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Published in:
Proceedings of Nordes 2023: This Space Intentionally Left Blank

DOI:
10.21606/nordes.2023.51

Published: 12/06/2023

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Kaarakainen, J., Falin, P., Huaman, L., Mäkelä, M., & Lautenbacher, N. (2023). The possibilities of geopolymers for greener studio ceramics. In V. Rodrigues, C. Westin, & S. Holmlid (Eds.), *Proceedings of Nordes 2023: This Space Intentionally Left Blank* (Vol. 10, pp. 53-64). (Nordic design research conference; Vol. 10). Design Research Society. https://doi.org/10.21606/nordes.2023.51

Nordes Conference Series

Jun 12th, 9:00 AM - Jun 14th, 5:00 PM

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Kaarakainen, J., Falin, P., Huaman, L., Mäkelä, M.,and Lautenbacher, N.(2023) The possibilities of geopolymers for greener studio ceramics, in Holmlid, S., Rodrigues, V., Westin, C., Krogh, P. G., Mäkelä, M., Svanaes, D., Wikberg-Nilsson, Å (eds.), *Nordes 2023: This Space Intentionally Left Blank*, 12-14 June, Linköping University, Norrköping, Sweden. https://doi.org/10.21606/nordes.2023.51

2023 NORDES

THE POSSIBILITIES OF GEOPOLYMERS FOR GREENER STUDIO CERAMICS

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ABSTRACT

This paper introduces initial findings from interdisciplinary project-based research concentrating on investigating the potential of using geopolymers in ceramic practices within the context of a university workshop. Geopolymers are examined from the point of view of reducing energy consumption currently needed for studio ceramics and exploring how geopolymers could be used as part of ceramic production and education. The initial findings show that the ceramic workshop and the basic raw materials used for ceramics are applicable when making geopolymers. A material hardened through geopolymerisation can be produced with lower energy consumption compared to traditional processes in ceramics. However, the qualities and the nature of geopolymers are not equal to ceramics, which can limit the usage of geopolymers within the context of ceramics, but also create promising possibilities for further research. This study opens the discussion on using geopolymers within creative practices.

INTRODUCTION

Ceramics are commonly perceived as a natural and rather sustainable choice as a material for everyday objects such as tableware and utensils because of its qualities. Ceramics, as a high-fired material, is durable and can endure time and erosion so long that ceramics shards found can help to tell the stories of lost cultures from our history. Looking forward in time, contemporary-produced objects will be telling our story when discovered hundreds or thousands of years from now. However, the future looks different; instead of cherishing a found shard of porcelain, the surviving ceramics will be part of waste mountains left behind as a result of overconsumption and reckless usage of resources.

To create a better future, all usages of materials and resources are challenged; further practices and processes need closer evaluation. In this research, we focus on creative practices in the context of ceramic workshops to discover what can we do as creative practitioners and educators to create a more sustainable future when working in the university environment.

https://doi.org/10.21606/nordes.2023.51

University workshops are used here as a platform not only for research on materials and related processes but also for educators to consider how to facilitate transitions towards more sustainable ways of making. Currently, this aspect of education is recognised as a general topic of interest (Groth & Fredriksen, 2022). This project-based research is conducted among students and other educators, and thus concurrently having an impact within the studio environment when the material investigation is openly carried out.

Regarding contributions to the green transition, a recent survey shows that the most critical aspects in creative fields are energy consumption, transportation, waste disposal and recycling (Tuovinen & Nuora, 2022). In addition, the creative fields are seen to have the power to support green transitions. For example, design can have a valuable role in offering sustainable solutions and models for other fields (Lebedeff & Grekov, 2022). However, the creative fields and related education are also part of the global transition, where alternative sustainable solutions must be found to lower emissions caused by material usage and production processes.

In this, we focus on the ceramic studio setting within Aalto University in Espoo, Finland, and examine the potential for using geopolymers instead of traditional ceramics to lower the energy consumption in creative practice and evaluate the potential of geopolymers as an alternative material in the field of ceramics. This paper discusses the initial results and also envisions the future directions and possibilities that the project will continue exploring.

GEOPOLYMERS

This research is based on geopolymers originally developed by Joseph Davidovits (2020). Geopolymers are inorganic polymers consisting of chains of mineral molecules linked with covalent bonds; they take advantage of chemically reactive materials in alkaline or acidic medium to form new compounds for various applications (Davidovits, 2020, 4).

Although Davidovits is considered the inventor and developer of geopolymers, there are examples in our history showing that similar materials, which could be called geopolymers, were used already thousands of years ago. For example, Romans used a form of concrete that outlasts contemporary concrete. Roman concrete is a mixture of volcanic ash and quicklime. Seawater contact seems to make it even stronger than at the time of mixing (Guarino, 2017). An alternative type of concrete was also developed in Ukraine in the 1950s due to a shortage of raw materials. This resulted in a type of geopolymer that was used to construct buildings (Partanen, 2022). Davidovits et al. (2019) also point out discoveries suggesting that ancient megalithic structures in Bolivia could have been made of a type of geopolymer made of volcanic tuff 1400 years ago (see Figure 1).

