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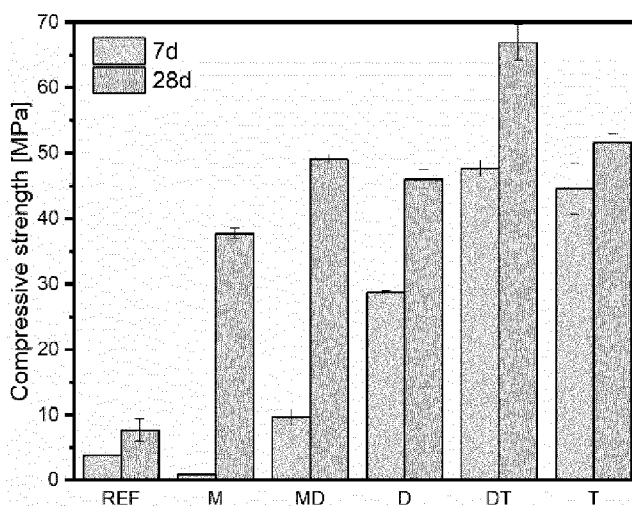


Fig.12

(57) Abstract: The invention relates to a method for activating Basic Oxygen Furnace (BOF) steel slag minerals comprising a step of adding an activator to the Basic Oxygen Furnace (BOF) steel slag minerals, wherein the activator is a phosphate compound selected from the group consisting of: monopotassium phosphate, monosodium phosphate, monoammonium phosphate, dipotassium phosphate, disodium phosphate, di-ammonium phosphate, tripotassium phosphate, trisodium phosphate, tri-ammonium phosphate, or a combination thereof. The invention further relates to a premix kit comprising the activated BOF steel slag minerals, as well as to building materials based on the activated BOF steel slag minerals.



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METHOD FOR ACTIVATING BASIC OXYGEN FURNACE STEEL SLAG

FIELD OF THE INVENTION

The invention relates to a method for activating Basic Oxygen Furnace steel slag minerals, to a mixture comprising the activated BOF steel slag minerals, as well as to a building materials or building products based on the activated BOF steel slag minerals.

BACKGROUND TO THE INVENTION

Basic oxygen steelmaking (abbreviated as BOS, BOP, or BOF), also known as Linz-Donawitz steelmaking or the oxygen converter process, is a method of primary steelmaking in which carbon-rich molten pig iron is made into steel. Blowing oxygen through a lance over the molten pig iron inside the converter lowers the carbon content of the alloy and changes it into low-carbon steel. The process is known as “basic” because fluxes of burnt lime or dolomite, which are chemical basis, are added to promote the removal of impurities and protect the lining of the converter.

A by-product from the basic oxygen steelmaking process is Basic Oxygen Furnace (BOF) steel slag. Around 80–110 kg of BOF steel slag is created per ton of steel produced. A considerable amount of BOF steel slag is currently landfilled or temporarily stored, causing potential environmental issues. The BOF steel slag is composed of: CaO 35–60 wt.%, SiO₂ 10–15 wt.%, total Fe content expressed as FeO 15–35 wt.% (with Fe₂O₃ 3–10 wt.% and FeO 15–25 wt.%), Al₂O₃ 1–5 wt.%, MgO 3–13 wt.%, and P₂O₅ 1–4 wt.%. Its mineral composition is represented by C₂S, C₃S, C₂F, RO phase (CaO-FeO-MgO-MnO solid solution), magnetite and C₄AF.

Blast furnace slag is distinct from BOF steel slag. Where blast furnace slag results from smelting iron ore, coke, and fluxes during the operations of extracting iron from the iron ore, the BOF steel slag is formed during refining operations converting the crude iron into steel by combining fluxes with the nonferrous oxides and other unwanted elements in the raw materials under molten state. Blast furnace slag is composed of: CaO 34–42 wt.%, SiO₂ 28–38 wt.%, Al₂O₃ 8–20 wt.%, MgO 6–12 wt.%, and a very low total Fe-content expressed as FeO (FeO, Fe₂O₃) of less than 2 wt.%.

