hoch3 FORSCHEN

Das Medium für Wissenschaft

Winter 2016

TECHNISCHE UNIVERSITÄT DARMSTADT

Imprint

Publisher
President of TU Darmstadt,
Karolinenplatz 5,
64289 Darmstadt,
Germany

Editor
Corporate Communication
Jörg Feuck (Editor-in-chief)
Ulrike Albrecht (Graphic Design)
Patrick Bal (Images)

Conceptual design
conclouso GmbH & Co. KG,
Mainz, Germany

Photography (title)
Katrin Binner

Circulation
6000

Next issue
15th of March 2017

Service for readers
presse@pvw.tu-darmstadt.de

Newsletter subscription
www.tu-darmstadt.de/newsletter

ISSN
2196-1506

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Climate-friendly cement substitute

Photo: Katrin Binner

Geopolymer concrete flows into a form (top), cured test pieces (bottom).

Photo: Katrin Binner

Researchers at TU Darmstadt are proposing geopolymers as an alternative to cement. These mineral binders are not only more environmentally friendly, they are also more resistant to chemicals and high temperature.

By Uta Neubauer

When discussing greenhouse gases, there is usually one aspect that comes off badly: building with concrete is affecting the climate by releasing more carbon dioxide per year than global air traffic. The reason lies in the production of the cement, the most popular binder in the construction industry. Cement is made by grinding and burning limestone, clay and marl. This requires a lot of energy and also removes the carbon dioxide from the limestone. More than 5% of global carbon dioxide emissions come from cement production. This does not have to be the case, thinks Professor Eddie Koenders, civil engineer and Head of the Institute of Construction and Building Materials at TU Darmstadt. His group is working with geopolymers as a promising alternative to cement.

"We are looking for solutions that are also economically interesting."

Geopolymers are two-component systems, comprising of a reactive solid, that contains silicon and aluminium oxide, and a basic activation solution of alkali hydroxides or alkali silicates in water. The solid is a natural stone or mineral, which is why it has the prefix "geo". When the activation solution is mixed with the grinded solid, to which aggregates and other substances belong to, depending on the application, the result will be a rock-hard, anorganic polymer. The molecular components, the monomers, are tetrahedrons with oxygen atoms at the four corners and a silicon or aluminium atom inside.

The term "geopolymer" was launched by the French chemist Joseph Davidovits in the seventies. Thus far, the materials did not made it onto the mass market, but the ongoing climate debate has now given new momentum to geopolymer research. "There is a great international interest," says a delighted Koenders, who together with companies and research scientists from Spain, France, Austria and the UK, is currently formulating an application for an EU project.

The first geopolymers were based on metakaolin, a heat-treated kind of kaolin clay. When heated to about 600 degrees Celsius, kaolin changes its structure, becomes more reactive and sets quickly whenever in contact with the activation solution. The issue is, that the pre-thermal treatment also consumes a lot of energy. But as kaolin does not contain any bounded carbon dioxide that will release during heating, and that the firing temperature is much lower than when burning cement, the carbon footprint is clearly better. However, metakaolin is an extremely fine material, and working with geopolymers made of it is very different than working with cement paste. They are, for example, thixotropic: when you stir them or shake them, they liquefy – like ketchup, that is initially reluctant to leave the bottle, but then suddenly gushes out. The activation solution also makes the geopolymers somewhat sticky, which is why it is more difficult to remove the formwork.

"Geopolymers will only ever replace concrete and cement on a large scale if they have the same workability", stresses Koenders. His staff, Dr Neven Ukrainczyk and Oliver Vogt, are testing different raw materials, to try to improve the handling. Less pure kaolins, containing iron oxide and other foreign minerals, are proving to be more suitable, as well as being more cost-effective. Fly ash, a waste product from flue gases, and the natural stone trass are a possible admixture or alternative to metakaolin. The researchers are getting the trass from the Eifel, where it was formed after volcanic eruptions. After excavation, the trass is grinded and can then be used directly. A further advantage is that it is rich in alkalies. This can reduce the concentration of the alkaline activation solution – which reduces the cost.