Figure 1: Megalithic structures at the archaeological site of Tiahuanaco, Bolivia, geopolymer made of volcanic tuff 1400 years ago. Photo: Ralph Davidovits, 2018

In our study, the type of geopolymer investigated is made of a mixture of silicates and alumino-silicates in alkaline medium, forming a resinous binder into which a wide range of inorganic and organic materials can be added as fillers (see Figure 8).

These nanomaterials were first developed by Professor Joseph Davidovits in the early 1970s and in 1975 creating the first liquid binder based on metakaolin and soluble alkali silicate at CORDI laboratory for insulating purposes. The addition of sodium silicate brought improvements to the mixture in terms of hardening speed, which allowed additional applications in high-tech ceramics and cement (Davidovits, 2020, 8). Later on, Lone Star Industries Inc. developed a new cementitious product by adding ground blast furnace slag, which brought improvements in setting time and compressive strength (Davidovits, 2020, 10). In 1987, heavy metal encapsulation of uranium mine tailings was successfully tested using a geopolymeric cement in Germany (Hermann et al., 1999).

From 1990 onwards, major emphasis was dedicated to low CO_2 cements based on geopolymers, given the growing need to develop environmentally friendly technologies. Concerning the potential of geopolymers to reduce CO_2 emissions, a thorough carbon footprint study compared the difference between Portland and geopolymer based cements, showing that the latter produces at least 9% less greenhouse gas emissions than conventional cements (Turner & Collins, 2013). This figure on a global scale makes this new technology a suitable candidate for carbon dioxide reduction, not to mention the diverse applications in which geopolymers can be used.

Besides the above mentioned, we can list some novel applications: wastewater treatment (Grba et al., 2023), dye adsorbents (Tochetto et al., 2022), additive manufacturing (Raza & Zhong, 2022), 3D printing (Zhong & Zhang, 2022), carbon capture and storage (Freire et al., 2022), energy conversion (Sánchez Díaz & Escobar Barrios, 2022), antibacterial cements (Rubio-

Avalos, 2018), etc. The current trend and future vision of the geopolymer field is to promote innovative and eco-friendly materials. To achieve this, the approach is to take byproducts and residues from other industries as secondary raw materials to elaborate new products, in other words, a "Circular Economy" perspective.

Some residues, such as blast furnace slag, coal fly ash or mine tailings, can be used as binders or fillers, so their use in their respective value chains can be extended, and their disposal can be reduced. To take geopolymer-based concrete as an example, a recent study showed that this new material contributes to 12 of the 17 sustainable development goals (SDGs) established by the United Nations (Shehata et al., 2022). However, in order to promote the use of geopolymers in the industry, it is necessary to address some technical and economic issues that will guide the direction of geopolymer research. Some of these challenges were listed in an article published by Zhao et al. (2021): development of cheaper or novel reagents, improvements in workability, regulation of hardening rate, in-depth analysis of the reaction mechanism, long-term properties, etc.

In summary, this new nanomaterial has demonstrated good potential to be used in various industries as an eco-friendlier technology than many currently used. However, in this research, we have considered geopolymers in the context of studio ceramics and thus widened the potential of geopolymers as a greener choice also in the context of creative practices.

This research opens the common points of contact between scientific research and the creative fields through the topic of geopolymers and highlights matters that require further investigation.

MATERIAL EXPLORATION

In our project, the aims of hands-on material research are three-fold. Firstly, as creative practitioners, it is crucial for us to gain a better understanding of geopolymers and their properties on a concrete, practical level so that evaluation on the further usability of the materials in the context of studio ceramics can be made. Secondly, we are looking into potential ways of utilising existing materials and facilities in a studio setting for producing geopolymers and coming up with new materials. Lastly, we aim to find means of using the knowledge gained to further the transition towards greener practices creating a more sustainable future.

Our approach to these matters follows the practices of material research in the field of ceramics. The methodology is largely based on the making of test samples, similar to the testing and developing clay bodies (Levy et al., 2022, 63-77), observing the properties and changes in tested materials during different stages of the overall process, and examining the results from the perspective of a designer applying the findings into real-life usage.

