P13_VN185

THE EVERLASTING EXPOSED CONCRETE

A DURABLE MATERIAL DESIGN CONCEPT

the idea

The concept of “the everlasting exposed concrete” represents a recipe for a cementitious material mixture that tackles the challenges of today from an architectural, environmental, and engineering perspective to create an ideal mixture to use for exposed concrete. Its main goal is to provide a recipe that sustains for as long as possible in strength and appearance with optimized CO_2 consumption.

Longevity of structures

Today, buildings and structures made out of concrete are built with steel reinforcement, which ultimately can be expected to have a working lifetime depending on many factors, such as the thickness of the concrete and the environmental conditions. Its service lifetime mostly reaches between 50 and the commonly used maximum of 100 to 200 years. As well, the environmental costs of rebuilding are certainly worth considering [1] [2].

Through the permeable porous material of the concrete, the process of carbonation, which binds CO_2 back into the concrete, decreases the pH value, and as soon as it touches the steel reinforcement, corrosion processes may start. The responsible chemical process is shown in the formula (1) beneath. These processes lead to a growth in the volume of the corrosion products and a crack initiation from within the structure, which therefore limits the service life of the structure. This process can be accelerated in chloride-rich environments [3] [4].

(1) $$CO_2 + Ca(OH)_2 \quad CaCO_3 + H_2O$$

The discussed recipe was designed to strengthen the exposed concrete on a micro level with non-corrosive recyclable basalt microfibers, which have the lowest energy consumption of any other fibrous material, and an optimized Schwanda packed combination of dry materials. The material composition and its single particle size distributions are shown in Figure 4. This helps to reduce crack formation during shrinkage and as well prevents negative impacts on the carbonation processes [5] [6] [7].

Additionally, the mixture is made out of a certain amount of larger CaO aggregates, which enable self-healing mechanisms as soon as a crack is formed. The boldly assumed mechanism is that the heaviest load will lead to cracks at the weakest point, which is assumed to be a CaO aggregate. In the moment the crack propagates through a CaO aggregate and a H_2O-rich solution is in contact, new phases can be built up and ultimately heal the crack [8].

“From these findings, we propose that persistent, aggregate-scale, high surface area lime clasts that result from this process could serve as a source of reactive calcium for long-term pore and crack filling and therefore provide a chemically dominated intrinsic self-healing mechanism.” [9]

3D model to sculpture

In order to symbolize the concept of an everlasting ideal exposed concrete recipe, a three-dimensional object has been cast using the exact formula of the proposed mixture. The texture of the 3D model on the left side was taken from a photograph of the surface of the material, as seen in Figure 1.
The slightly red color results from the substitution of 10m% of the total amount of white cement with a metakaolin powder to reduce the amount of CO_2 compared to regular formulas.

Figure 1: Texture of the everlasting exposed concrete recipe

Figure 2: Photographic representation of the used materials in weight representation. Quarzsand, Rutil, Metakaolin, Limestone Powder, basalt microfibers, Calciumoxid aggregates and white cement

Figure 3: Specimen and sculpture

Figure 4: Dense packing illustrated on a grinded surface and a graphical representation of a multi-sized spherical random closed packing system [10]

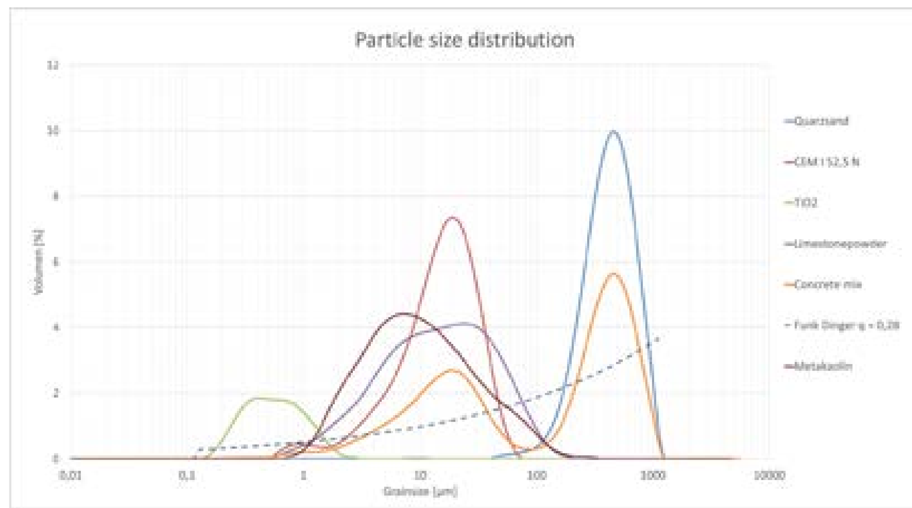

Figure 5: Particle size distribution of the single ingredients, the concrete mix and the target optimized Funk-Dinger curve optimized through a Schwanda packing model [11] [12]

