FIRE BOWLS MADE OF GEOPOLYMERE
at the NDU St. Pölten

In the winter semester, 2015 of the New Design University in St. Pölten students became acquainted with the new material class of geopolymers within the lecture "New Materials" and the practical exercise "Craft Centre".

Geopolymers are inorganic ceramic materials consisting of long chain aluminosilicates with incorporated balancing alkali metal cations. They can be easily produced at room temperature and they have a number of amazing features. Geopolymers are fire and acid resistant, they have very good mechanical properties and a shiny surface with an outstanding replication accuracy. For example, a basic recipe consists of special metakaolin (thermally treated china clay) and an alkali metal silicate solution (sodium or potassium water glass). Within 24 hours the mixture hardens to a rock-hard ceramic widely used as a binder, adhesive or coating.

According to the motto of the DU "Normal is dangerous," these materials, which are still unusual in Austria, were not only tested regarding their design capability, but they also had to undergo a trial by fire. Without the generous donation of metakaolin (M 1000) and cordierite fireclay (Artal 23) of ACAT /

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Imerys the tests could not be performed. We would like to take the opportunity to thank Mr. Gerhard Zima, who made this possible.
First, in an introductory lecture, the historical background, application examples and the chemical nomenclature, introduced in 1979 by the founder of the research of geopolymers, Prof. Joseph Davidovits, were explained. (Davidovits 2011), (http://www.geopolymer.org/). Then the students made 42 small test specimens. The basic recipe of metakaolin and special potassium water glass could be freely varied, and in the selection of aggregates creativity was given free reign. For example, pine needles, earth with grass, metal chips, vitamin C effervescent and salt were used. The results were really surprising (not expected hardening, millimeter thick efflorescence). After one week the test specimens were removed from the molds, stored at room temperature for 34 days and then soaked for four days.
26 samples passed the water test, eight samples were damaged and eight were destroyed. According to Davidovits the water test proves, whether it is indeed a geopolymer bond or it is only a water glass bond.
In October everyone was very busy at the Craft Studio – functional fire bowls would be designed and manufactured, which would be fired with firewood during an evening party in November. The team of students chose their starting materials from a range of six materials: High performance concrete (HPC), refectory concrete, ultra-high performance concrete (UHPC), roman cement, geopolymer based on meta-kaolin and geopolymer based on fly ash / slag sand. For the fiber reinforcement coated basalt short fibers (alkali-resistant)

14 bowls were made, three were made of metakaolin-based geopolymer, three of geopolymer based on fly ash / slag sand, three of HPC with sand, three of HPC with Artal 23, a UHPC and one was made of refractory concrete.

and glass fiber were used, for the surcharges predominantly cordierite fireclay (Artal 23) in two different particle sizes and ordinary quartz sand were used.
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The specification for the moulding was: With expandable membranes and intermediate thin layer of material, various molding strategies should be tried. Some mixtures were difficult to process (UHPC, refractory concrete) and some were completely unsuitable for this particular method (roman cement).

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The bowl before (left) and after firing (right) slightly damaged but structurally intact

But HPC and geopolymer could be easily adjusted to meet the rheological requirements of the foil method. The tests with geopolymer proved to be very useful for the addition of the liquid amount.
After one week the bowls were removed from the mold and stored at room temperature until the fire bowl party on 27 Novmber, 2015. The culture center "Lames" in St. Pölten with its gallery spaces and expansive outdoor areas was the perfect setting for the presentation of the project and the baptism of fire. Two cubic meters of firewood ensured sufficient fuel. The aim was to heat the fire bowls to the breaking point. The survival time of the bowls was between half an hour to several hours. Eight shells were completely destroyed, four were slightly damaged (hairline cracks, flaking); one really beautiful bowl, which was not fully fired, and one bowl "survived"despite several hours of firing without any damage.

This cup with a wall thickness of about 15mm was made of geopolymer based on metakaolin and green pigment suitable for concrete. The reinforcement were basalt fibers and the surcharge was cordierite fireclay (Artal 23).
Throughout the evening the bowl was used as a "hot dog stand" and it had only discolorations inside. There were no hair cracks and when knocking the sound was just like before firing. It is possible to fire it once again. The bowl made of geopolymer based on fly ash / slag sand survived the baptism of fire almost undamaged, just with one hairline crack. Two HPC bowls had small damages. Some bowls withstood the firing for a long time, but they broke into several parts when demounted.
The determination of the heat flux density the bowls were exposed can be obtained from literature. The specified combustion temperatures for the three main components of wood, cellulose, hemi-cellulose and lignin are 240-

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350 ° C, 200-260 ° C or 280-500 ° C (Spear Point 1999). The heat flux density of burning branches determined by Sullivan and others see diagram 1.
The steps in the curve resulting from the gradual combustion of twigs with different thickness, the thinnest ones burn first. The amount of energy (kWs / m²) consumed by the workpiece can be determined graphically (area under the curve). Alternatively, the heat current density can also be determined by the modified Stefan-Boltzmann law for non-black bodies (Lambertian reflectance)
$P = \varepsilon(T)\ \sigma\ A\ T4$,
By substituting the following values an average heat flux of P = 19,84 kW/m² is obtained: the Stefan-Boltzmann constant σ = 5.670 × 10-8, T constant 500 ° C (773 K) and a common emissivity for wood of ε=0,98. Then the area-based energy is
$Ef = 19{,}84 * t\ [kWh/m^2]$.
For 5 hours Ef = 19.84 * 5 = 99.20 kWh / m², which is significantly (estimated 2x) more than obtained by the more-realistic curve by Sullivan. But you can gain a qualitative estimation of the magnitude of the not inconsiderable energy exposed to a fire bowl.
Which factors were decisive for the fire resistance? Clearly positive was the use of fireclay instead of quartz sand, although the volume-increasing conversion of α-quartz into β-quartz only takes place at 500-575 ° C. It seems that the lower (factor 10) expansion coefficient of the fire clay is decisive.
The amount of basalt fibers used had a positive effect also - the more, the better. In contrast, the glass fiber grid could not prevent the concrete chipping above the grid. From about

300 °C up, the evaporated crystal water of the CSH phase of the concrete systems caused explosive spalling. This was the case with one of the four damaged bowls. About 25 minutes after starting combustion there was a spalling with a loud bang directly under the seat of fire. A favorable shape of the bowl can compensate for this, as it turned out that despite intensive firing a round step pyramid shape was only slightly damaged (1 hairline crack).
As the chemistry of geopolymer compounds works without bonded water, this risk factor is eliminated in geopolymers. An additional positive impact on the strength of the geopolymer

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are longer mixing times of the metakaolin and alkali-silicate solution. The geopolymeric solidification reaction takes place in two stages: first there is a resolution of metakaolin and then a polycondensation or a geopolymerisation. The efficiency of the reaction can be increased by the supply of mixing energy during solution phase.

In summary, up to about 500 ° C simple geopolymer mixtures can also be used for fire-resistant applications, if certain conditions are observed (suitable fiber reinforcement, mixing, fireclay). High performance concrete with microsilica is equal to it, if it is sufficiently reinforced with fibers and if fireclay instead of sand is used.

The setting of the workshop was not made on the basis of academic criteria to allow an informal experimentation and to get to know the new material. Nevertheless, the experiences gained are very important for all participants, for the future handling of geopolymers and for the arising of curiosity regarding this promising material.

Geopolymer plate broken at the hole edge (left) when removed; no damage: "hot dog stand" (right)