In this paper, six different geopolymer test samples are introduced. They all contain a similar binder, based on the reaction of sodium silicate and metakaolin (MK750). Metakaolin as used in our study is produced by calcining kaolin at 750 degrees Celsius for 3 hours, which is described as the standard set by the Geopolymer Institute (Davidovits, 2020, 159). Calcining refers to the process of thermally treating inorganic material to remove volatile components, and to improve the processing characteristics in various operations (Rand, 1991); simplified, in our study it is used to increase reactivity (Badogiannis, 2005). Research into alternative materials to replace energy-intensive ingredients such as metakaolin is part of our research; however, it is outside the scope of this paper. Instead, the focus here is on testing various filler materials and their properties, so the binder remains the same. The following materials were tested as fillers: chamotte, two variations of local Finnish iron-rich clay, volcanic rock, Finnish potassium feldspar, and porcelain waste (see Figure 2). A breakdown of the chemical components in each filler material is listed in Table 1.

Figure 2: Selected geopolymer test cubes. Clockwise from the back: calcined Finnish clay, raw Finnish clay, chamotte, volcanic rock, feldspar, and porcelain waste. Photo: Johannes Kaarakainen, 2022.

Information on chemical compositions is provided to allow for comparison between the used materials, and for evaluating practical findings from the standpoint of chemistry. It is worth noting, that the oxide analyses for some of the materials, namely raw Finnish clay and porcelain waste, are only indicative, since they represent entire categories of materials which, depending on location and availability, would have variations in their contents. Values for raw Finnish clay are for the average chemical composition of Finnish clay (Volhard & Westermarck, 1994, 27). Values for porcelain waste are derived from a classic recipe of typical porcelain (Jylhä-Vuorio, 2020, 23). Information on volcanic rock, feldspar and chamotte is gathered from the respective product datasheets. Values on the calcined Finnish clay from Somero, Finland, are based on its chemical analysis (Hortling, 1992).

Table 1: The percentages of the chemical components of filler materials. 1: raw Finnish clay, 2: calcined Finnish clay, 3: volcanic rock, 4: potassium feldspar, 5: chamotte, 6: porcelain waste.

Compound	1	2	3	4	5	6
SiO_2	58.6	50	43.7	68.3	74.0	72.1
Al_2O_3	16.0	17.1	13.9	18.0	20.5	21.5
Fe_2O3	5.42	9.0	11.1	0.01	1.0	0.40
MnO	0.11	n/a	0.19	n/a	n/a	n/a
MgO	2.81	3.3	9.31	0.02	0.40	0.10
CaO	2.17	1.5	11.7	0.09	0.20	0.10
Na_2O	2.65	2.0	2.92	5.05	0.20	0.10
K_2O	3.27	4.2	3.33	6.02	2.50	5.20
TiO_2	0.69	n/a	2.74	0.05	1.20	0.40
Organic	0.87	n/a	n/a	n/a	n/a	n/a
Others	7.28	12.9	0.98	2.40	n/a	n/a

The procedure of making the geopolymer mixes has been consistent. It follows the pattern of first mixing the binder in a planetary mixer for 10 minutes. After which, the filler material is added and mixed for another 10 minutes. Then, the slurry is cast into a cube-shaped 5 x 5 x 5 cm silicone mould, vibrated to help the material degas and spread evenly, and covered in an airtight container. Finally, the covered test pieces are placed in a kiln for either 4,5 or 24 hours at a temperature of 80°C. The curing times follow Davidovits' findings on the relativity of compressive strength and curing time, and the phases in which the material has reached its highest achieved level of strenght (Davidovits, 2020, 178).

For the initial tests, a cube-shaped mould was chosen mainly for practical reasons: casting numerous samples of geopolymer mixtures with viscosities varying from liquid consistency to very stiff paste required an easy-to-cast shape for the repetitive process to be done efficiently. In addition, the reasoning was that a non-complex shape would allow for a better comparison of material properties instead of drawing attention to the design of the sample piece. Simple shape with smooth surfaces also makes it easy to observe changes that sometimes occur during and after curing, such as appearing of cracks and deformations. More complex shapes were planned to be tested at later stages in the project after having done an initial selection of promising geopolymer recipes.

Silicon as a mould material was ideal for various reasons. It is airtight and prevents the unwanted evaporation of moisture, it is flexible and allows for effortless unmoulding of the hardened piece, and it is easy to clean from the geopolymer residues that stick tightly to many materials.

In the following, all the tested materials are discussed individually. First, the material is introduced, and its origin is disclosed. Then, practical findings from during the making of the sample are briefly examined. Finally, an initial evaluation on the usability of the materials for geopolymers is provided.

CHAMOTTE

Chamotte, also known as grog or firesand, is calcined clay that contains high amounts of alumina and silica. In ceramics production, it is used for reducing shrinkage and cracking, and to give texture and structural strength for clay bodies. For the geopolymer sample, chamotte of grain size 0-0.5 mm was used, and it is manufactured by Sibelco with the product name FSN.

Figure 3: Sample with chamotte as filler. Photo: Johannes Kaarakainen, 2022.

