The application of geopolymer concrete in the first mobile 3D-printer for buildings construction

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Renca RUS, LLC (Joint Italian and Russian company)
Géobéton, LLC (Russia)

OUR TEAM:

We have met in 2015 in Saint-Quentin thanks to GP Camp by Geopolymer Institute.

In the beginning of 2016 joint Italian-Russian society Renca RUS, LLC was founded, which is located in Chelyabinsk, Russia

Alex Reggiani - geologist and minerologist, CTO
designer of geopolymer concrete recipes for 3D printing and "data-centre" of our team

Andrey Dudnikov - researcher and engineer, CEO
lab organising, trial tests and production of geopolymer cement

Marina Dudnikova - general administration and CFO
connecting everything together and makes it work, also makes economical calculations and marketing

Chelyabinsk region: everything you need for geopolymers

Ural region in Russia is the most reach source of raw materials of natural origin and by-products of metallurgical and power plants

Chelyabinsk region:

Chelyabinsk Region is among Russia's oldest mining regions and has enormous, highly unique and long- lasting mineral reserves.

The region currently has about 300 explored and assessed deposits and fields, the most important of which are iron and copper- zinc ore deposits, gold fields, deposits of fireproof raw materials, talcum, graphite, kaolin, calcite, lime and quartz.

There are about 150 upstream and downstream mining enterprises in the region.

Raw materials and by-products of Chelyabinsk region, suitable for GP production:

GGBS
ground granulated blastfurnace slag

Metakaolin
kaolin burned at 750℃

Fly-ash
type F

Microsilica
silica fume

Soluble silicates
Na- and K- based water glass

GGBS

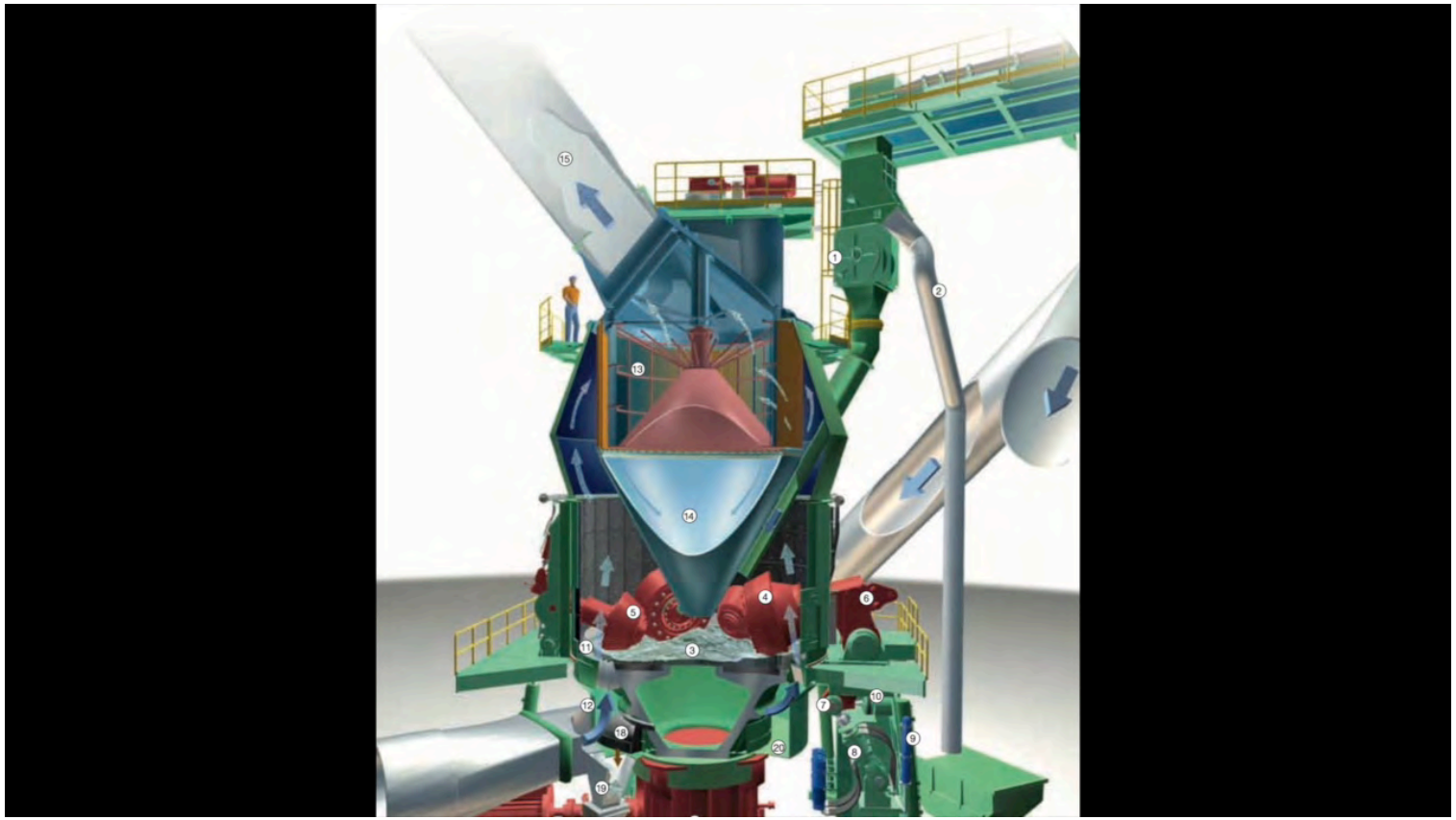
ground granulated blastfurnace slag

Two major producers of iron in Russia are located in Chelyabinsk region.

They are Mechel and MMK with a total amount of granulated blastfurnace slag accumulated per year about 3 million tons.

In 2013 Mechel has installed a milling site equipped with two vertical roller mills designed for grinding granulated blastfurnace slag.

They are the first and only for now in Russia who produce GGBS with high fineness more than 4000 Blain.



Vertical roller mill for GGBS

We have carried out a research project for the company Mechel-Materials to elaborate industrial standards and grinding regimes for GBS in vertical roller mills. The aim was to receive a product suitable for the substitution of up to 80% of OPC in concrete production as well as for use in geopolymer cement and concrete.