Patent document US-5,553,670 discloses a method and composition for cementing a well by combining water, blast furnace slag and a phosphate-ion containing compounds to form a cement slurry, displacing the cement slurry into the well, and allowing the cement slurry to set. The use of sodium hexametaphosphate, sodium tripolyphosphate, and tetrasodium polyphosphate are disclosed as activator to reduce the setting time of the cement slurry. In the examples a commercial available “NEWCEM” blast furnace slag is used in combination with 50% distilled water by weight of slag.

Patent document US-2011/0232532-A1 discloses a composition capable of setting to produce a building material, the composition comprising: 1-55 wt.% of a pozzolan, 1-30 wt.% of an activator, 40-90 wt.% of an aggregate, and liquid landfill leachate in a sufficient amount such that the composition sets to a building material having a compressive strength of at least 2.0 MPa. The pozzolan is selected from fly ash, silica fume, metakaolin, ground granulated blast furnace slag, and mixtures thereof. Preferably the pozzolan is fly ash. Preferably the liquid landfill leachate is recovered from a landfill including at least one coal combustion product (CCP) selected from fly ash, bottom ash, boiler slag, and flue gas desulfurization material.

The use of BOF steel slag however in cement and concrete industry is limited due to a number of technological barriers, i.e., a low hydraulic activity due to low amorphous content, high amounts of inert phases, volume instability problems due to the presence of free CaO, and contamination with heavy metals, in particular vanadium and chromium. Additionally, even after application as a building material, the carbonation resistance is always relevant as carbonation can cause the leaching of heavy metal ions.

DESCRIPTION OF THE INVENTION

An object of the present invention is to provide a method for activating BOF steel slag minerals.

An object of the present invention is to provide BOF steel slag minerals to be used as a reactive binder in the field of cement and concrete technology.

Another object of the present invention is to enhance the carbonation resistance of BOF steel slag minerals, in particular when used in BOF steel slag-based building materials.

Another object of the present invention is to provide BOF steel slag minerals in which leaching is effectively controlled under carbonation.

These and other objects and further advantages are met or exceeded by the present invention according to claim 1 and with preferred embodiments set out in the dependent claims.

In order to achieve these objects, the present invention proposes, in a first aspect, a method for activating Basic Oxygen Furnace (BOF) steel slag minerals for use in building products, the method comprising a step of adding an activator to the Basic Oxygen Furnace (BOF) steel slag minerals, wherein the activator is a phosphate compound selected from the group consisting of: monopotassium phosphate, monosodium phosphate, monoammonium phosphate, dipotassium phosphate, disodium phosphate, di-ammonium phosphate, tripotassium phosphate, trisodium phosphate, tri-ammonium phosphate, or a combination thereof.

On basis of the above one or more objects have been achieved. In accordance with the invention it has been found to transform BOF steel slag powder into a cement-free cementitious materials with the addition of a phosphate compound selected from the group of monopotassium phosphate,

monosodium phosphate, monoammonium phosphate, dipotassium phosphate, disodium phosphate, diammonium phosphate, tripotassium phosphate, trisodium phosphate, tri-ammonium phosphate, or a combination thereof, satisfying the requirement of strength development and environmental protection.

In an embodiment the total amount of monopotassium phosphate, monosodium phosphate and/or monoammonium phosphate is at most 15 wt.%, preferably at most 10 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals.

In another embodiment the total amount of dipotassium phosphate, disodium phosphate, diammonium phosphate, tripotassium phosphate, trisodium phosphate and/or tri-ammonium phosphate is at most 10 wt.%, preferably at most 5 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals.

In a preferred embodiment the activator is a phosphate compounds selected from the group consisting of: monopotassium phosphate, dipotassium phosphate, tripotassium phosphate, monosodium phosphate, disodium phosphate, or a combination thereof. Experimental results have shown that these compounds and in particular at least each of monopotassium phosphate and dipotassium phosphate can provide about the same compressive strength levels in a building product, or building material, and where each of dipotassium phosphate and tripotassium phosphate require a lower amount to be added to achieve about the same result as does monopotassium phosphate. And it has been demonstrated that dipotassium phosphate and tripotassium phosphate provide even better leaching results, at least for vanadium and chromium, compared to monopotassium phosphate. All these components as activator provide leaching properties of vanadium and chromium within the limits of the Dutch Soil Quality Decree, 2007, "Regeling Bodemkwaliteit", Annex A, as part of section 3.3. (viz. SQD limit values: V <1.80 mg/kg, and Cr <0.63 mg/kg).