In use, chamotte performs well as a filler. Depending on the amount used, it can result in either a rather liquid or moderately stiff mix. Based on material testing, the range of particle sizes from fine dust to small grains seems optimal in terms of both usability and the end result. At 0–0.5mm grain size, the filler is coarse enough to provide structural stability but reproduces fine details and smooth surfaces well (see Figure 3). A white or light grey chamotte can also be colored with pigments and metal oxides, for example.

The chemical composition of chamotte bears a close resemblance to porcelain. In our research, chamotte was the first filler material to be tested and its performance gave some indications on how materials such as finely ground high-fired porcelain waste, which was later tested as well, could be made of use as geopolymer filler materials.

While chamotte seems to be a well-suited for geopolymers as a filler, its use does not particularly advance the movement towards greener practices in ceramics production. Chamotte is a material that needs considerable amounts of energy to manufacture.
The chamotte used for our tests has been calcined at

1200 °C, but depending on the product, calcination temperatures can reach up to 1600 ºC degrees. As the proportion of filler in a geopolymer mix is high, waste materials of similar chemical composition, such as high-fired porcelain, would be preferable to using chamotte in geopolymer applications. That said, from the perspective of availability and usability in a studio context, chamotte is a viable option.

RAW FINNISH CLAY

In Finland, ceramics production built around locally sourced materials has relied on low-fired earthenware products such as bricks. This is because the vast majority of natural clays found in Finland represent a type of red clay that typically is of Nordic glacier origin (Jylhä-Vuorio, 2020, 38). It is high in iron content and fires into a reddish-brown colour. It is widely available, especially in coastal areas of Southern and Western Finland (Hyyppä, 1980, 4).

A great impact on the CO2 footprint could be achieved by using waste clays and crushed rock produced in local construction sites and other nearby industrial wastes. For example, in Finland, the amount of waste clays is growing, and landfill areas are rare, especially in metropolitan areas (Härmä et al., 2010, 34). Large masses of clay are constantly relocated from construction sites, and natural clay becomes waste that has to be relocated to the dumpsites on the outskirts of urban areas. While the natural clays may be too impure for industrial needs, for geopolymers, these aspects of natural clay are not a problem. On the contrary, the constant flow of unwanted material away from construction sites and the difficulty of finding places for disposal would mean an easy way to acquire raw material (see Figure 4). In addition, since geopolymers are not fired, the relatively limited heat resistance in comparison to high-fired clay materials is also not an issue.

Figure 4: Deposits of natural clay can be found from an open construction sites. Material used for the raw clay sample was extracted from this site at Otaniemi, Espoo, Finland.
Photo: Priska Falin, 2022.

In the project, the usability of these types of waste clays was tested with a local material. The material used for making the sample with raw clay was acquired from a natural clay deposit at a construction site on the premises of Aalto University. Prior to use, the clay was prepared by sieving and milling (see Figure 5).

Figure 5: Sample with raw Finnish clay as a filler.
Photo: Johannes Kaarakainen, 2022.

At the time of mixing, the material turned out to be very challenging to handle. When the dried, finely milled clay powder was introduced to the binder in a planetary mixer, it quickly absorbed the liquid and formed into small, dusty clumps and grains that were difficult mix. After a small addition of water and manual effort to break down the largest chunks, the material eventually formed into a stiff, sticky paste that was very difficult to cast in a mold due to its high viscosity.

This behaviour can be explained by the flat, hexagonal shape of clay particles, which results in the malleability of plastic clays (Jylhä-Vuorio, 2020, 33). Small amounts of water considerably increase friction between the particles, making the mix stiff. Substantial amounts of water would be needed to lubricate the contact surfaces of these particles sufficiently for the ideal viscosity for casting. However, this is not a solution, as excess water decreases the compressive strength of geopolymer material (Davidovits, 2020, 464). While the material has yet to be properly tested on its mechanical strength, it resembles some of our earlier test samples which did not harden properly. It has a relatively brittle feel and a matte surface texture.

Our initial hypothesis was, that these qualities might be explained at least partly by the considerable iron content of the clay. It has been suggested by Essaidi et al. (2014) that presence of iron can affect the compressive strength of the material adversely. However, Davidovits implies that the role of iron is a controversial matter, and it is unclear how it really functions in geopolymers (Davidovits, 2020). The more successful results with calcined Finnish clay, and another promising sample with over twice the iron content (see Table 1), volcanic rock, do not seem to be in line with the original hypothesis. That said, these are initial tests, and further research should be done to validate the results.

In addition to the presumed inferiorities with mechanical strength, the inconvenience in the difficulty of mixing is also noteworthy. It gives some early indication that raw plastic clay might not be an optimal material with metakaolin-based geopolymer binders, especially for methods such as casting.

CALCINED FINNISH CLAY

After the attempt at using raw milled clay as a geopolymer filler, with unsatisfactory results, another test was made with calcined Finnish clay (see Figure 6) of relatively similar chemical composition. The clay used in the sample is from Somero, Finland.