Multifunctional principals of the everlasting exposed concrete recipe

Optimized rheological parameters

In order to enable an on-site rheologically workable concrete mix, the recipe has been optimized to have self-compacting properties according to the Okamura scheme [13]. This principle uses a specific dosage of superplastifiers to allow the concrete to self-consolidate and therefore fill without external vibrations, even with a water-to-binder ratio below 0,3. To enable workable high-performance concrete, a delayer has been added, and a 120-minute consistency window has been enabled.

Figure 6: Slump spread testing

Long-lasting appearance and reduced CO_2 usage

Exposed concrete has high demands on appearance and the ability to be colored. To possible minimize the change in appearance over the service life, the recipe exchanges 10m% of the cement content with metakaolin. This calcined clay mineral reacts in a pozzolanic way with the Portlandite and additional limestone powder in such a way to minimize secondary chemical crystallizations and provide comparable strength to ordinary concrete recipes. This approach also substitutes a part of the cement with calcined clay to reduce the overall CO2 consumption of the material composition [14] [15].

Figure 7: Metakaolin added to the mxiture

Self-cleaning photocatalytic properties

An additional easy-to-apply concept is to add TiO2 to the recipe in the configuration of Rutil; see Figure 8. This material used in many industry branches enables higher packing and therefore durability and strength improvements. But as a result of its multifunctional impact, it is able to be UV-activated. Already an addition of 1m% of the cement weight of Rutil to the mixture enables photocatalytic properties that degrade air pollution in the form of NOx degradation by up to 15% which has been realized in the recipe. Additionally, anti-bacterial behavior has been shown to prolong the design appearance of exposed concrete when adding Rutil to the recipe [16].

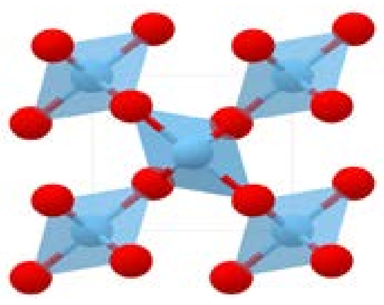

Figure 8: Rutil structure [17]

Self-healing and crack prevention

As shown in Figure 8 and described in the top section, the use of CaO aggregates can help to self-heal the binder matrix when cracks occur and a solution gets in touch with the CaO aggregates. Additionally, basalt microfibers have been added, as seen on the surface of the concrete in Figure 9, to prevent shrinkage cracking in the first place.

Figure 9a left: Crack healing mechanism by addition of CaO
Figure 9b right: Image of the healing process investigated in [9]

Figure 10: Photographic representation of the matrix and the included distributed basalt microfibers on the surface and before wet mixing

Conclusions and discussion points

The main concern in designing a recipe with CO2-intensive cementitious material to make it as durable as possible is the usual higher demand for cement mass per cubic meter of material.
Therefore, it is necessary to design the composition as densely as possible to enable durability, which allows the building, in the best case, to never be replaced. Not only is the durability increased, but it would be ideal to decrease the needed volume to such a degree that the CO_2 consumption is lower than using ordinary concrete while sustaining the same needed strength of the structure.
To make this possible in the discussed concept, further investigations are needed, but still, using the approach of a high packing system and self-healing mechanisms can be beneficial. Hence, the idea is that a structure of concrete has the ability to fully carbonize, self-heal, and recapture parts of the released CO_2 due to the burning of the clinker of the cement [18].
This process should go hand in hand with the least amount of future corrosion products in the steel reinforcement due to constant crack-preventing mechanisms such as a self-healing matrix.

Thus the concept of constantly self-healing cementitious and limestone-calcined clay binding materials and highly packed multifunctional systems has yet to be fully experimentally verified and discussed. But it most likely be a part of the journey for future scientific projects and hopefully ease the way for a more sustainable industry with an eye for technical finess, design, and appearance.

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