The research focuses not only on the main components of the geopolymers, but also on finding new admixtures, designed to give the new construction material specific properties. Conventional

Information

Institute of Construction and Building Materials
Prof. Dr.ir. Eddie Koenders
Phone: ++49 (0)6151/16-22210
Email:
koenders@wib.tu-darmstadt.de
www.wib.tu-darmstadt.de

Testing the reactivity of the raw material: Dr Neven Ukrainczyk (right) and Professor Eddie Koenders

Photo: Katrin Binner

superplasticizers, for example, that separate binder particles in self-compacting concretes, do not work in geopolymers because of their different chemical composition, and they therefore have to be re-designed. Vogt and Ukrainczyk are the perfect team to do this, because as a qualified civil engineer, Vogt always keeps an eye on the practical application, while chemical engineer, Ukrainczyk, is an expert for the molecular basis and the physico-chemical analytics.

When he joined TU Darmstadt in 2014, Koenders agreed that it might be possible to set up a micro-laboratory for examining geopolymers and other construction materials on the micro to nano scale. How much water is needed for a new material to react? What is its molecular structure? How does it behave at different temperatures, such as at minus 60 and at more than 100 degrees Celsius? A calorimeter, X-ray defractometer, viscometer and other special equipment are available in the micro-laboratory to answer questions like these. The next purchase will be an atmospheric scanning electron microscope, which can examine construction materials at different humidities and temperatures, as well as under mechanical loading. Conventional scanning electron microscopes, of which there are a few at TU Darmstadt, only work in a high vacuum and do not reflect the ambient conditions under which construction materials are used.

Cement is still the most-used construction material in the world, but geopolymers have the potential to contest this ranking when it comes to special applications. Not only does their carbon footprint give them a better performance, they also have technical advantages. Geopolymers are more heat-stable than concrete – the bound water which builds up vapour pressure in the event of a fire, results in spalling or cracking. They are also more resistant to chemicals, as they do not contain hydration products, which dissolve when exposed to acids or other aggressive substances. It is also worth noting that it only takes one day for geopolymers to develop compressive strengths that are similar to high performance concretes. They can be quickly demoulded, making them suitable for mass production of prefabricated construction elements. The TU Team is currently busy making geopolymer sewer pipes that are resistant to bio-chemicals. Until now, the new construction materials are more expensive than conventional cement or concrete, says Koenders, but their durability would justify the higher price. “We are looking for solutions that are also economically interesting. We want to put geopolymers into practice as quickly as possible.”

The author is a science journalist with a doctorate in chemistry.

Facts and figures

Publication: N. Ukrainczyk, O. Vogt, E. A. B. Koenders: Reactive Transport Numerical Model for Durability of Geopolymer Materials. Advances in Chemical Engineering and Science (6) S. 355-363, 2016 (http://file.scirp.org/pdf/ACES_2016091614060072.pdf)

Additional focuses of the research of Professor Eddie Koenders working group:

- Mineralised foam as an insulating material, already installed in the ETA Factory at TU Darmstadt
- Integrating phase change materials in walls and floors, to reduce the energy requirement for cooling and heating
- Concrete components for the production of renewable energies
- Rubber aggregate made from old tyres as an additive for road surfaces, to improve durability

Symposium on geopolymers: 10 February 2017, TU Darmstadt, Institute of Construction and Building Materials, contact: Ms Aysen Cevik, ++46-6151/16-22210, cevik@wib.tu-darmstadt.de).

For powerful arguments

There is a sea of information and argumentation on the Internet covering every possible world-shattering subject. The Ubiquitous Knowledge Processing Lab at TU Darmstadt is developing tools for a quality check.

Photo: Sandra Junker

Quality check on sources: Prof. Iryna Gurevych (left) and her team.

By Jutta Witte

Should plastic water bottles be banned? Has India the potential to become a world power? Should children be allowed to use mobile phones at school? You can find supporting arguments and help in decision-making from experts and non-experts on the net for virtually every controversy nowadays. But what about the quality of these technical texts, the information provided by interested amateurs and the contributions to debates? "So far, the vast majority of them are not validated", explains Professor Iryna Gurevych, Head of the Ubiquitous Knowledge Processing (UKP) Lab at TU Darmstadt. So she and her research team are developing software instruments designed not only to filter the arguments out of the texts, but also to check their quality.