Figure 6: Sample with calcined Finnish clay as a filler.
Photo: Johannes Kaarakainen, 2022.

The assumption was that since after calcination, clay particles are no longer in their original shape and organic matter is no longer present, calcined clay might not have the same properties in terms of plasticity, which had made handling raw Finnish clay difficult. Additionally, it was presumed that calcining might make the material more reactive, as is the case with metakaolin. The result with local calcined clay indeed proved to be somewhat better in comparison to raw clay, and it was slightly easier to handle. However, it is probable that calcining to a higher temperature would make a more significant difference.

The properties of geopolymers making use of calcined iron-rich clay are yet to be further researched but based on material testing we can already see that they show some potential. On an industrial scale, waste material from brick factories might be usable for geopolymer applications, and on a smaller studio scale, it is possible that ground earthenware could be used in a similar manner.

VOLCANIC ROCK

The volcanic rock powder used in the test piece was a sort of wild card within the range of tested filler materials. It is neither a material that can be locally sourced from Finland, nor an industrial by-product or waste. In the research project, volcanic rock was chosen as one representative of non-Finnish natural materials that are abundant in their location of origin, and which in terms of availability, might be a good candidate as geopolymer fillers. This particular material is a commercial product, ready-made volcanic rock powder named Lavamehl 134 from Carl Jäger Tonindustriebedarf GmbH, intended for use in ceramic glazes, for example. Due to the colour of the material, we were also curious to see how it would work aesthetically in geopolymer applications.

In use, volcanic rock performed in a similar manner to feldspar, the results of which we will discuss next. When combined with the binder, it formed a thick and viscous paste, which, unlike raw clay, could be considerably thinned with a small addition of water.

The result with volcanic rock is relatively good. The color is greyish purple with a slightly grainy texture (see Figure 7). The surface is shiny and smooth, and the overall feel is very solid.

Figure 7: Sample with volcanic rock as filler.
Photo: Johannes Kaarakainen, 2022.

While the properties observed during making of the sample piece showed some signs of further potential, the mechanical strength and chemical resistance of a geopolymer material with volcanic rock as filler is yet to be tested. Researching the usability of volcanic rock as a geopolymer material in locations where it is naturally available in large amounts could be valuable.

FINNISH POTASSIUM FELDSPAR

Potassium feldspar, along with other feldspars, is a common mineral in many parts of the world, and widely used in ceramics production. In most ceramic studios, feldspar is one of the most essential stock materials for making glazes, thus readily available. The feldspar used for our tests is a product named FFF K6-60 from Sibelco and mined in Finland.

In the geopolymer mix, feldspar performed well. A slight addition of water was necessary to adjust the viscosity to a more suitable level for casting and to help the feldspar mix with the binder properly. The fine particle size resulted in a particularly smooth surface on the hardened sample. The pastel pink or orange hue of potassium feldspar was preserved well (see Figure 8). This is a good example of how in geopolymers the original colours of filler materials can be taken advantage of. In ceramics production, feldspar is usually fired up to a temperature where it melts and the colour becomes translucent white or pale yellow.

Figure 8: From left: metakaolin, potassium feldspar and sodium silicate. The cube on the right is a finished sample made with potassium feldspar as the filler component. Photo: Johannes Kaarakainen, 2022.

The availability of feldspar around the world is comparatively good, and its properties match those required of geopolymer fillers. An important characteristic of a good filler is reactivity, which allows the creation of chemical bonds with the binder and results in a higher strength (Davidovits, 2020, 499). Therefore, feldspar can be considered a potential candidate for a filler to be used in real-world applications of geopolymers.

PORCELAIN WASTE

In ceramics production, raw clay is an infinitely recyclable material. Plastic clay is wet and soft, and it becomes hard through drying. Dry clay can be restored to its malleable form by wetting it. This cycle is repeatable, and it makes clay a very efficient material when it comes to making use of leftovers and recycling failed pieces.

However, once clay is fired, its mineral structure changes and it can no longer return to its original state. Broken, hard shards of fired ceramics are usually considered waste material and discarded. This has traditionally been an unsolved problem in ceramics production. Some industrial applications exist, such as recycling porcelain waste resulting from tile production back into making new tiles (Ke et al. 2016) and manufacturing eco-friendly cement mortar from porcelain aggregate (Nasr et al. 2020). Even so, aside from producing chamotte from fired refractory clays, ways of recycling ceramic waste within a studio context seem to be scarce.

With geopolymers, this material could be restored to use and made into a valuable resource. As described in the case of raw Finnish clay sample, raw clay has plastic properties that make its use difficult in geopolymers, especially with methods such as casting. When clay is sintered, it becomes more suitable for use as a filler material. Sintering is a phenomenon that occurs during firing, in which particles begin to bond tighter to each other, forming a stronger matrix. As a result, the material becomes denser and stronger (Hansen, n.d.). Importantly, sintered clay also no longer breaks down when exposed to water. Since this procedure is energy-intensive, it is not ideal for the sole purpose of creating a geopolymer filler. However, as ceramics industry produces high-fired waste as part of its normal production, a source for suitable ceramic material already exists. For testing recycled porcelain, we used crushed plates manufactured by Iittala (See figure 9).