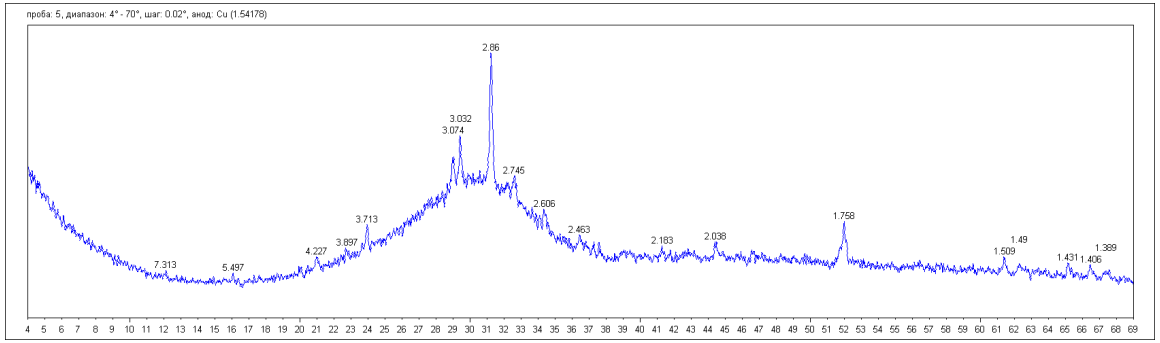
GGBS

ground granulated blastfurnace slag

Two major producers of iron in Russia are located in Chelyabinsk region.

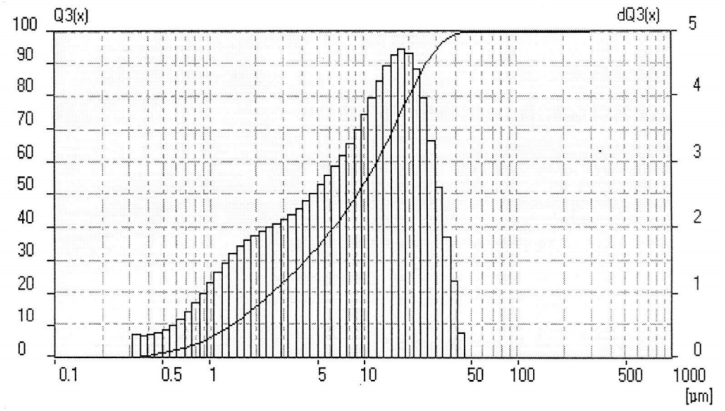
Mineralogical composition:

The mineralogical composition of GGBS is represented by amorph phase (97-98%), the crystalline phase is represented mainly by melilite (2.0-3.0%).



Particle distribution, μm:

Median diameter d_{50} less than 11 μm



Properties:

- biege powder
- H2O content - less 0,1%
- Specific area (BET) - 4500-5000 cm^3/g
- Bulk density - 1,14 t/m^3

Chemical composition:

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	MgO	MnO	K_2O	Na_2O	CaO	L.O.I.
12,27 %	38,16 %	0,67 %	1,63 %	10,34 %	0,67 %	0,76 %	0,44 %	34,92 %	<0,10%

Metakaolin

kaolin
burned
at 750℃

Zhuravliniy Log is the biggest producer of kaolin and metakaolin in Russia. They are only producer in Russia of suitable for geopolymers high quality metakaolin by baking the raw materials at the temperature of 750℃

The company produces three brands of metakaolin with whiteness being their distinguishing feature: colour coordinate L* CIELAB (lightness) according to (ISO 787/1) (C/2°) for MKZL -1 — 97–94,5%, for MKZL -2 — 95–93%. MKZL -3 metakaolin has a distinct cream tone colour.

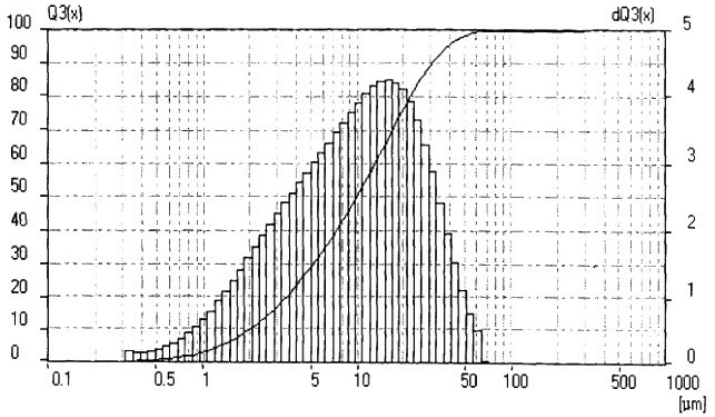
Mineralogical composition:

The mineralogical composition of metakaolin is represented by fully amorphized kaolinite (90-93%), the crystalline phase is represented by muscovite (2.5-3.0%) and quartz (4-5%), crystalline growths (mullite, cristobalite) are almost absent.

The degree of amorphization of kaolin indicator value is determined by the absence of the maximum reflection of kaolinite and mullite in the diffraction patterns.

Particle distribution, μm:

Median diameter d_{50} less than 10 μm



Properties:

- Specific surface area is not less than 16500 cm^3/g
- Bulk density 0,25–0,3 t/m^3.
- Pozzolanic activity is not less than 1400 mg $Ca(OH)_2/g$

Chemical composition:

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	K_2O	Na_2O	CaO	Losses at calcination
42–43%	53–54%	0,4–0,8%	0,3–0,5%	0,8–1,1%	0,05 %	0,15 %	up to 1,5%

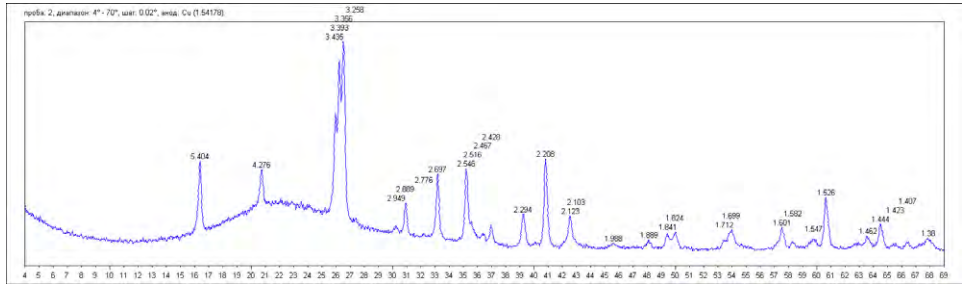
Fly-ash
type F

Power plant Reftinskaya property of Italian company ENEL in the neighbouring region of Ekaterinburg, is a major producer of coal waste in Russia, it produces 5,5 million tons of fly-ash per year.

Another power plant producing fly ash type F is situated in the south of Chelyabinsk region and produces 2,3 million tons of fly-ash per year.