In an embodiment the activator is monopotassium phosphate (KH_2PO_4). The total amount of this activator is at most 15 wt.%, preferably at most 10 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals. In an embodiment at least 0.10 wt.% is present, and preferably at least 0.50 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals.

In an embodiment the activator is dipotassium phosphate (K_2HPO_4). The total amount of this activator at most 10 wt.%, preferably at most 5 wt.%, and more preferably at most 3.5 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals. In an embodiment at least 0.10 wt.% is present, and preferably at least 0.50 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals.

In an embodiment the activator is tripotassium phosphate (K_3PO_4). The total amount of this activator at most 10 wt.%, preferably at most 5 wt.%, and more preferably at most 3.5 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals. In an embodiment at least 0.10 wt.% is

present, and preferably at least 0.50 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals.

When monopotassium phosphate, dipotassium phosphate and/or tripotassium phosphate are added in combination, e.g. dipotassium phosphate together with tripotassium phosphate, the combined total amount of phosphate compounds is in a range of 0.10-10 wt.%, and preferably in a range of 0.10-5 wt.%, and more preferably in a range of 0.50-3.5 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals, and with preferred ranges as herein described and claimed.

As known to the person skilled in the art a solution comprising the activator monopotassium phosphate or dipotassium phosphate or a combination thereof can be made also using phosphoric acid in combination with tripotassium phosphate in the appropriate stoichiometric ratios.

Each of monopotassium phosphate, dipotassium phosphate and tripotassium phosphate are known in other non-metallurgical technical fields and accepted as additives or agents for example as a fertilizer, food additive, acidity regulator, or emulsifying agent.

In an embodiment the method for activating Basic Oxygen Furnace (BOF) steel slag minerals further comprises a step of adding water to the mixture of activator and Basic Oxygen Furnace (BOF) steel slag minerals.

In an embodiment a water to solid ratio is at most 0.25, preferably at most 0.22, and more preferably at most 0.20, wherein solid refers to the amount of Basic Oxygen Furnace (BOF) steel slag minerals and activator in the form of a phosphate compound. Hence if any further additions such as sand are added, these additions are not regarded in the water to solid ratio. Preferably the activator is a phosphate selected from the group consisting of monopotassium phosphate, dipotassium phosphate, tripotassium phosphate, monosodium phosphate, disodium phosphate, or a combination thereof. In an embodiment the water to solid ratio is at least 0.10, and more preferably at least 0.12. At a water to solid ratio of a slag mixture below 0.10, the slag mixture will be too dry, and therefor difficult to process. Hence the water to solid ratio is preferably at least 0.10 to enable mixing and casting of the paste. Excessive water would cause an increase in porosity and decrease in compressive strength of building products. Therefore the water to solid ratio is preferably at most 0.25. Also to avoid bleeding and segregation the water to solid ratio should be preferably below 0.25.

In an embodiment of the method for activating Basic Oxygen Furnace (BOF) steel slag minerals further comprises a step of mixing water with the activator in the form of a phosphate compound, and a subsequent step of adding the mixture thus obtained to Basic Oxygen Furnace (BOF) steel slag minerals. In an embodiment the water to solid ratio is at most 0.25, preferably at most 0.22, and more preferably at most 0.20, and wherein solid refers to the amount of Basic Oxygen Furnace (BOF) steel slag minerals and activator in the form of a phosphate compound. In an embodiment the water to solid ratio is at least 0.10.

In an embodiment according to the invention, the BOF steel slag minerals particle size is at most 500 microns, preferably at most 150 microns. The BOF steel slag particle size is preferably at most 500 microns in order to increase the exposure of the hydrating phases to the activator, to reduce the reaction time and to improve the homogeneity of the product. Such BOF steel slag particle size can be obtained by several methods as known by a person skilled in the art.