Figure 9: Geopolymerised porcelain waste and larger fragments of the same crushed ceramic material. Photo: Johannes Kaarakainen, 2022.

Powdered porcelain waste mixes into the binder solution relatively well and achieving a consistency suitable for casting causes no problems. Overall, porcelain waste performs in a predictable, controlled manner, very similar to chamotte. Based on the initial tests, it shows potential for further experimenting and research.

Recycling waste porcelain by using it as a geopolymer filler is a feasible proposition. That said, preparing the ceramic material into a suitable form, grinding it down into a fine powder, can prove challenging in a studio context. While small amounts of ceramic material can be manually smashed into small grains and ground further with a mortar and pestle, milling machinery of some type, such as a ball mill, is needed for reaching smaller, more uniform particle sizes, and for processing larger amounts.

FITTING OF GEOPOLYMERS IN CERAMIC STUDIO

There are some properties in geopolymers which largely define how they can be used. One of the most notable characteristics is the ability of geopolymers to absorb and release high quantities of water (Okada et al. 2009). This is very different from high-fired ceramics, which are typically used for applications where water absorption needs to be minimised or eliminated. Therefore, with geopolymers, it might be difficult to replace ceramics in applications where waterproof and easy-to-clean surfaces are needed. On the other hand, in ceramics production, materials such as plaster are used particularly for their ability to absorb water, for example, in mould-making. Looking into similar existing processes could lead to novel applications for geopolymers.

When considering the use of geopolymers within a ceramics studio context, one key difference between geopolymers and ceramics involves with the drying of the material. In conventional ceramic practice, a carefully controlled drying process is a necessary step between shaping the plastic clay and making the changes permanent through firing in high temperatures. Clay has to be dry prior to firing, as rapidly evaporating water and uneven shrinkage during excessively rapid drying during heating are likely to cause cracks or even explosions in the material.

Conversely, avoiding water evaporation from a non-hardened geopolymer mixture is of critical importance. Successful polymerisation of metakaolin-based geopolymer material requires the presence of free water. It is the medium that carries sodium and/or potassium cations in the silico-aluminate network until they become permanently attached (Davidovits, 2020). In practice, this means that the geopolymer material must be sealed with a film or hydrophobic spray or kept in an airtight container throughout the curing stage, during which the actual polymerisation takes place. Only after this can the piece be dried, which also halts the chemical process that is happening inside the material. This sets some challenges for curing geopolymer material. While the curing temperature is relatively low at around 60–80°C, it still poses some difficulties with some otherwise ideal airtight materials such as plastics, which can become soft and leak.

When considering traditional ceramic practice, where a practitioner engages directly with the material using hands-on techniques, the main quality is the plasticity of the clay when moist (Sutherland, 2005). The plasticity, as an elemental quality of clay during handling, creates a major difference when comparing geopolymers as part of ceramics and creative practices. The utilisation of many traditional techniques in ceramic crafts, such as hand-building or wheel-throwing, are not suitable for shaping current geopolymers. This is due to the aforementioned need to prevent evaporation of water, poor plasticity and thixotropic properties of the material. Thixotropy is a property of becoming less viscous when subjected to stress such as vibration or stirring. In practice this means that even a seemingly solid piece can as a result of handling lose its viscosity to a point where it collapses. Geopolymers, depending on what raw ingredients are used, behave closer to cement during the production phase than clay. This aspect alone indicates that geopolymers are not to be considered a replacement for the use of traditional clays but as a greener option to use when practicable.

In comparison to working by hand in direct contact with clay, there are also work safety related aspects that make clay and geopolymers very different. In the case of metakaolin and alkali silicate based geopolymers, the most substantial hazards are related to the usage of corrosive highly alkaline ingredients and inhalation of dust and fine particles. Prevention of the latter is already a prerequisite for all hands-on work within the ceramics industry, whereas the safe usage of alkaline materials might require some additional familiarisation as well as concrete changes in the working environment.

Davidovits has been a long-term advocate for user-friendly systems, and selecting alkaline conditions that could be classified as “irritant” as opposed to “corrosive”, is one of his solutions for minimizing risks related to handling corrosive materials (Davidovits, 2020). However, for ceramists who engage directly with the material, even the classification of geopolymers as “irritant” can be limiting in terms of techniques used and potential applications.