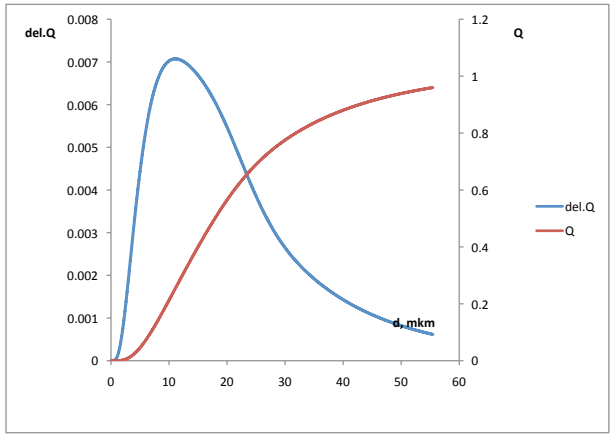
Mineralogical composition:

The mineralogical composition of fly-ash is represented by amorph phase (63-65%), the crystalline phase is represented by mullite (31%), graphite (3%), hematite (1%) and quartz (2%).



Particle distribution, μm:

Median diameter d_{50} less than 21 μm



Chemical composition:

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	MgO	MnO	K_2O	Na_2O	CaO	L.O.I.
28,27 %	59,00 %	5,22 %	1,15 %	0,68 %	0,12 %	0,60 %	0,62 %	1,75 %	2,14 %

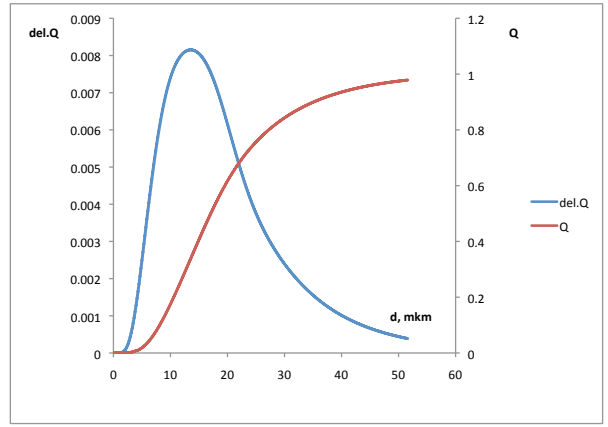
Microsilica black colour

silica fume dense

Chelyabinsk electro metallurgical plant produces black microsilica that is now widely used by concrete producers and suitable for geopolymers.

Particle distribution, μm:

Median diameter d_{50} less than 19,78 μm

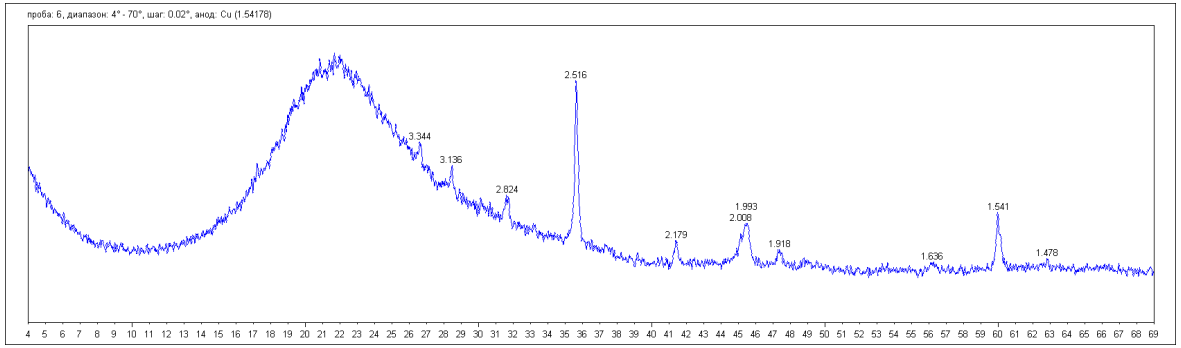


Mineralogical composition:

The mineralogical composition of microsilica is represented by fully amorphized silica (96%), the crystalline phase is represented by moissanite (3%) and magnetite (1%).

Properties:

- Dark black colour
- Bulk density 0,4–0,7 t/m^3.



Chemical composition:

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	MgO	MnO	K_2O	Na_2O	CaO	L.O.I.
0,94 %	87,98 %	2,79 %	0,05 %	1,25 %	0,45 %	1,4 %	0,78 %	0,59 %	2,62 %

Microsilica light grey colour

silica fume

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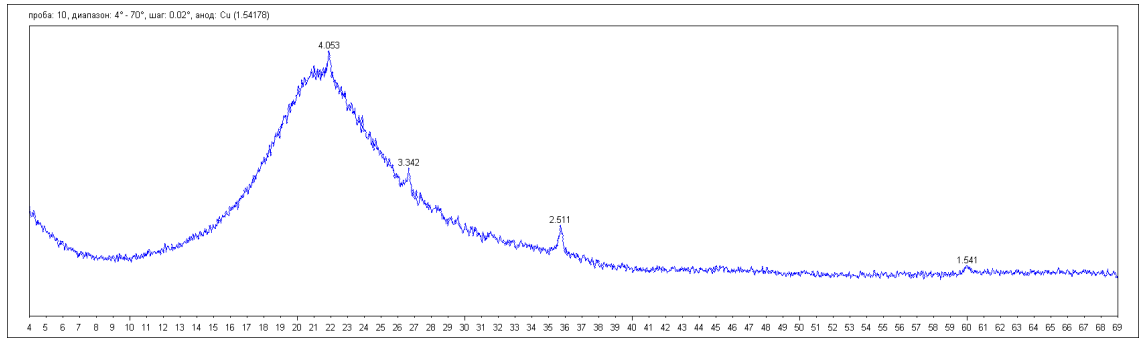
Grey microsilica is a by-product from pure silica production plant

Properties:

- Light grey colour
- Bulk density 0,4–0,7 t/m^3.

Mineralogical composition:

The mineralogical composition of microsilica is represented by fully amorphized silica (99%), the crystalline phase is represented by quartz (less 1%) and SiC (less 1%)



Chemical composition:

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	MgO	MnO	K_2O	Na_2O	CaO	L.O.I.
0,05 %	95,33 %	0,22 %	0,05 %	0,18 %	0,03 %	0,33 %	0,12 %	0,44 %	2,52 %