With the aid of the debate about the use of mobile phones, the "Digital Humanities" expert explains a possible scenario, in which a learning machine identifies arguments in a specific collection of documents and analyses them along with the associated corroborations should parents encourage their children to limit their mobile phone use? A mother takes to the net looking for answers. The analysis system recognises the topic and uses keywords – such as children, parents, mobile phone or radio frequency emissions – to find the text fragments relevant to the query. It then starts a so-called predicate argument analysis in the individual fragments, which means that it is looking for the deed and its frame of reference in the sentences.

After the analysis of the individual fragments, references with regard to content are created between all the text passages found, and it uses its own knowledge database, as well as feedback from users who have commented on the relevant texts on the net, to identify premises, assertions and supporting or contradictory corroborations for the particular argument. The evaluation follows this categorisation. If, for example, a statement only relates to "some study or other", i.e. its sources are extremely vague, or if it is one-sided and only contains supporting corroboration, the system will recognise these shortcomings in the argumentation. At the end, the anxious mother is presented with a graphic, showing whether the respective arguments are plausible and credible.

This is one of many application ideas for the automated analysis of argumentation on which the research scientists of the UKP Lab are currently working. Gurevych is convinced that this kind of quality checking would be a great step forward in this complex research field. What the experts really need is all sorts of quality-checked training data to feed into their systems, so that they can develop the necessary algorithms, methods and ultimately also prototypes for the new generation of search engines. They have

Information

Computer Science department
Prof. Dr. Iryna Gurevych
Phone:++49 (0)6151/16-25290
Email:
gurevych@cs.tu-darmstadt.de
www.ukp.tu-darmstadt.de

just created a database called "UKPConvArg2". The new collection encompasses around 9,000 pairs of arguments from social media discussions that people have evaluated with regard to quality, and coded. In each case, they are the arguments for and against a socially relevant topic.

"This database, which we are making available to the scientific community, does not only show which arguments are convincing and why. It also forms the basis for developing new methods for the empirical analysis of text data from the Internet", explains Ivan Habernal, a research scientist at the UKP Lab. "It allows us to start a new discussion about the possibilities of machine learning." The UKP experts estimate that simple applications, such as segmenting texts into argumentative and non-argumentative parts within clearly defined text types, will be achievable in the near future – perhaps as an additional tool for Google Search. Writing assistants, to discover the weaknesses in the arguments in a student essay, for example and include them in a scoring system for exams, are also already technically feasible.

"But it will always lack the world knowledge of mankind, which is indispensable for categorising and transferring new information in larger contexts."

But the major challenge is still the editing of texts from heterogeneous sources ranging from scientific papers to articles on social media. Firstly, because creating the training data is a highly complex task, and secondly because the methods of analysis are developed for a specific type of text on the basis of this data, and can hardly be transferred, as things stand at the moment. "We have yet to resolve the question of scaling", says Gurevych. "This is a research task for the next five years." The "ArgumenText" project has just been given a positive funding recommendation, and the UKP experts want to use it to look into this question and transpose to new applications the tools for the automated analysis of assertions and corroborations that have already been used successfully in a specific application context.

Potential users of the new analysis instruments being produced in the UKP Lab include not only educationalists looking for help in correcting exam papers, but also companies who want to evaluate customer reports on their products, or journalists wanting to quickly and comprehensively research the viewpoints of the different factions involved in the latest "hot topics". The humanities and social sciences can also benefit from this, for example, when it is a matter of collecting and evaluating all the relevant text data that could substantiate or refute a theory. "Nowadays it is not possible to do this by hand, because we simply do not have the capacity", says the IT specialist. The aim would be to create a tool to tap into and pre-structure the vast amounts of information from the different channels. But the interpretation of this machine-generated knowledge still remains the province of man. Gurevych and Habernal stress that a machine could process vast amounts of data according to specific patterns, without getting tired. "But it will always lack the world knowledge of mankind, which is indispensable for categorising and transferring new information in larger contexts".

The author is a science journalist with a doctorate in history.