In an embodiment of the invention the Basic Oxygen Furnace (BOF) steel slag minerals are milled in such a way that the median grain size of Basic Oxygen Furnace (BOF) steel slag minerals is at most 25 microns, preferably at most 20 microns, and more preferably at most 15 microns. The median grain size is preferably at most 25 microns in order to increase the exposure of the hydrating phases to the activator, to reduce the reaction time and to improve the homogeneity of the product.

In an embodiment of the invention the Basic Oxygen Furnace (BOF) steel slag minerals are milled in such a way that the D50 average grain size of Basic Oxygen Furnace (BOF) steel slag minerals is at most 25 microns, and preferably is at most 20 microns, and more preferably is at most 17 microns. The term "D50" refers to the mean or average particle diameter, considered to be the average particle size by mass. An D50 of 25 microns means the average particle diameter is 25 microns; it also means that 50% of the sample mass consists of particles smaller than 25 microns, and 50% are bigger. The D50 does not exceed at most 25 microns to increase the exposure of the hydrating phases to the activator, to reduce the reaction time and to improve the homogeneity of the product. The inventor has found that, although a lower D50 value is appreciated, excellent results may be obtained when the D50 has a lower limit of at most 10 microns. In an embodiment the D90 average grain diameter is at most 35 microns, and preferably at most 30 microns.

The particle size distribution of BOF steel slag minerals may be measured for example by laser diffraction technique (e.g., Mastersizer2000, Malvern).

In an embodiment according to the invention the BOF steel slag comprises 10 – 30 wt.% brownmillerite, 0 - 15 wt.% magnetite, 25 – 60 wt.% C₂S, 10 – 30 wt.% Mg-Wuestite 0 – 20 wt.% C₃S, and 0 - 6 wt.% free-CaO. C₂S or belite and brownmillerite are commonly present in converter steel slag. Analyses of the solid phases of steel slag pastes showed that the addition of monopotassium phosphate, dipotassium phosphate, tripotassium phosphate, monosodium phosphate, disodium phosphate, or a combination thereof promotes the dissolution and hydration of C₂F and C₂S and thereby contributing to the compressive strength development of the resulting building product.

In an embodiment according to the invention the BOF steel slag comprises 35 - 60 wt.% CaO, 10 – 17 wt.% SiO₂, 15 – 35 wt.% of \sum Fe Oxides, 1 – 5 wt.% Al₂O₃, 1 – 13 wt.% MgO, 0 – 4 wt.% P₂O₅, 0 – 2 wt.% TiO₂, and balance impurities.

In an aspect of the invention it relates to a steel slag mixture or paste comprising of the combination of BOF steel slag minerals, the activator in the form of a phosphate compound as herein

described and claimed and water alone. The steel slag mixture may be used to prepare building products or building materials with excellent compressive strength. In an embodiment the building products or building materials have a seven-day compressive strength and/or a twenty eight-day compressive strength of at least 20.0 MPa and 35.0 MPa, respectively. In an embodiment the building products or building materials have a twenty eight-day compressive strength of at least 40 MPa. In these embodiments the steel slag mixture typically has a water to solid ratio of at most 0.25. Alternatively the steel slag mixture may comprise further additions such as sand, gravel and/or limestone, resulting in a mortar or concrete like mixture. This allows for a wider application of the BOF steel slag minerals in high end building products, thereby providing the potential to significantly reduce landfilled BOF steel slag.

In another aspect of the invention there is provided a method for preparing a building product comprising the steps of:

- a) providing Basic Oxygen Furnace (BOF) steel slag minerals; and
- b) optionally providing solid additions, such as sand, gravel and/or limestone;
- c) adding an aqueous solution of the activator comprising a phosphate compound as herein described and claimed;
- d) mixing the ingredients of step a) to c) to obtain the steel slag mixture paste according to the specification above;
- e) applying the steel slag mixture or steel slag paste in a mould;
- f) curing the steel slag mixture or steel slag paste to obtain the building product.