In ceramics, the usage of glazes plays a major role in defining how a final object looks and feels, and what physical properties it has. The common temperatures for glazes range between 1000 to 1300 degrees Celsius, much higher than the temperatures needed for polymerisation. Due to this, the usage of traditional glazes on geopolymers makes little sense from the standpoint of developing more sustainable materials. Instead, researching alternative methods for coating geopolymers would be preferable, and more importantly still, developing ways for adjusting the geopolymer material itself so that additional coatings would not even be needed.

One way of affecting the aesthetic qualities as well as mechanical properties of geopolymers is the choice of filler material. Geopolymers allow for a wide range of filler materials and additives to be used, which opens up possibilities that fired clay does not allow. As earth-based materials go through heat treatment at high temperatures, they often change their colour. This is not always desirable. One example of this are the natural kaolin clays, which can have shades of different colours (see Figure 10). The colours mostly disappear, change or fade when fired. Yet, in geopolymers, raw materials retain most of their original colour.

Figure 10: Raw Finnish kaolin samples in various colours. Photo: Johannes Kaarakainen, 2022.

Looking beyond the physical properties of materials, there are ways in which geopolymers could change making processes in studios. The usage of geopolymers as opposed to ceramics can decrease the timeframe within which items can be finished. The hardening process of a geopolymer object can be complete within 20 hours from casting, when cured at 80°C (Davidovits, 2020, 178). For a ceramic piece, the timeframe is usually several days, as clay must first slowly dry, and only after this can it be fired.

ENERGY CONSUMPTION IN THE CERAMIC STUDIO

As a durable material, ceramics can be perceived as a 'green' choice compared to other materials, such as plastic. However, ceramics production requires a considerable amount of energy when the clay is fired and hardened into ceramics at high temperatures. This energy consumption can be considered a void in the perception of ceramics and thus challenges the idea of ceramics as a 'greener' choice of material. These kinds of voids in our perception of materials and their production processes need closer evaluation.

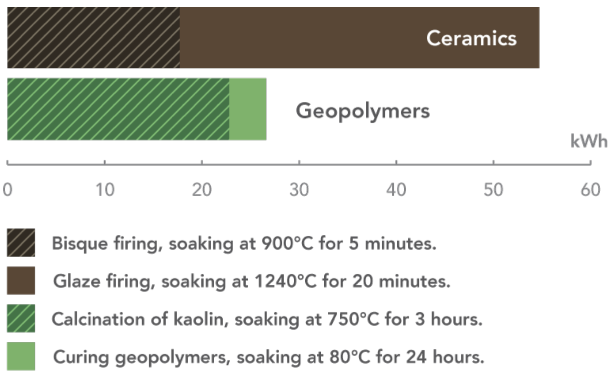
When simplified, ceramics are hardened clay. Traditionally clay is transformed into ceramics when it is fired. Commonly in ceramics, when producing objects out of high fired clays, there are two steps when making a ceramic object; first, a bisque firing and then the final glaze firing that can reach over 1300 °C. In bisque firing, the temperature is commonly around 900 °C degrees. Bisque firing hardens clay into ceramics but leaves the clay body still porous, which makes the bisque-fired object easier to handle and glaze. The finishing glaze firing depends on the clay material used, but a typical temperature is around 1240 °C degrees for semi-porcelain clay bodies that are commonly used within the University workshop. In this particular ceramic studio, where this research has been executed, firings are done almost daily with eleven kilns that vary in size, energy use (gas or electric) and power (see Figure 11).

Figure 11: Kiln room in the university ceramics workshop. Photo: Johannes Kaarakainen, 2022.

The process which makes geopolymers solidify is based on an entirely different type of chemical reaction, which is not dependent on heating in high temperatures. Compared to traditional firings for ceramics, the heat treatment of metakaolin-based geopolymers requires a temperature between 60-80 degrees Celsius, usually maintained for around 24 hours.

Table 2 shows that the traditional firings used for making ceramics are considerably higher than those needed for making geopolymers, even when using calcinated (to put it simply, heat-treated at a high temperature) material such as metakaolin. It is noteworthy that in reality, the energy consumption of geopolymers is even lower, as calcined kaolin only makes up approximately 20–30% of the entire item, whereas ceramic items have to be fired as a whole.

Table 2: Comparison of energy consumption between traditional firings and geopolymer processing within a studio context. The reference kiln used for measurement has a connected load of 9 kW and volume of 110 litres.



In the data shown in Table 2, only the energy consumption taking place within the studio context is taken into account. Energy-intensive manufacturing processes of raw ingredients, such as sodium silicate or chamotte, are not considered. However, the total energy consumption values in producing ceramics and geopolymers, from raw materials to a finished product, are not directly comparable, as the utilization of recycled waste materials is one of the goals of geopolymer research. From the perspective of an individual workshop, on the other hand, the energy consumption resulting from internal processes is relevant and can be accurately measured.