New database

The "UKPConvArg2" database contains 9,111 pairs of for and against arguments. They come from 16 debates on the portals createdebate.com and convinceme.net, and were evaluated and tested for their convincingess by around 800 crowdworkers in accordance with 17 different criteria.
Initial experiments with machine learning models for working with the training data are already showing promising results. The new collection and the relevant experimental software are available under licence CC-BY-SA for further experiments at:
https://github.com/UKPLab/emnlp2016-empirical-convincingness

Future Data Analytics for Humanities

The research scientists at TU Darmstadt are stepping up their communication and coordination so that together they can explore and develop new methods of data analysis for humanities and social sciences. So far, approaches to the analysis of humanities and social sciences data often fail because of the variety, complexity and heterogeneity both of the data and the questions being asked. The new methods must manage with little training data, be able to work around data of differing quality and composition, continuously learn from interaction with the researchers, semantically analyse and link objects from different data sources, and transpose the knowledge from external sources onto existing and new questions.

The data analysis embraces fields of research such as automatic speech processing, visual computing and machine learning. Prototypical users in humanities are researchers from philosophy, philology, history, online and communication studies, and archaeology.

Genetic materia

The more we know about our genome data, the better our doctors will be able to treat us in the future. But how can we make use of this sensitive data, without allowing it to be misused? The IT specialists around Stefan Katzenbeisser and Kay Hamacher from the Technische Universität Darmstadt want to encrypt genome data so skilfully that it is still possible to carry out mathematical analyses.

By Boris Hänßler

Dirk von Gehlen is a journalist who works for the Süddeutsche Zeitung newspaper, which is published in Southern Germany. He was recently visited by colleagues from the North German Broadcasting Corporation, Norddeutscher Rundfunk (NDR). They brought him a USB stick on which was stored a complete month of his browser history – the websites he had visited, the search keys he had entered in Google and the train journeys he had booked. The NDR reporter had bought the data over the Internet. Gehlen was flabbergasted! He had no idea that a company was using a harmless browser add-on to secretly record the Internet activities of millions of users and offer the data for sale internationally.

"Once you agree to deposit your genome data, it is not so easy to withdraw it from circulation."

Researchers fear that something similar could happen in future with genome data that provides ever-deeper insights into our biological identity. A few years ago, for example, customers of the American company 23andme were already paying a fee and sending in a saliva sample. The company analysed the inherited genetic variations – the so-called SNPs (Single Nucleotide Polymorphisms). From this, they could discern whether someone has an increased risk of developing cancer, Huntington's disease or Parkinson's disease. Admittedly the American authorities banned the transaction, because they feared that customers could misunderstand the findings without medical advice. But the company is still able to keep on collecting genome data, so that now it can ascertain the customers' genetic parentage. The data is digitally stored and could theoretically be sold on. It would be worth its weight in gold to medical insurance and life insurance companies.

But despite everything, it is not a good idea to ban the storage and use of this data. Because it could revolutionise medicine. "Genome data is the basis for personalised medicine", says Kay Hamacher, bio-informatics specialist at the TU Darmstadt. "Behind it is the vision that in future, doctors will be able to offer their patients individually tailored forms of treatment on the basis of genetic information." The genome data could, for example, provide information about whether or not someone will tolerate certain medication, or whether a particular treatment would work really well.

Kay Hamacher and Stefan Katzenbeisser from the Cybersecurity (CYSEC) profile area are looking to harness genome data for these purposes, whilst making its misuse as impossible as current crypt-technology allows. The risk is always present, when doctors and clinics release the data for research. Genome research is assigned to powerful computers, so IT service providers often have to be involved, using super-computers to trawl through the data. "So we need a method that, although it encrypts the data, still allows its use in subsequent calculations", says Stefan Katzenbeisser. "It must never be possible for the service provider performing the calculation to see the unencrypted data."

The method is called homomorphic encryption. The simplified example below shows how it works. The numbers "1" and "2" are sent to a service provider as the encrypted values A and B. The service provider can add up A and B, and send the result C back to the client. But the service provider does not know the value of A, B or C. The client, on the other hand, can decrypt C to reveal the result, in this case "3". Highly complex calculations can be carried out in a similar way.