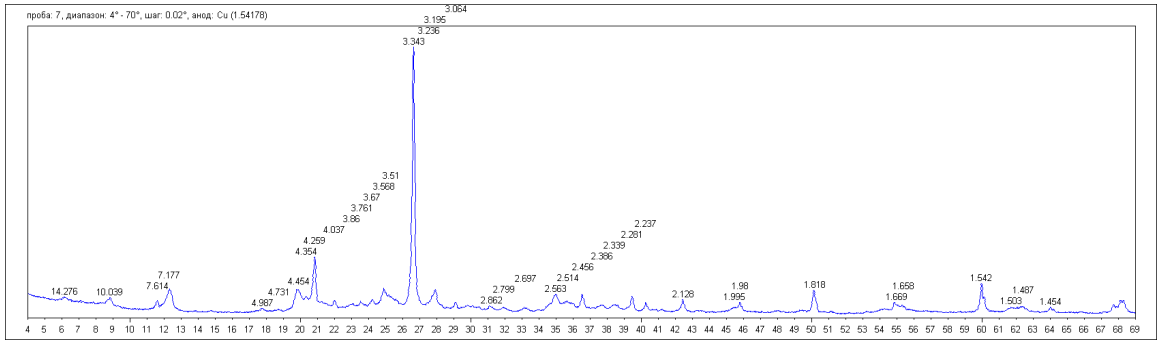
Coal mining wastes

naturally burned clay

Chelyabinsk region has the oldest and biggest open coal quarry in Euroasia. As a result of coal mining large amounts of burnt rock were accumulated near the shafts. Chemical and mineralogical composition of this formations is of interest for utilization in geopolymer production.

Mineralogical composition:

The mineralogical composition of coal mining wastes is represented by fully amorph phase (28-35%), the crystalline phase is represented by quartz (24%), kaolin (18%), plagioclase (5%), chlorite (5%), hematite (2%) and muscovite (18-19%).



Chemical composition:

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	MgO	MnO	K_2O	Na_2O	CaO	L.O.I.
19,42 %	52,21 %	7,12 %	1,06 %	1,95 %	0,08 %	1,73 %	1,12 %	2,03 %	1,18 %

Coal quarry

Being the biggest and the oldest coal quarry in Eurasia it has a with of 3,5 and length of 4 km and depth of more than 500 meters. One has to travel 150 km of roads to reach the bottom. It has a waste deposit that stretches for 5 km along one of its banks.

Coal mining wastes

Deposits of burnt rock are spread around the south of the region and pose a tricky task of recultivation for the local government. At the same time they can be an interesting source of raw materials for geopolymers.

Soluble silicates
water glass

Two major producers of soluble silicates are situated in Chelyabinsk region. They supply raw materials to producers of water glass all over Russia.

Based on their raw materials, on our site, located in Chelyabinsk, we organised a production process of hardener or reagent for geopolymer cement and concrete - **geosilicate™**

Properties:

- Density at 20℃: approx. 1,398 g/cm^3 (might be adjusted on request)
- Solubility: soluble in water
- Base: potassium silicate (or sodium silicate on request)
- Dry content: 38…40% (depending on application)

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Meteorite strike in 2013 in Chelyabinsk region. Thus, some more materials are arriving to our region giving even more unknown “mineral” resources to our land from space.

Background in Russia:

Background of alternative cementitious materials in Soviet Union

Background in Russia

Due to the rich mineral base Glukhovskiy's school was widely spread in the second half of the 20th century in Chelyabinsk region. Numerous specialists were occupied with research of alkali activated cements and concretes.

Major draw back of concretes elaborated in Soviet times was implementation of alkali slag activation. As a result - unstable properties, efflorescence as well as technological difficulties and high hazard (due to highly alkali materials, mostly NaOH, for slag activation).

This fact together with high cost of grinding of granulated slag caused by low grindability of material and high energy consumption, stopped the spreading of technology and it was gradually lost.

Moreover, as geopolymers were not known in the country yet, it was impossible to implement successfully such ready-to-use raw materials that do not require grinding and processing as fly-ash from the local power plants.

Process of road construction with alkali-activated concrete, length 6 km, to the quarry of mountain Magnitnaya. Magnitogorsk, Russia, Ural, 1984, inspection visit in 1999.

Standardisation issue:

In Soviet Union more than 65 documents, including national standards, were written to enable implementation of alkali-based cements in various industries. These standards allowed the use of geopolymer cements also (cements without portlandcement) in road construction, civil and industrial construction.

With the collapse of Soviet Union most of these documents were lost.

Today we have prepared a list of corporate standards enabling the use of geopolymer cements in road construction, pre-cast concrete production and civil and industrial construction at the constructors risk.

Moreover, in collaboration with the National Association of Developers we work on national standards allowing the use of geopolymer cements in civil and industrial construction.

Unfortunately we don’t have LEED certification (carbon credits) yet and this is the main reason of delay in popularity of geopolymer cement.

Background in Italy:

Roman cement and heritage in Italy:

First geopolymer traces are from Etruscan low temperature colored ceramics .

Then 2000 and more years old with Romans , that probably have known bases of technology from egyptians, grew up Roman cement use in important architectural structures like Pantheon in Rome (for example) and this technology was generally named “opus siginum” or “carbunculus” and uses natural pozzolana from Naples and Pozzuoli (from Vesuvio Volcan and Campi Flegrei lavas and tuffs).

After Romans this technology was lost during the centuries and now has been re discovered in last years.

Apis Cor first mobile 3D printer:

the first company to invent a mobile 3D printer capable of printing buildings from the inside

APIS COR NEEDS:

01.

Adjustable setting time system to permit fastest 3D printing of buildings.

02.

Siberia has a very harsh climate (permafrost) so find and use an alternative, to Portland cement binder is mandatory to work both below to 0°C and more than 30°C.

03.

Good flexural and compressive strength to be structural and to be used also in earthquake areas.

04.

Fireproof and waterproof materials, to avoid other protective superficial systems.

05.

Good compressive strength in short period of time to allow print a houses as fast as possible.