The method according to the invention as such can be used to produce high strength prefabricated building elements or building products at ambient conditions. The BOF steel slag minerals are activated with the activator in the form of a phosphate compound, thereby obtaining a high performance of the resulting building product, e.g. high compressive strength, low porosity and very limited leaching of heavy metals, if any. The solid ingredients may be added in any order and are mixed with an aqueous solution of the activator comprising a phosphate compound. A steel slag mixture composed of the combination of BOF steel slag minerals, the activator in the form of a phosphate compound and water alone is commonly referred to as a paste. And a steel slag mixture composed of the combination of BOF steel slag minerals, the activator in the form of a phosphate compound, water and sand (commonly about 2/3 by mass being sand) is commonly referred to as a mortar. By mixing, a homogeneous steel slag mixture is obtained, which can be added to a mould. The method can be carried out at ambient conditions and no special curing conditions are required. Sufficient workability of the mixture is reflected in homogenous distribution of the phases in the hydrated mixture, sufficient spreadflow of the mixture, as well as the low porosity of the final shaped building product.

Alternatively, there is provided a method for preparing a building product comprising the steps of:

- a) providing Basic Oxygen Furnace (BOF) steel slag minerals;

- b) optionally providing solid additions, such as sand, gravel and/or limestone;
- c) providing an activator comprising a phosphate compound as herein described and claimed, and mixing the ingredients of step a) to c);
- d) adding water;
- e) mixing the ingredients of step a) – d) to obtain the steel slag mixture (paste or mortar) according to the specification above;
- f) applying the steel slag mixture in a mould;
- g) curing the steel slag mixture to obtain the building product.

These methods can be used to produce high strength prefabricated building elements at ambient conditions. The BOF steel slag minerals are activated with the activator in the form of a phosphate compound, thereby obtaining a high performance of the resulting product (e.g. high compressive strength, low porosity). The solid ingredients may be added in any order, optionally premixed, and mixed with water. By mixing, a homogeneous slag mixture is obtained, which can be transferred to a mould. The method can be carried out at ambient conditions and no special curing conditions are required. Sufficient workability of the mixture is reflected in homogenous distribution of the phases in the hydrated mixture, sufficient spreadflow of the mixture, as well as the low porosity of the final shaped building product.

For both methods, the slag mixture is preferably setting in the mould within a desirable setting time, wherein the setting time ranges between 1 – 72 hours. The setting time is related to the amount of activator and water added. The setting time is preferably at least about 1 hour, to allow the worker to mould the slag mixture in its desired shape. The setting time is preferably at most about 24 hours. After setting the building product can be demoulded, thereby reducing the time in the mould. The curing typically continues after demoulding, and the mould can be used for the next building product.

The present invention is useful for turning currently landfilled or low grade applied BOF steel slag minerals into high end shaped building products with high compressive strength. Additionally, in Europe, the annual production of BOF steel slag is over 10 million tons. No special investments are needed, BOF steel slag-based building materials can be produced at concrete making companies directly. As BOF steel slag is currently landfilled, production costs are limited to the price of the activator in the form of a phosphate compound as herein described and claimed and water. No additional equipment is required in comparison with standard paste or concrete manufacture. The resultant building products have a seven-day compressive strength and/or a twenty eight-day compressive strength of at least 20.0 MPa and 35.0 MPa, respectively, and measured in accordance with EN 196-1 (in three replicates for each composition). In an embodiment the building products or building materials have a twenty eight-day compressive strength of at least about 40 MPa.

In an embodiment according to the invention, the building product has a mesoporous structure. The average pore diameter is preferably in the range of 2 to 50 nm, more preferably in the range of 2 to 20 nm. A mesoporous structure has the advantage that a higher homogeneity and a higher compressive strength can be obtained, as well as a high durability.

In an embodiment according to the invention, the leaching properties of the building products, both before and after carbonation, and most in particular for vanadium and chromium, are within the limits of the Dutch Soil Quality Decree, 2007, "Regeling Bodemkwaliteit", Annex A, as part of section 3.3. (viz. SQD limit values: V <1.80 mg/kg, and Cr <0.63 mg/kg).