But that is not all there is to it. The data sets of genome data are huge. Researchers or drug manufacturers therefore concentrate only on the SNPs or mutations of the DNA that are relevant to their current question. As a result, the IT service provider can theoretically deduce from their access to the sequence, what the researchers are currently working on – even if the result of the query remains encrypted.

"The DNA string I am examining reveals a lot about the diseases and substances I am working on", says Katzenbeisser. "To prevent this, we carry out a kind of deception, the so-called oblivious RAM. The physical memory is constantly scrambled while the database is being consulted. No-one can then comprehend whether the questioner is accessing the same data several times, or has accessed a lot of different data. So the intention of the query is disguised."

Information

Cybersecurity profile area
Prof. Dr. Stefan Katzenbeisser
Email: katzenbeisser@seceng.informatik.tu-darmstadt.de
Prof. Dr. Kay Hamacher
Email: hamacher@bio.tu-darmstadt.de
www.cysec.tu-darmstadt.de

l on offer

The research is run by the Collaborative Research Centre funded by the German Research Foundation (DFG) "CROSSING – cryptography-based security solutions: enabling trust in new and next generation computing environments" and the Centre for Research in Security and Privacy (CRISP), based in Darmstadt. Hamacher and Katzenbeisser's teams first want to devise the basic techniques for the cryptographic process. As these are highly complex, the researchers are also developing tools to implement the process without error. IT staff can thus implement the necessary protocols, even if they have no cryptography expertise.

The processes must also become even more powerful. Thus far, most of the techniques have focused on smaller sets of data. Working with genome data would be beyond them. The genome of a human being has an information content of 100 megabytes to 200 gigabytes – depending on whether you store the complete DNA, or just the mutations. Added to this is the fact that for meaningful investigations, you need to take into account the genome data of as many people as possible. It all adds up.

"It is also our wishto consult small clinics any clinics and institutions where genome data is present", says Katzenbeisser. "They are more sceptical, as they only collect data from a few patients. You could easily draw conclusions about their identity. The encryption processes should make the clinics feel safe about contributing this type of data to this important research."

Greater confidence in the infrastructure of genome research is urgently required. Otherwise Germany will be at a disadvantage. American companies are already investing a lot of money in these areas. Although the details of what they actually intend to do with the data are vague. Kay Hamacher says: "Once you agree to deposit your genome data, it is not so easy to withdraw it from circulation. With genetic material, you are also making a decision for your mothers, fathers and grandchildren at the same time. Last but not least, we must remember that we are only at the start of genome research – we do not know what will be possible to glean from it in future. So it is very important that we get to grips with data security early on."

The author is a technology journalist.

Photo: Katrin Binner

Professor Stefan Katzenbeisser develops special methods to encrypt genomic data.

Names and facts

Prof. Stefan Katzenbeisser supervises the S5 Privacy-Preserving Computation project of the CROSSING Collaborative Research Centre and is head of the Security Engineering Department at TU Darmstadt. Prof. Kay Hamacher supervises the Scalable Privacy-Preserving Protocols project in the Centre for Research in Security and Privacy (CRISP), which is funded by the federal government and the state of Hesse, with substantial support from TU Darmstadt. He also leads the Computational Biology & Simulation research group at TU Darmstadt.

