Use of Pyrochar to reduce the CO2 content of the atmosphere

Prof. Dr.-Ing. Hans-Peter Leimer

BBS INSTITUT / Hefei University Anhui-China / HAWK Hildesheim
38302 Wolfenbüttel, h-p.leimer@bbs-institut.de

Abstract.

Plant residues release the CO2 bound in them when burned or decomposed. If, however, plant residues are converted into Pyrochar during a pyrolysis process, the CO2 is bound to a large extent in the coal. Extensive research activities in different countries have been carried out on topics related to the production and use of Pyrochar. The aim of this research project is to work out, together with the participating institutions, the possibilities of using Pyrochar to generate a true decrease of CO2 in the atmosphere, in order to realize the goals set by the respective countries for the intended nationally determined contribution to climate protection under the Paris Agreement. The use of Pyrochar is thus increasingly becoming a solution in the construction industry. The areas of application are based on the specific properties of coal. The extremely large surface area of Pyrochar results in a strong cation exchange capacity and a strong tendency to absorb and release a lot of moisture. Within the scope of our research project from 2018, the successful addition and storage of Pyrochar in mineral materials was investigated. The main part of this report will be to describe the positive influences of Pyrochar in different mineral materials, e.g. lime-, lime/cement-, cement plasters. The research shows that the modulus of elasticity of the material, the strength properties, sorption isotherm, the moisture content and the capillarity could be influenced in an extremely positive way to increase the material quality or decrease the amount of cement or sand in the materials. To verify these preliminary results a new science and research project, Methods for extracting atmospheric carbon dioxide - Creating Longterm Carbon Sinks: Utilization of Pyrochar for Construction Materials, has been proposed by Fraunhofer IBP, BBS and other partners.

Basics of photosynthesis and CO_2-absorption of plants

During photosynthesis, the chloroplasts produce glucose and oxygen from water and carbon dioxide with the help of solar energy. The plant uses the glucose for its growth, the oxygen is released into the environment, and the CO_2 is stored in the plant in the form of carbon.

This CO_2, stored in the plants, is released back into the atmosphere when the plants are burned or rot and thus pollutes our environment. The storage capacity of CO_2 in plants depends on various factors such as location, age of the plant, size of the plant, and density of the plant.

The following ecosystems provide repositories for CO_2:

Forests: German forests store about 13 tonnes of CO_2 per hectare per year. This value is determined by the age groups and species of the trees.

Trees: How much CO_2 a tree absorbs depends on the following factors: Tree species, wood density, age, tree height. In general it can be said that deciduous trees produce less oxygen than coniferous trees. In addition, young trees produce more oxygen than old trees.

Example:

- Spruce - Ø 50 cm; age 100 years; height: 35 m
- Filter capacity/absorption: 2.6 t CO_2
- Beech - Ø 50 cm; age 120 years; height: 35 m
- Filter capacity/absorption: 3.6 t CO_2

Crops: Plants cultivated by humans also contribute to the reduction of CO_2

Example:

CO_2 absorption in

- Tomatoes: approx. 3.1 kg CO2/m²a
- Oat/Wheat/Barley: 1.15 to 1.35 kg CO2/m²a
- Watermelon: approx. 0.63 kg CO2/m²a.

This results in filter capacities / absorption capacities of

- 1 ha forest = approx. 13 t/a
- 1 ha park/field = approx. 10 t/a.

Basics of producing Pyrochar by pyrolysis

Pyrochar consists mainly of pure carbon, which can only be broken down very slowly by microorganisms. If the plant cell tissue is heated to over 400 °C under exclusion of oxygen, the biomass is split. Cellulose, hemicellulose and lignin decompose to volatile components and carbon. Extrapolation models show that in the Pyrochar obtained by the pyrolysis process, more than 80% of the carbon remains stable for more than 1000 years. This presents a possibility to extract the CO_2 originally assimilated by plants from the atmosphere, store it in the long term, and thereby slow down climate change. Depending on the pyrolysis process, about 60% of the energy can be stored in combustible gas and oil and about one third of the energy in bio- or Pyrochar.

The energy from oil and gas is then available for further energetic use. For example, in Thermo-Catalytic Reforming (TCR®), the conversion process developed by the

Fraunhofer Institute's UMSICHT division in Sulzbach-Rosenberg, oil and gas can be used directly for cogeneration in combined heat and power plants. Alternatively, however, pure heat can also be supplied to dry the input material.

Significance and application

The annual capacity of the first Pyrochar plant operated by Swiss-Pyrochar and the Delinat Institute is 1000 t of biomass, which is converted to 330 t of Pyrochar and about 1000 MWh of heat. The pyrolysis plant is able to remove from every two tonnes of green waste about one tonne of CO_2 from the atmosphere.

All energy expenditures, such as the transport of the green waste, its shredding, the operation of the plant, as well as the introduction of the Pyrochar into the soil, are already taken into consideration. The pyrolysis plant is energy self-sufficient and is operated in a continuous process. The energy required to heat the biomass to over 400 °C must be supplied. The energy for the further process comes from the biomass itself and is generated by burning the gas produced during pyrolysis.