The leaching can be measured according to EN 12457-2 (one stage batch leaching test).

The cementitious phases (belite and brownmillerite) are also the most contaminated phases in the steel slag, implying the risk of heavy metal leaching during the hydration and service life of the steel slag pastes and mortars. As the heavy metals originated from brownmillerite (mainly chromium and vanadium) and belite (mainly vanadium) are also present in the hydration products, the steel slag mixture according to the invention leads to immobilization and hence significant reduction of leaching of heavy metals.

In another aspect of the invention it relates to a premix kit, i.e. in a dry form, for obtaining a building product comprising of the BOF steel slag and an activator in the form of a phosphate compound, wherein the phosphate compound ranges between 0.10 and 15 wt.%, preferably between 0.10 and 10 wt.%, and more preferably between 0.10 and 5 wt.%, by mass of BOF steel slag minerals. The BOF steel slag minerals and the phosphate compound activator are as herein described and claimed. The premix kit can be used to instantaneously prepare a high-end shaped building product by adding water, and mixing and curing as known in the art.

In another aspect of the invention it relates to the use of a phosphate compound selected from the group of: monopotassium phosphate, dipotassium phosphate, tripotassium phosphate, monosodium phosphate, disodium phosphate, or a combination thereof, as activator for BOF steel slag minerals in the production of shaped building products and to reduce the leaching of at least vanadium and chromium within the limits of the Dutch Soil Quality Decree, 2007, "Regeling Bodemkwaliteit", Annex A, as part of section 3.3. (viz. SQD limit values: V <1.80 mg/kg, and Cr <0.63 mg/kg). The total amount of monopotassium phosphate is in a range of 0.10-15 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals, and with preferred ranges as herein described and claimed. The total amount of dipotassium phosphate is in a range of 0.10-10 wt.%, and preferably in a range of 0.10-5 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals, and with preferred ranges as herein described and claimed. The total amount of tripotassium phosphate is in a range of 0.10-10 wt.%, and preferably in a range of 0.10-5 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals, and with preferred ranges as herein described and claimed. When monopotassium phosphate,

dipotassium phosphate and/or tripotassium phosphate are added in combination, e.g. dipotassium phosphate together with tripotassium phosphate, the total amount of phosphate compounds is in a range of 0.10-10 wt.%, and preferably in a range of 0.10-5 wt.%, and more preferably 0.50-3.5 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals, and with preferred ranges as herein described and claimed.

The invention will now be explained by means of the following non-limiting figures and embodiments according to the invention.

Fig. 1 shows (a) the particle size distribution of BOF steel slag used, and (b) the cumulative particle size distribution.

Fig. 2 is the compressive strength of the BOF steel slag pastes with dosages of mono- potassium phosphate from 0 to 10 wt.% after 7-days and 28-days curing.

Fig. 3 shows (a) cumulative heat evolution and (b) heat flow of BOF steel slag pastes with dosages of monopotassium phosphate (MKP) varying from 0 to 10 wt.%.

Fig. 4 is XRD data of hydrated samples with dosages of monopotassium phosphate (MKP) (Legend: B-Brownmillerite, L-Larnite, M-Magnetite, W-Wuestite, H-Hydrogarnet, Ht-Hydrotalcite).

Fig. 5 is the FTIR spectra of BOF steel slag pastes after 28 days of hydration.

Fig. 6 is the thermal analysis (DTG) of BOF steel slag pastes with dosages of mono- potassium phosphate (MKP) varying from 0 to 10 wt.% after 7 and 28 days of hydration.

Fig. 7 is the representative BSE image and phase distribution map of 28d-hydrated BOF steel slag paste with MKP dosage of 5 wt.%.

Fig. 8 is the compressive strength of the BOF steel slag pastes with dosages of dipotassium phosphate (DKP) from 0 to 3 wt.% after 7- and 28-days curing.

Fig. 9 is XRD data of hydrated samples with 2 wt.% dosages of dipotassium phosphate (DKP) (Legend: H-Hydrogarnet, Ht-Hydrotalcite).