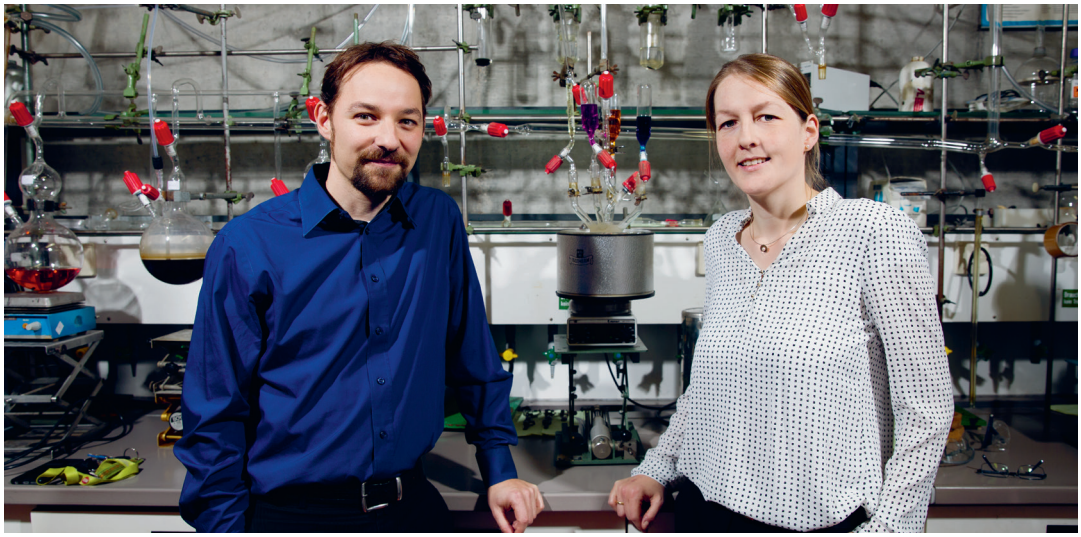

Photo: Katrin Binner

Pursueing two scientific approaches: Dr.-Ing. Markus Gallei, Asst. Prof. Annette Andrieu-Brunsen.

Stimuli-responsive polymers

Two research groups at TU Darmstadt are developing intelligent synthetic materials that respond to external stimuli. Nature is the teacher.

By Hildegard Kaulen

Synthetic materials are usually static. They do not switch back and forth between different structures as conditions change, as some organic materials do. Switchable polymers that respond to light, pressure, temperature or other chemical or physical stimuli and change their properties, would be interesting for many applications, especially smart filters and sensors.

No less than two research groups are working on this topic at TU Darmstadt. Assistant Professor Dr. Annette Andrieu-Brunsen from the Chemistry department makes the nanometre-sized pores of a ceramic membrane functional with ultra-thin layers of switchable polymers, which she uses to control the transport of ions and tiny molecules. She initiates polymerisation in the tiny pores and employs different detection methods to check for the correct result. She wants to know how the responses in the tiny pores have to be controlled and restricted to achieve the required transport. Depending on how the pores are made functional, the molecules will then no longer be filtered just by size, but also by the properties assigned by the switchable polymer. Andrieu-Brunsen works with pores in the mid nanometre range, so-called mesopores. She uses light, redox reactions and other stimuli to switch them. She takes her inspiration from organic membranes. They transport ions and molecules selectively in one direction and if necessary, also actively by supplying energy. "We ask ourselves, what is the best way to implement these three transport parameters using our synthesis concepts for the porous, ceramic membranes that we have made functional", says the Assistant Professor. "However, we know that organic membranes will always be quite a bit ahead of us".

Information

Chemistry department
Asst. Prof. Dr. Annette Andrieu-Brunsen
E-Mail: brunsen@cellulose.tu-darmstadt.de
Dr.-Ing. Markus Gallei
Email: m.gallei@mc.tu-darmstadt.de

Dr Markus Gallei, the Head of the Early Career Research Group at the Ernst-Berl-Institute for Technical and Macromolecular Chemistry, adopts a different approach. He turns to switchable polymers and allows photonic crystals and porous membranes to be produced by self-organisation. Gallei determines the switchable properties of the crystals and membranes by his choice of source materials. His lattice structures and pores are between 50 and 600 nanometres in size. He uses his porous materials to detect or filter molecules and molecular substances in this magnitude. Gallei uses source products that are robust and scalable, so that the intelligent material can also be made on an industrial scale, if required. There is an important reason why he is turning to photonic crystals. "The colours of the photonic crystals are structural colours and are caused by the reflection of light, not by absorption, as is the case with pigments", says the Head of the Early Career Research Group. "They are the colours of butterfly wings, peacock feathers and opals. If the structure of the crystal is altered by a change in temperature, a voltage, a magnetic field or other stimulus, the crystal reflects a different wavelength. So when a photonic crystal switches, it is immediately obvious with the naked eye, because the colour changes."

The technology platform of Andrieu-Brunsen could be used for the detection and removal of heavy metal ions, Gallei's platform lends itself to the detection and removal of impurities from drinking water and to optical security features. These are just two examples of the many potential uses.

The author is a science journalist with a doctorate in biology.