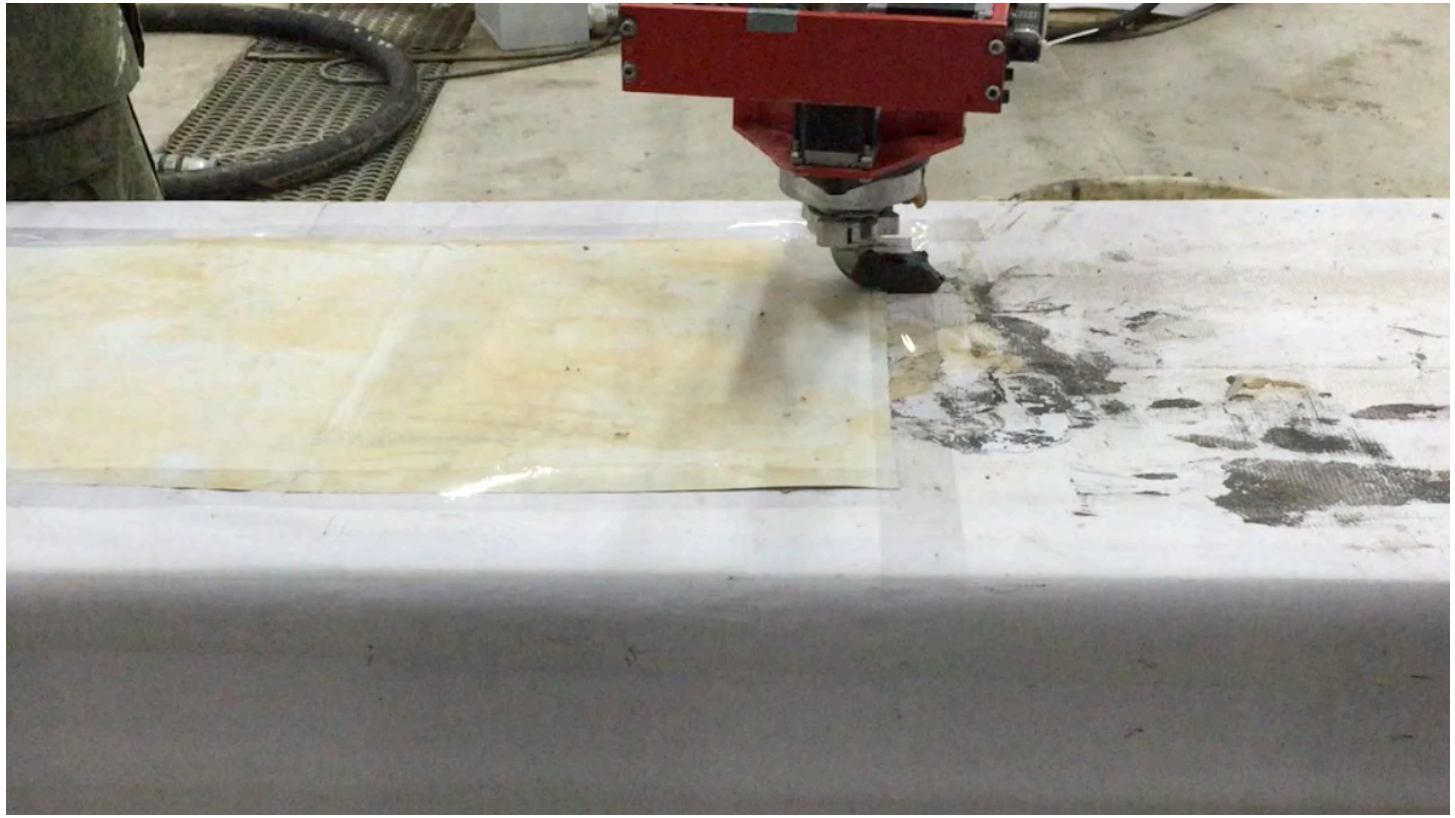
GEOPOLYMER CONCRETE MIX DESIGN:

According to needs of Apis Cor there were designed three mixes and three types of geopolymer concretes:

Black super performance GP

Beige MK-750 based GP

Grey Fly-Ash based GP



Black super performance GP concrete:

Fly-ash and GGBS based geopolymer with addition of microsilica and other components to achieve ultra performance properties. With **geosilicate™** reagent as liquid hardener part and several types of quartz sand concrete grade.

Beige MK-750 based GP concrete:

Metakaolin (Zuravliny Log, 750℃ calcined) based geopolymer with addition of GGBS. With **geosilicate™** reagent as liquid hardener part and several types of quartz sand concrete grade.

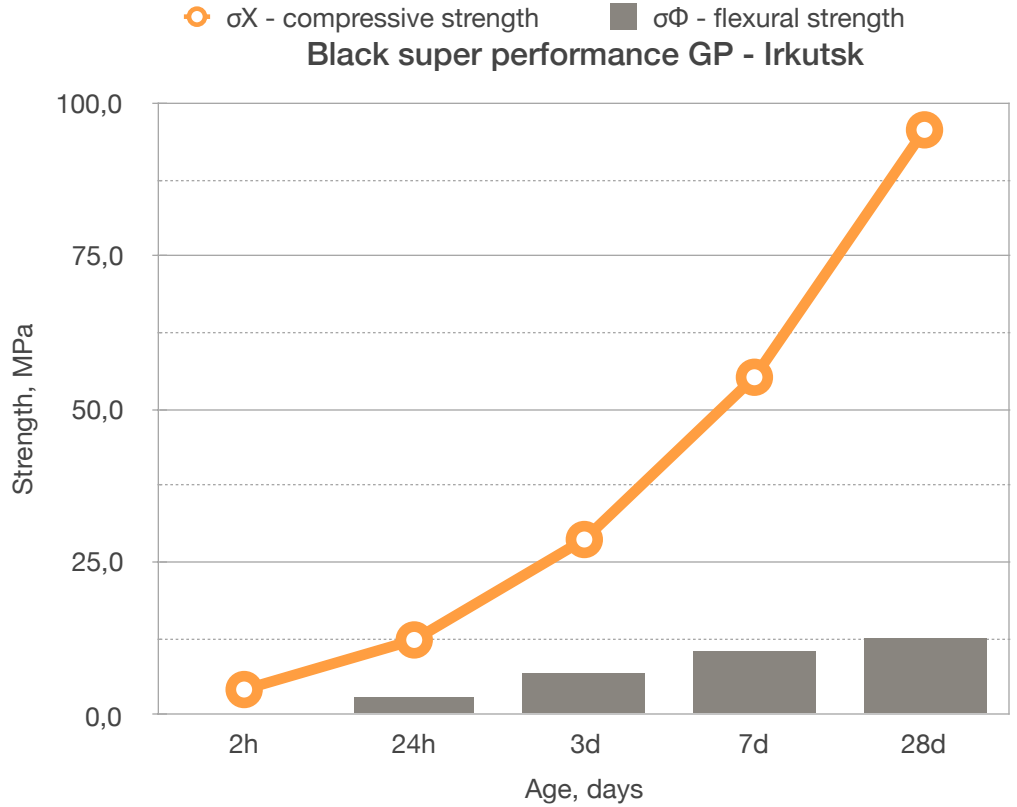
Grey Fly-Ash based GP concrete:

Fly-ash and GGBS based cheap geopolymer. With **geosilicate™** reagent as liquid hardener part and several types of quartz sand concrete grade.