Within the scope of a separate research project from 2017, the possibility of planning a CO_2-neutral city was investigated. The project identified the areas in which CO_2 emissions are generated in a city and the options available for reducing and saving these emissions. The CO_2 emissions for the city of the future in China with two million inhabitants were determined. The basic question in this project was: *"Is it possible to optimize the CO_2 emissions of a new city in such a way that a CO_2-neutral city can be created with the help of parks and green spaces?"*

The research project clearly shows that it is possible to optimize the planning/energy efficiencies in such a way that the plants in the parks can almost completely absorb the CO_2.

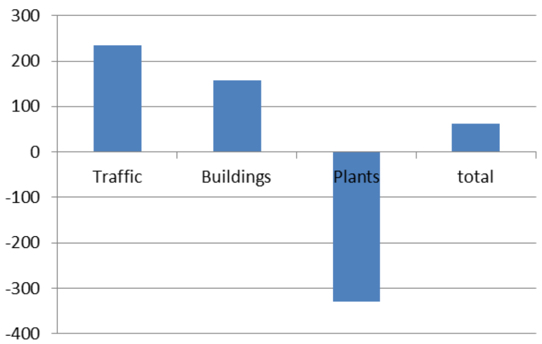

Figure 1: CO_2 emissions per year (in 1000 t) in the city of the future

So only one question remains to be answered: "What happens to the tree and plant cuttings that are produced annually in the cities and release the stored CO_2 back into the atmosphere when composted or burned?"

On the basis of a city with two million inhabitants, this results in approx. 300,000 t/a of green waste, giving an annual potential of approx.

- 100,000 t of Pyrochar as a recyclable material
- 300,000 MWh of heat from the pyrolysis process

and

- thus the permanent binding of approx. 330,000 t of CO_2, the total CO_2 binding of the city's plants!

Recyclable materials from Pyrochar

The pyrolysis process that has been further developed by the Fraunhofer Institute's UMSICHT division can produce biogenic recyclables while at the same time providing renewable energy in the form of electricity, heat and fuels. These are versatile, environmentally friendly, cost-effective and offer a rudimentary solution to current air pollution and the CO2 targets.

The following basic materials can be converted into Pyrochar: landscaping material, brush cuttings, compost, straw, fermentation residues, forest wood, but also separated liquid manure, dung, fermentation products from biogas plants, and sewage sludge.

The Pyrochar resulting from the process can be used for water treatment, feed material (EU VO 68/2013), soil-related use, and plant fertilizer.

Soil decontamination with Pyrochar

The mechanisms of action of both Pyrochar and activated carbon are based on the fact that introducing Pyrochar into the soil raises the pH value and thus, at least with regard to heavy metals, these pollutants are immobilized. This prevents or at least significantly reduces the uptake of heavy metals by plants.

The aging process of Pyrochar allows various carbonyl groups to accumulate on its very large surface. These carbonyl groups are able to bind various organic pollutants due to their polarity. All in all, the large specific surface area of Pyrochar gives it a very good cation exchange capacity, which benefits the agronomic properties of soils treated in this way. Especially the report "Use of pyrochar and compost as soil additives for the immobilization of pollutants at contaminated sites" of the University of Vienna seems to be a good approach in this respect. It suggests that Pyrochar which has been loaded with nutrient cations by adding compost can be used to treat contaminated soils by immobilizing heavy metals and absorbing existing organic pollutants. This results in a reduction of pollutants in the soil and a significant improvement of the soil conditions.

Pyrochar as a substitute for aggregates in mineral materials

Recent research by the German Center for Integrative Biodiversity Research shows that the effects of sand extraction have taken a threatening toll on ecosystems. The global demand for sand far exceeds what is generated by weathering. In the UN report of 2014, "Sand—scarcer than you might think", the current consumption of sand is estimated at about 50 billion tonnes per year.

Because desert sand is too smooth, it is hardly suitable for the production of concrete. Sand is therefore extracted from the sea bed, but also from lakes or rivers. The consequences for sensitive ecosystems are often devastating. Riverbeds sink, coasts erode, the fauna in the oceans is destroyed, whole islands disappear. Protective mechanisms that prevent storms and tsunamis are rendered ineffective. Thus, Pyrochar could be used here not only as a fine grain, but also as an additive in materials in general.

The use of Pyrochar is thus increasingly becoming an issue in the construction industry. The areas of application are based on the specific properties of coal. The extremely large surface area of Pyrochar results in a strong cation exchange capacity and a strong tendency to absorb and release a lot of moisture. Within the scope of our own research project from 2018/2021 ("Use of Pyrochar in construction materials"), the successful addition and storage of Pyrochar in mineral materials was investigated.

