Brick-based geopolymer building materials - 100 % secondary raw material based and recyclable

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Concrete, a mixture of cement, aggregate and water, is the number one building material in the world today. It is a ubiquitous material that is used in almost all areas of the construction industry. The cement used as a binder is decisive for the strength of concrete. In 2019, global cement production amounted to 4.1 billion tonnes. [CEMBUREAU, 2020] The flip side - with 8 % of global anthropogenic CO_2 emissions, the cement industry is one of the largest single emitters of climate-relevant carbon dioxide. [WWF, 2019], [Ellis, 2020] Furthermore, the extraction of gravel and sand, which are used as aggregates in concretes and mortars, causes serious and sensitive interventions in local ecosystems. [Elsner, 2018], [Elsner, 2020]

In view of global warming and the growing awareness of climate and environmental protection, the building materials sector needs to develop new types of climate-friendly materials.

Geopolymer-based building materials represent an environmentally friendly and sustainable alternative to this. Geopolymer technology involves inorganic low-calcium polymers based on silicon and aluminium oxide, which have adequate properties compared to cement-based building materials. Their production is comparable to that of conventional mortars and concretes. They consist of an aluminosilicate binder, an aggregate and a hydrous alkaline activator.

Metakaolin is most commonly used as a primary binder in geopolymer products. However, in terms of sustainability, metakaolin-based geopolymer building materials have a reduced carbon footprint of up to 50% compared to cement-based building materials. If the binder is substituted by a secondary raw material, this leads to a further reduction of the global warming potential by up to 30 percentage points, resulting in a CO_2 footprint that is up to 80 % lower than that of conventional cements. [McLellan, 2011], [Abbas, 2020], [Luukkonen, 2018], [Habert, 2016]

The aim of the work was therefore to develop geopolymer building materials that consist of 100 % secondary raw materials and are recyclable at the same time. The use of secondary raw materials avoids expensive primary raw materials and minimises mining interventions in nature. This results in a positive CO_2 balance and an effective contribution to achieving climate protection goals. Furthermore, the use of residual materials that would otherwise have to be landfilled eliminates the costs of landfill. Instead, such residues are reintegrated into the value chain.

Brick-based residues represent a secondary raw material-based alternative. These secondary raw materials are available in the form of burnt brick residues, crushed bricks (sawing waste from construction sites) and as brick-rich masonry residues contaminated by plaster and mortar adhesions or other ceramics. In Germany, a total of about 10 million tonnes of this waste is produced annually. The proportion of fire-cracked material alone amounts to 220,000 tonnes per year. Current recycling routes for this material include environmentally friendly surface courses in field and forest road construction (4 %), brick sands as surfacing on tennis courts and sports facilities (28 %) or as substrate in vegetation construction (3 %). However, none of these applications corresponds to real recycling, because the residue is not returned to its original use with the same properties. Instead, they represent downcycling. [Rosen, 2017], [Rosen, 2020]

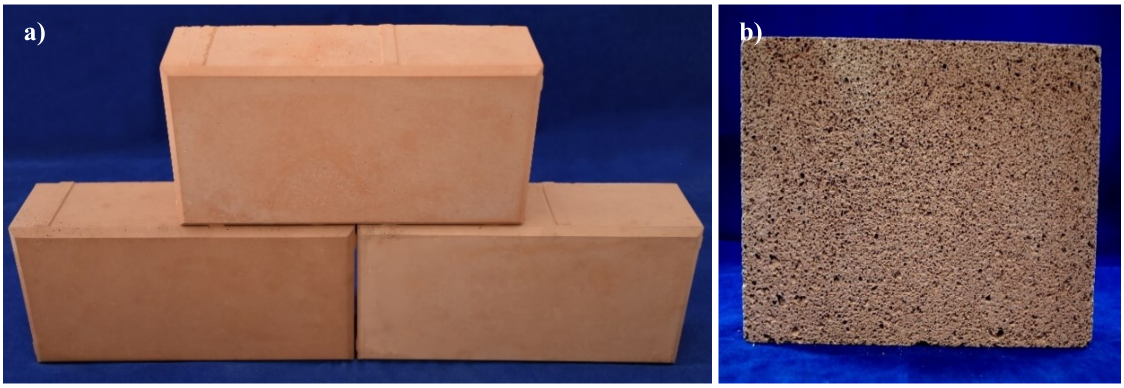
With the help of geopolymer technology, it has been possible to develop a brick that is 99.2 wt.-% based on secondary raw materials (figure 1). It should be emphasised that both the binder and the aggregate are based on brick residues. The alkaline activator was a sodium aluminate solution, which is a residual material in aircraft construction. This geopolymer-based brick with compressive strength values >20 MPa thus has adequate strength properties compared to classic bricks and it is fully recyclable after its life cycle. In this way, brick materials can be fed into a real recycling process as a secondary raw material after end-of-life, from which a brick can be turned back into a brick with comparable properties.