PROPERTIES OF BLACK SUPER PERFORMANCE GP CONCRETE:

Properties:

- Setting time: from 45 to 60 min. (at 18℃ in Irkutsk warehouse)
- Viscosity - thixotropic (shock table test)
- Density 2,2 g/cm^3.
- Ability to harden at -20℃ (after defrost for 2 hours in 20℃): 24h flexural strength: 2,3 MPa; compressive strength: 6,2 MPa
- Freeze-thaw resistance: 500 cycles
- Water resistance: W18



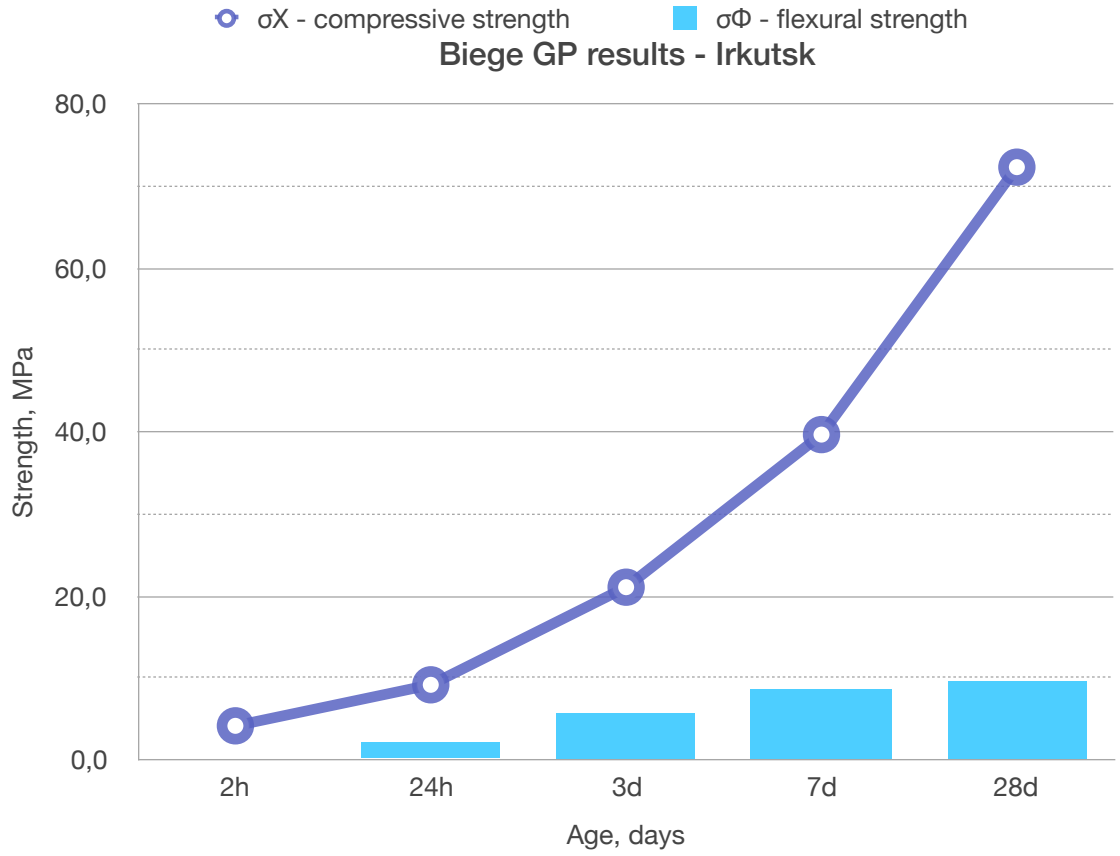
Test Results of strength black SP GP - Irkutsk

Age	σX, MPa	σΦ, MPa
2h	4,2	0,0
24h	12,3	3,1
3d	28,7	7,0
7d	55,2	10,3
28d	95,6	12,6

PROPERTIES OF BEIGE MK-750 BASED GP CONCRETE:

Properties:

- Setting time: from 90 to 115 min. (at 18℃ in Irkutsk warehouse)
- Viscosity - thixotropic (shock table test)
- Density 2,0 g/cm^3.
- Ability to harden at -20℃ (after defrost for 2 hours in 20℃):
  24h flexural strength: 1,0 MPa;
  compressive strength: 5,2 MPa
- Freeze-thaw resistance: 500 cycles
- Water resistance: W16



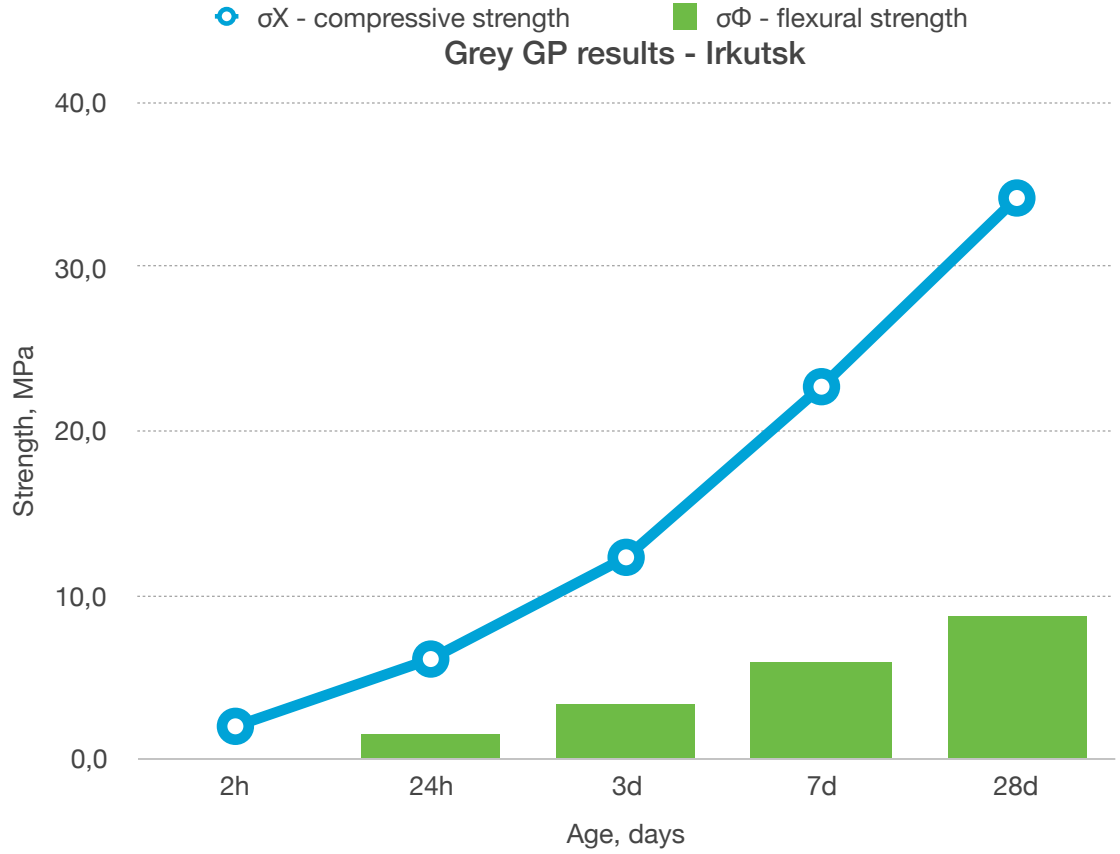
Biege GP - Irkutsk

Age	σX, MPa	σΦ, MPa
2h	4,2	0,0
24h	9,2	2,1
3d	21,1	5,8
7d	39,7	8,8
28d	72,3	9,6

PROPERTIES OF GREY FLY-ASH BASED GP CONCRETE:

Properties:

- Setting time: from 60 to 120 min. (at 18℃ in Irkutsk warehouse)
- Viscosity - thixotropic (shock table test)
- Density 2,3 g/cm^3.
- Ability to harden at -20℃ (after defrost for 2 hours in 20℃):
  24h flexural strength: 0,5 MPa;
  compressive strength: 3,1 MPa
- Freeze-thaw resistance: 400 cycles
- Water resistance: W12



Grey GP - Irkutsk

Age	σX, MPa	σΦ, MPa
2h	2,0	0,0
24h	6,1	1,5
3d	12,3	3,4
7d	22,7	5,9
28d	34,2	8,7

MIXING PROCESS:

Mobile mixing plant for geopolymer concrete:

RENCA RUS is developing an innovative mobile plant to create geopolymer concrete directly on site and permit production without stops. Mobile plant solves all problems about geopolymer transportation, related to quick reactions that occur in geopolymers chemistry, especially in high temperatures conditions.

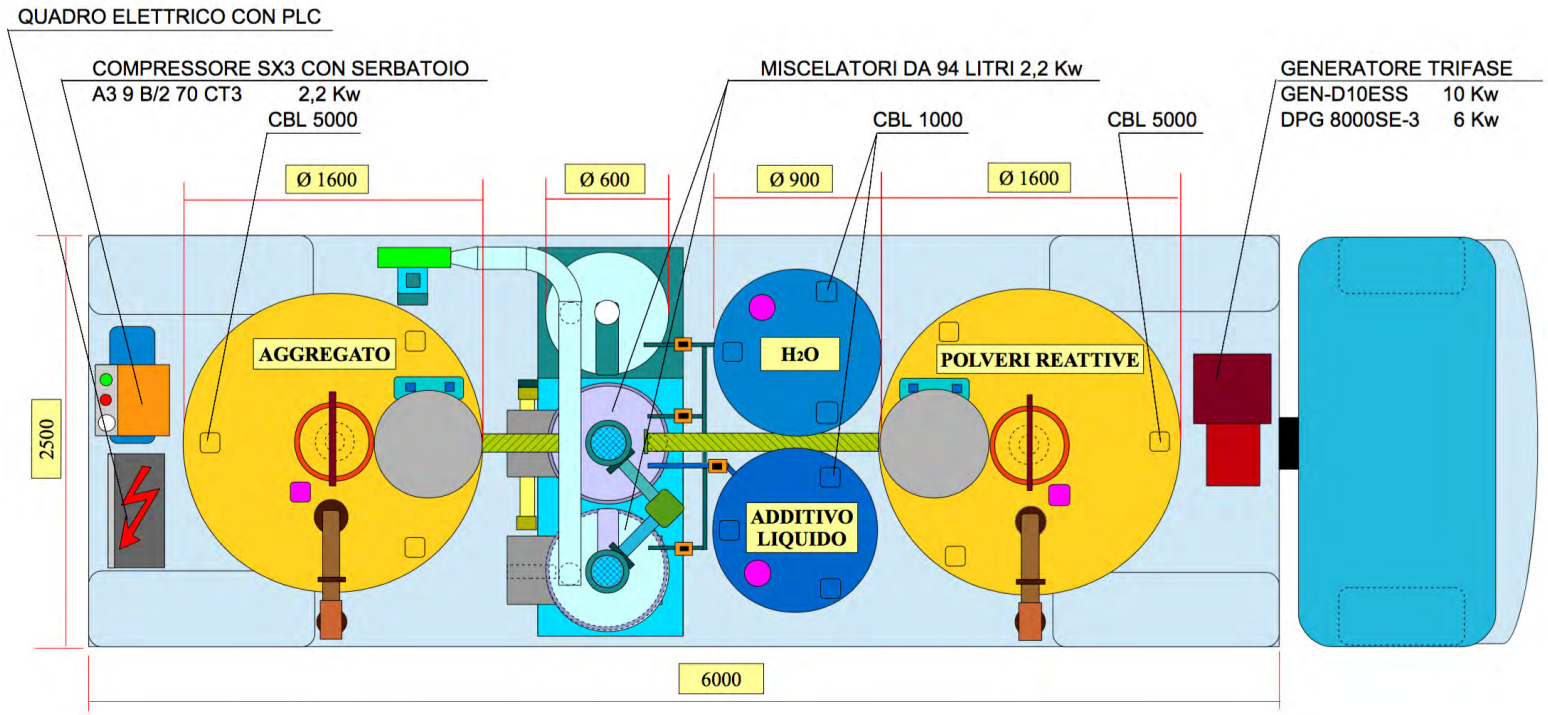
MOBILE MIXING PLANT:

Production is ensured by 2 mobile 94 litres of capability mixers. Self-rechargeable system allows to produce geopolymer concrete in a continuous cycle.

Save costs and reduction of wastes, it will be product only the necessary amount of geopolymer to work. Also water used for cleaning will be pushed to tanks to reduce environmental impact.

This technology can also be used by non-experts in the field of geopolymers, because final user doesn't touch fiscally materials, everything will be programmed and set in a touch screen control panel.

As optional, all settings of plant will be possible to organise directly using an App on a smartphone or tablet .



technology and research by
Alex Reggiani and designer
Athos Reggiani

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AUTOMATED MIXING AND PUMP SYSTEM:

technology and research by
Alex Reggiani and designer
Athos Reggiani

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Geopolymer binders, which are delivered to the concrete pump are mixed with a certain amount of liquid reagent (**geosilicate™**), then aggregates are added and ready geopolymer concrete is pumped to the printer as a homogenous mix.

With automated mixing and pump system process of printing is executed with machine precision. Pre-calculated and stable proportions of components allows to produce a geopolymer concrete with guaranteed quality.

Efficient mixing

Our automated mixing system allows an excellent mixture quality. It handles big volumes of material with ease, providing an optimal flow speed and supply proportions of printing mixture.