Fig. 10 is the thermal analysis (DTG) of BOF steel slag pastes with dosages of dipotassium phosphate (DKP) varying from 0 to 3 wt.% after 7 days and 28 days of hydration.

Fig. 11 is the thermal analysis (DTG) of 28d-hydrated BOF steel slag pastes with dosages of dipotassium phosphate (DKP) varying from 0 to 3 wt.% after 3 days and 14 days of carbonation.

Fig. 12 is the compressive strength of the BOF steel slag pastes with dosages of monopotassium phosphate (MKP), dipotassium phosphate (DKP), tripotassium phosphate (DKP), and combinations thereof after 7 days and 28 days curing.

Table 1 relates to the mineralogical and chemical composition of typical BOF steel slag used for these investigations.

Table 2 relates to average chemical composition of the main phases in 28-days hydrated BOF steel slag.

Table 3 relates to leaching of inorganic contaminants measured by one stage batch leaching test and the SQD limit values as specified in the Dutch Soil Quality Decree.

Table 4 relates to leaching of inorganic contaminants measured by one stage batch leaching test on 28-days cured BOF steel slag pastes and the SQD limit values as specified in the Dutch Soil Quality Decree.

Table 5 relates to leaching of inorganic contaminants measured by one stage batch leaching test on 14 days carbonated BOF steel slag pastes and the SQD limit values as specified in the Dutch Soil Quality Decree.

Table 6 relates to the porosity of dipotassium phosphate (DKP) activated BOF steel slag before and after carbonation against non-activated BOF steel slag.

Table 7 relates to the phase composition of dipotassium phosphate (DKP) activated BOF steel slag after 28-days hydration.

Table 8 relates to the dosages of MKP, DKP, TKP, and some combinations tested for the compressive strength after 7- and 28-days curing.

BOF steel slag contains considerable C_2S and C_2F and X-ray amorphous accounting for in this example about 65-70 wt.% in total of the mineral compounds as shown in Table 1, which are the targeted phases to be activated. The BOF steel slag is ground for 15 minutes using disc mill to obtain a median grain size of about 17 microns as shown in Fig. 1, in order to expose the hydrating phases. Monopotassium phosphate (MKP) is first chosen as the activator, which may be used also as a fertilizer, food additive, or buffering agent in other technical fields. The maximum addition of monopotassium phosphate is 15 wt.%, and preferably maximum 10 wt.%, by the mass of BOF steel slag. Monopotassium phosphate is mixed with BOF steel slag powder directly to obtain a homogenous distribution and then the water is added with a water to solid ratio of 0.2. The operation is conducted at ambient conditions and no special curing conditions are required. The prepared specimens gain a 7-days compressive and a 28-days compressive strength up to 19.8 MPa and 44.5 MPa, respectively (Fig. 2). The setting time varies from 3 minutes to 24 hours or even longer, depending on the addition amount of monopotassium phosphate. The addition of monopotassium phosphate promotes the dissolution and hydration of C_2F and C_2S and then enhances the mechanical properties in comparison to reference samples, in line with the high heat release shown in Fig. 3. The main hydration products are hydrotalcite, hydrogarnet, C-S-H gel and hydroxyapatite-like minerals as shown in Fig. 4 and Fig. 5, which is further confirmed by

thermogravimetric analysis (Fig. 6). Meanwhile, leaching of BOF steel slag pastes after 28 days of hydration fulfills the legislation requirements (Table 3), which can be explained by the incorporation of heavy metals in the hydration products (Table 2).