Material test

The use of pyrochar in the building materials has remained largely unexplored, and there are currently hardly any areas of application for pyrochar in the building industry. Initial tests were carried out on plasters, bricks, clay pots, paving slabs and thermal insulation materials to investigate the effects of pyrochar on the properties of the above-mentioned building materials and their environment (e.g. indoor climate).

Within the scope of the conducted investigations, the effects of pyrochar were examined with respect to bending tensile and compressive strength, capillary absorption behaviour, re-drying behaviour and bulk density when the pyrochar was used in conjunction with a lime- / limecement- / cement plaster.

The test specimens were manufactured in accordance with DIN EN 196-1:2005-05 and consist of a ready-mixed dry mortar that can be reproduced at any time and to which a defined percentage of pyrochar was added. The test series S1-S6 correspond to the percentages [V-%] of pyrochar with S1-0%; S2-25%; S3-33%; S4-50%; S5-66%; S7-75%.

The present test results show a strong influence of the addition of pyrochar on the renders..

Test of Hygrothermal performance of building materials and products - Determination of hygroscopic sorption properties according ISO 12571:2013

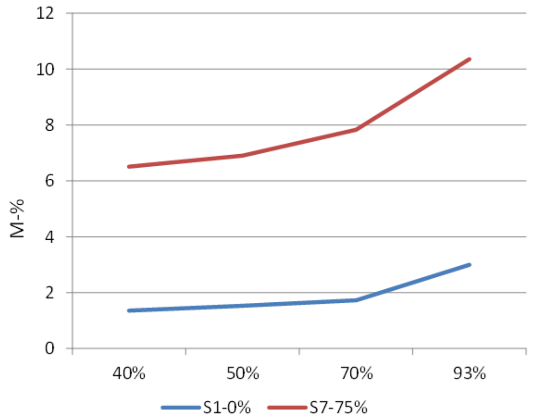

Figure 2: water absorption / sorption isotherm in M%; Test-Serie S1 und S7

Methods of testing cement - Determination of strength according EN 196-1:2016;

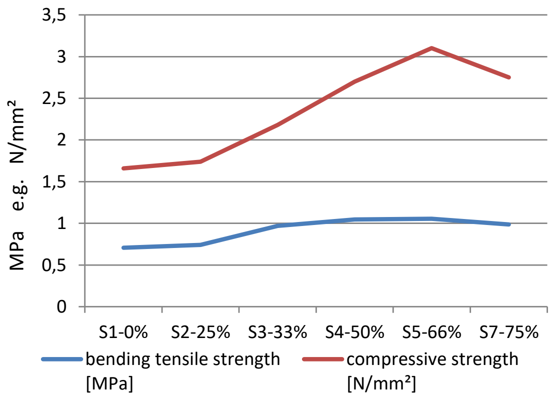

Figure 3: bending tensile strength / compressive strength Test-Serie S1 - S7

Results/Conclusion

The strength tests show that pyrochar makes the plaster heavier, more compressive and more elastic.

In the context of sorption, the plasters show increased moisture absorption from the room air due to the addition of pyrochar. Humidity simulation calculations show that fluctuations in room air humidity can thus be better damped.

In the context of capillary suction, in the case of direct contact with liquid water (e.g. driving rain), plasters show a slowed water absorption and water release due to the addition of pyrochar, but a significantly higher absorption of the water quantity.

Thus, based on the results obtained so far and the general properties of pyrochar, such as high water retention, large surface area and, depending on the method of production, dusty or coarse-grained structure and low thermal conductivity, pyrochar can be considered to have a high potential for use in building construction..

Literatur

[1] Deryck, Henrike; Die CO2 neutrale Stadt, HAWK Hildesheim 2017

[2] Schwedhelm, Jan-André; Einsatz von Pflanzenkohle im Baubereich, HAWK Hildesheim, 2018

[3] Bode, Ingo; N-Team, Hameln

[4] Stenzel,Fabian; Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik UMSICHT

Curriculum Vitae

Prof. Dr.-Ing. Hans-Peter Leimer

<u>Vita:</u>

seit 1990	selbstständige Tätigkeit BBS INGENIEURBUERO / BBS INTERNATIONAL GmbH
seit 2000	Professur für Baukonstruktion und Bauphysik an der HAWK Hildesheim - Hochschule für angewandte Wissenschaft und Kunst
seit 2001	Leiter des BBS Institut - Forschungs- und Materialprüfinstitut für angewandte Bauphysik und Werkstoffe des Bauwesens
2001 – 2013	Präsident der WTA- Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege
seit 2007	Leitung des Institutes für angewandte Bauphysik und Qualitätssicherung an der Hefei University - China
seit 2007	Gast-Professor für Bauphysik an der Hefei University – China
seit 2009	CEO BBS INTERNATIONAL Ltd. - China
seit 2014	Leiter des neuen HAWK Labors für Bauphysik, Hildesheim
seit 2017	CTO und Partner der Firma BERLIND (Shanghai) Engineering Ltd sowie. BERLIND (Kunshan) Factory Ltd.
since 2020	CSO und Partner CARBONplus GmbH – Deutschland