Ease of use

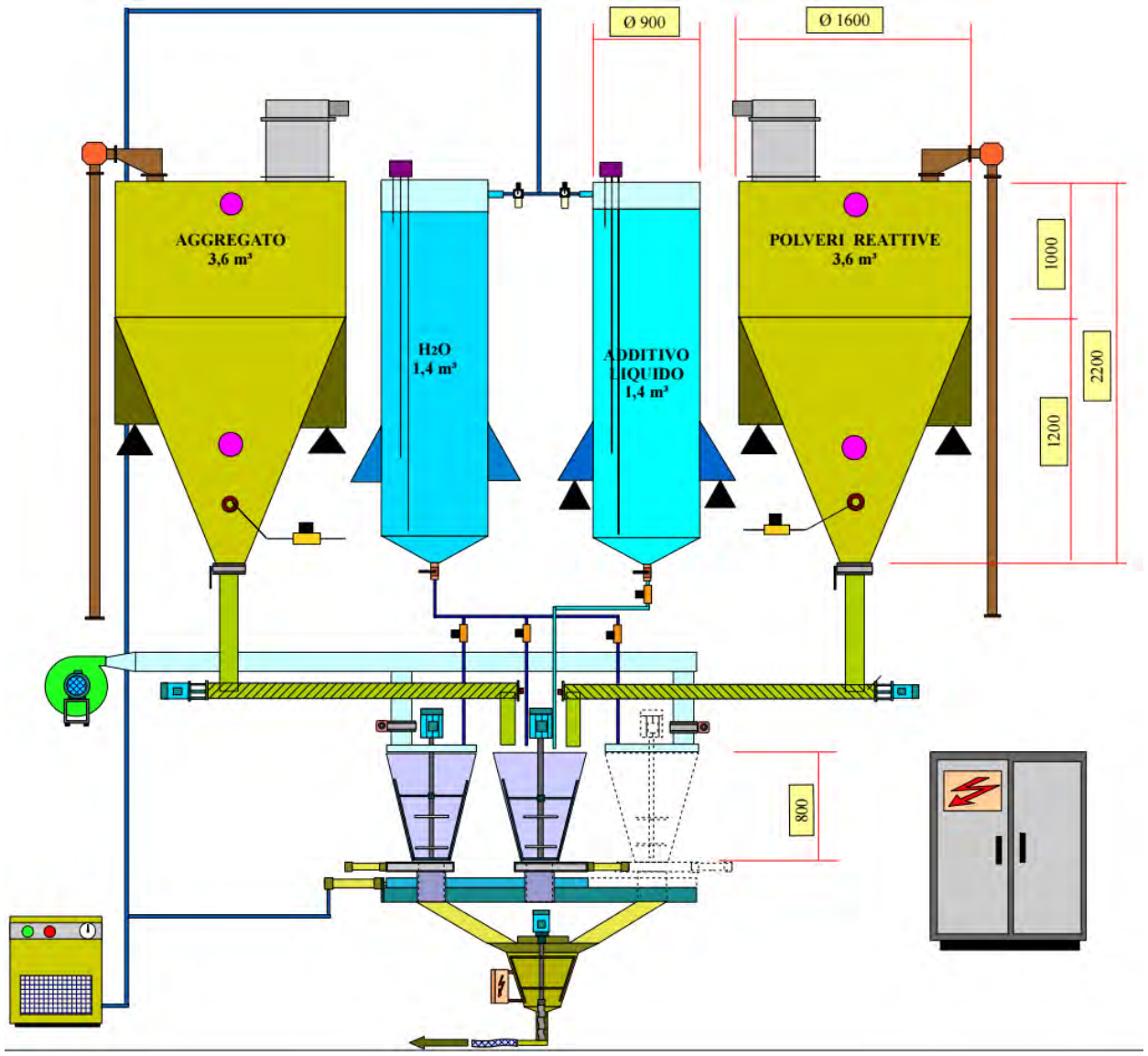
The mixer is extremely easy to use. It has a handy panel with comprehensive indication and logical error code display.

Increased durability

Combination of plated and polyurethane components greatly increases mixer durability in comparison with other commercially available models.

Fast cleaning

Mixer structure includes polyethylene components which, unlike metallic ones, allow to avoid caking of mixture. By reducing the amount of sediment on mixer surfaces cleaning procedures require less time and effort.



Mobile mixing plant layout:

Plant works and is located on a 22 tons truck with the materials required for refills placed in a trailer.

technology and research by
Alex Reggiani and designer
Athos Reggiani

Apis Cor and Renca RUS signed am MOU for promoting printer as well as supplying geopolymer cement with geopolymer reagent geosilicate™ to users of their 3D printer. The next step is to build a house in Austria in September 2016, next is demo-house in California, US

Future projects and plans:

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PROJECTS:

Architectural concretes

We continue improving geopolymer concrete for the use in architectural concrete, the aim is to make it more convenient for creating statues, monuments as well as countertops and decorative panels. It's like our playground

Soil-Stabilisation

We have a task from Moscow metro building company to create a geopolymer cement based mix for deep soil stabilisation. The mix must have water/cement ratio 1,0 - 2,0

GP coating

We have received a request for creating a solution for the coating of asbestos panels on metakaolin base, aim is to avoid efflorescence and create a good-looking and fire-resistant surface.

Water storage system

We have a request for special concrete for water reservoirs that should withstand corrosion.

PROJECTS:
Insulation panels and finishing

In collaboration with an Italian company HERES, s.r.l., located in Treviso, there are several products developed: geopolymer-based thermal and acoustic insulation panels, plasters and finishing mortars and self compacting geopolymers

HERES

PROJECTS:

High Voltage Insulators

We are working on solution for glass electric insulators that are produced in our region, aim is to avoid shrinkage or expansion of concrete to prevent the glass parts from breaking, it should also withstand a thermal shock that occurs in high voltage lines.

GLOBAL INSULATOR GROUP

PROJECTS:

Wooden Blocks (arbolite) **and Hemp panels**

We are working on substitution of OPC in production of wood concrete blocks to lower the costs and accelerate the hardening.

Tecolit

Renca RUS products and technology:

We have started a production of two component geopolymer cements in Russia (with liquid reagent **geosilicate™**), and we plan to expand the product variety by offering special purpose cements and compositions as well as exporting raw-materials for geopolymers in Europe.

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PRODUCTS:

RAW materials

supplier of raw materials for geopolymer cement production

geosilicate™

geosilicate - liquid reagent / hardener for geopolymer cements and concretes

geopolymer cements

geopolymer cements for general construction application, repair works, architectural application

3D geopolymer cements

geopolymer cements for 3D constructional printers

mobile mixing plant

fully automated mobile mixing plant for geopolymer concretes and 3D printers

geopolymer cement and geopolymer reagent geosilicate™:

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Thank you!

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