The heat needed for polymerisation is relatively low (60–80 degrees Celsius), which opens up the possibility of thinking creatively on how existing environment could be of use. For example, the excess heat escaping from the glass furnace in the university glass workshop could be harnessed for making geopolymers. These kinds of ideas emerge when openly working and discussing the project among students and staff in the university studio environment.

CONCLUSIONS

Geopolymers have untapped potential in the field of ceramics as well creative practices in general. During our research, we have been looking at geopolymers not only as materials, but as something to be incorporated into existing processes and systems in the context of studio ceramics production, with the goal of creating greener practices.

We have found that as a study environment, a ceramics workshop with equipment, machinery and materials commonly used for ceramics production is well-suited for geopolymer research. Many of the materials needed, such as kaolin clays for the binder and various mineral-based options to be used as fillers, are readily available in many ceramic studios. Mixers and mills used for making clay bodies and glazes are also suitable for making geopolymers, too. Kilns can be used for processing raw materials, such as calcinating kaolin to make metakaolin, and for heating geopolymer pieces at precise temperatures for the purpose of hardening and drying the material.

In some respects, geopolymers offer potential benefits over ceramics. Our initial findings indicate that the energy consumption associated with using geopolymers in a studio context is considerably lower than in ceramics production. In addition to the environmentally beneficial aspects of geopolymers over ceramics, there are very practical process-related advantages as well. Works made of geopolymers are free of the restrictions set by the kiln space, which has traditionally limited the sizes and usage of ceramic works. This aspect of geopolymers could enable the production of works on a scale that would not be possible with ceramics kilns. In addition, the overall hardening time of geopolymers can be significantly shorter over the entire process of drying and firing ceramics.

The possibility of using a wide range of fillers as part of the geopolymer mix opens new ways of recycling waste materials and getting creative with material development. In a ceramics workshop, recycling of porcelain waste is one potential area of interest. Geopolymers allow advantage to be taken of the original colours of the ingredients used since the hardening process does not involve firing. This can be beneficial when choosing the used filler material, for example.

There are also significant downsides to using geopolymers as a replacement for ceramics. The behaviour of geopolymers when working by hand produces a very different haptic sensation compared to clay, as the material tends to collapse easily and is not plastic enough for properly shaping by hand. Instead, geopolymers appear to be better used with methods such as casting or 3D printing. For artists, craftsmen and designers, this sense of distance from the material and difficulty of working in direct contact with it can be a considerable limitation. Another limiting aspect in terms of direct contact with the material is the irritating or corrosive quality of the alkali silicate, which is one of the main ingredients in metakaolin-based geopolymers. The need for additional attention to work safety-related issues can be a concern.

In terms of real-world applications, the highly water-absorbing character of the material can be a restrictive aspect, and research into non-absorbent geopolymers could open up new possibilities. Nonetheless, geopolymers could also find novel applications in ceramic practice precisely for this defining quality.

Based on our research, geopolymers should not be considered a replacement for ceramic materials altogether but instead an additional option for particular uses. Ceramic studios can benefit from the usage of geopolymers in the form of a new inlet for waste materials, such as crushed high-fired ceramics, and as an alternative for uses where the distinct qualities of geopolymer materials offer benefits over ceramics.

DISCUSSION

A ceramist works at an interesting intersection of practices and disciplines. On the one hand, the role is that of a designer or an artist, which encompasses the aspects of craftsmanship, self-expression, and the practical application of theoretical knowledge. On the other hand, material chemistry is an intrinsic part of ceramics. In geopolymer research, this double role of a ceramist can be of use when bridging between the understanding of material research and design for making real-world applications. This overlap between the knowledge areas of a ceramist can be very helpful in making functional and meaningful communication possible when collaborating with other professionals, such as chemists, geologists and engineers.

The ongoing research with geopolymers and ceramics materials provides an interesting platform for testing different aspects of combining old and new materials. Prototyping, testing, and pushing boldly the boundaries of these new materials through artistic practice will provide valuable information together with the scientific research of the material´s mechanical and chemical properties. Geopolymers can offer a less energy-consuming testing phase in studio practice. In the future, geopolymers could open up new possibilities in three-dimensional prototyping and the making of mock-ups, and even, in some parts, provide an alternative to ceramics. The next direction is to test different ways of shaping, moulding, and using additive technologies for building with these new materials. The aim of the next phase of the research is discover out the most appropriate and efficient ways to manufacture different shapes with geopolymers.

Finding a way to practice ceramics design and art without needing to fire the clay has always been an exciting, but idealistic, even utopian, idea. With the use of geopolymers, the vision of unfired ceramic material no longer seems that far-fetched an idea at all.

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ACKNOWLEDGEMENTS

For the invaluable support in the material research and development, we want to also recognize the contribution of the University workshop master Tomi Pelkonen. His wide and deep knowledge in ceramics is not only in value for students and staff working in the ceramics studio, but also when examining, developing and testing within projects such as Radical Ceramics.