Furthermore, a brick-based lightweight geopolymer building material was developed, the properties of which are competitive with conventional flat blocks made of aerated concrete (figure 1). [Bertau, 2020] The special feature of this lightweight stone is that it is 100 % residue-based. All components, such as the binder, the alkaline activator and also the porosity agent, correspond to secondary raw materials. In terms of its properties, such as porosity, compressive strength, bulk density and thermal conductivity, this lightweight block is competitive with conventional blocks made of aerated concrete. A particular advantage is that this lightweight geopolymer building material consists entirely of residual materials, which were themselves originally produced in energy-intensive processes and are thus returned to an adequate application instead of being dumped in cost-intensive landfills. This results in the reintegration of secondary raw materials into the cycle of recyclable materials. The manufacturing process itself is also not based on any energy-intensive processes, and there is also no need for steam pressure curing, as is the case with conventional aerated concrete production. This results in a positive CO_2 balance for the production of the brick-based lightweight geopolymer block.

In addition, cost calculations showed that the manufacturing processes for the two brick-based geopolymer building materials are economically feasible and that they are competitive products compared to conventional building materials.

During the conference, we would like to present the detailed results of these investigations.

Figure 1. Geopolymer building materials based on brick residues: a) brick, b) lightweight block.



References

[Abbas, 2020] R. Abbas, M. A. Khereby, H. Y. Ghorab, N. Elkhoshkhany, *Clean Technol. Environ. Policy* **2020**, *22*, 669–687.

[Bertau, 2020] M. Bertau, P. Frohlich, M. Kraft, K. Dombrowski-Daube, J. Sachl, H. Lange, R. Huber, DE102020134133.4, **2020** (EP21212465.5, **2021**).

[CEMBUREAU, 2020] CEMBUREAU - The European Cement Association (Hrsg.), *Activity Report 2020,* https://cembureau.eu/media/m2ugw54y/cembureau-2020-activityreport.pdf, Brussel, **2020**.

[Ellis, 2020] L. D. Ellis, A. F. Badel, M. L. Chiang, R. J.-Y. Park, Y.-M. Chiang, *PNAS USA* **2020**, *117*, 12584–12591.

[Elsner, 2018] H. Elsner, Bundesanstalt für Geowissenschaften und Rohstoffe (Hrsg.), *Sand - auch in Deutschland bald knapp?,* https://www.bgr.bund.de/DE/Gemeinsames/Produkte/Downloads/Commodity_Top_News/Rohstoffwirtschaft/56_sand.pdf%3F__blob%3DpublicationFile%26v%3D5, Hannover, **2018**.

[Elsner, 2020] H. Elsner, M. Szurlies, Bundesanstalt für Geowissenschaften und Rohstoffe (Hrsg.), *Kies - Der wichtigste heimische Baurohstoff!,* https://www.bgr.bund.de/DE/Gemeinsames/Produkte/Downloads/Commodity_Top_News/Rohstoffwirtschaft/62_kies.pdf?__blob=publicationFile&v=5, Hannover, **2020**.

[Habert, 2016] G. Habert, C. Ouellet-Plamondon, *RILEM Tech. Lett.* **2016**, *1*, 17.

[Luukkonen, 2018] T. Luukkonen, Z. Abdollahnejad, J. Yliniemi, P. Kinnunen, M. Illikainen, *Cem. Concr. Res.* **2018**, *103*, 21–34.

[McLellan, 2011] B. C. McLellan, R. P. Williams, J. Lay, A. van Riessen, G. D. Corder, *J. Clean. Prod.* **2011**, *19*, 1080–1090.

[Rosen, 2017] D. Rosen, *EU-Recycling* **2017**, *09*, 17.

[Rosen, 2021] D. Rosen, *Mauerwerk* **2021**, *25*, 74–81.

[WWF, 2019] WWF Deutschland (Hrsg.), *Klimaschutz in der Beton- und Zementindustrie. Hintergrund und Handlungsoptionen,* https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/WWF_Klimaschutz_in_der_Beton-_und_Zementindustrie_WEB.pdf, Berlin, **2019**.