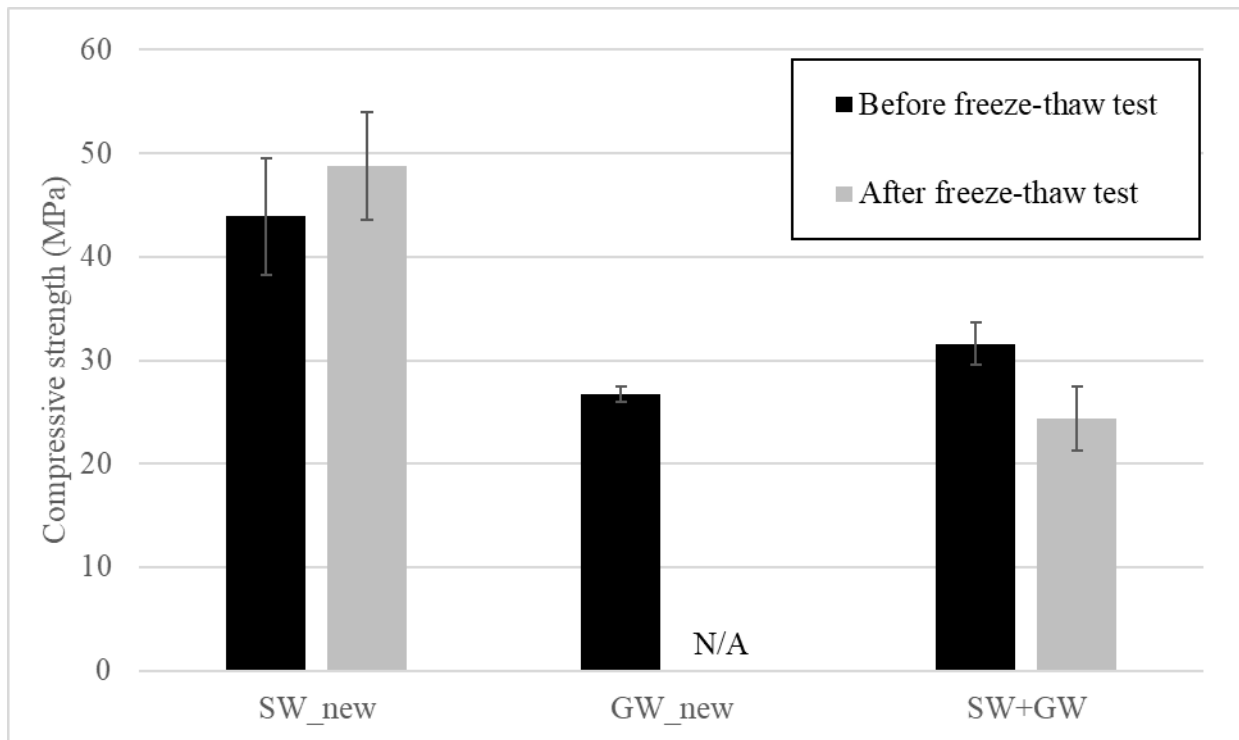


Figure 3. Compressive strengths of alkali-activated mineral wool samples before and after the freeze-thaw durability test.

#### 4. Summary

Alkali-activated materials, also known as geopolymers, can provide significant CO<sub>2</sub> emission reductions for the construction industry. The key point is to use local source raw materials in order to minimise the environmental burden of transportation of raw materials. One currently underutilised inorganic mineral side stream is mineral wool waste.

Based on the results presented, mineral wool waste is suitable as geopolymer precursor despite its age and small amount of impurities. Particularly, stone wool and mix of stone wool and glass wool showed good durability even under aggressive freeze-thaw conditions.

Further research should focus on dissolution mechanism of mineral wools under alkaline conditions, optimization of mix design with particular consideration on choosing alkali-activator, and optimization of mineral wool fibre length.

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