Dipotassium phosphate (DKP) with high water solubility can replace monopotassium phosphate (MKP), which may also be used as a fertilizer, food additive, or buffering agent in other technical fields. The maximum addition of dipotassium phosphate is 10 wt.%, and preferably maximum 5 wt.%, by the mass of BOF steel slag. In this embodiment the water to solid (BOF slag + DKP) ratio is 0.18. Dipotassium phosphate is first added to the water to ensure a homogenous dispersion prior to the mixing. The operation is conducted at ambient conditions and no special curing conditions are required. The prepared specimens gain a 7-day compressive and a 28-day compressive strength up to 26.7 MPa and 42.5 MPa, respectively (see Fig. 8). Similar to monopotassium phosphate, the addition of dipotassium phosphate promotes the formation of hydrotalcite, hydrogarnet, C-S-H gel and hydroxyapatite-like minerals as shown in Fig. 9 and Fig. 10. The high carbonation resistance of dipotassium phosphate-activated BOF steel slag has been proved via thermogravimetric analysis, which shows minor changes after 14-days carbonation comparing to the reference sample. Additionally, both leaching behavior of 28-days hydrated BOF steel slag pastes before and after 14-days carbonation fulfills the legislation requirements (Table 4 and Table 5).

The present method for activating Basic Oxygen Furnace (BOF) steel slag minerals can be used to produce high-strength prefabricated building elements with high carbonation resistance at ambient conditions.

For Table 1 the elemental composition is determined by the XRF (fused beads method). The mineralogical composition of BOF steel slag is analyzed by X-ray diffraction (D2 PHASER X-ray Diffractometer equipped with Co X-ray tube) with Corundum external standard method. Samples were scanned on a rotating stage (with a spinning speed of 10 rpm) using a step size of 0.02° and a time per step of 2 s for a 2θ range of $7-90^\circ$. Quantitative Rietveld refinement was performed with TOPAS Academic software v5.0.

For Table 2 the oxide composition of the phases in the hydrated BOF steel slag is derived from PARC results (PhAse Recognition and Characterization) as described by C. vanHoek et al., in "Large-Area Phase Mapping Using PhAse Recognition and Characterization (PARC) Software", *Microscopy-Today*, September 2016, pp.12-20.

For Table 3 the batch leaching test was performed on the 28-days cured steel slag pastes according to EN 12457-2 (one stage batch leaching test). Obtained elements concentrations were compared with the limit values specified in the Dutch Soil Quality Decree.

For Table 4 the batch leaching test was performed on the 28-days cured slag pastes according to EN 12457-2 (one stage batch leaching test). Obtained elements concentrations were compared with the limit values specified in the Dutch Soil Quality Decree.

For Table 5 the batch leaching test was performed on the 14-days carbonated BOF steel slag pastes according to EN 12457-2 (one stage batch leaching test). Obtained elements concentrations were compared with the limit values specified in the Dutch Soil Quality Decree.

For Table 7 the elemental composition is determined using a D4 ENDEAVOR X-ray Diffractometer equipped with a LynxEye detector and a Co X-ray tube (operating at 40KV and 40 mA). The diffraction measurements were performed with a step size of 0.019° and a counting time of 1 second per step. Variable divergence slits ($V20$) were employed, and the scanning range covered 10 to $90^\circ 2\theta$.

For Figure 1 the BOF steel slag is milled in a disc mill (Retsch, RS300XL). The particle size distribution of BOF slag after mechanical treatment is measured by laser diffraction technique (Mastersizer 2000, Malvern). For Fig.1(b) the $D50$ is 17 microns and $D90$ is 107 microns.

For Figure 3 an isothermal conduction calorimeter (TAM Air, Thermometric) was used. In order to evaluate the cumulative heat, the integration of the heat flow curve was performed between 45 min and 23 days. Notably, MKP2.5 was tested till 32 days because it underwent a quite long induction period.

For Figure 5 bands located at 1034 cm^{-1} , 604 cm^{-1} and 502 cm^{-1} are associated with the phosphate groups in apatite-like minerals.

For Figure 11 the minor change of the calcite peak in the dipotassium phosphate-activated BOF steel slag shows the excellent carbonation resistance in comparison to the reference BOF steel slag.

Examples

The reference sample in comparison to the monopotassium phosphate-activated BOF steel slag was prepared using a mixer with a water to solid ratio of 0.2, which is 0.18 for the reference sample in comparison to the dipotassium phosphate-activated BOF slag based on the results from preliminary experiments. The BOF steel slag powder was first mixed with water at a low speed for 30 s and then subsequently manually homogenized for another 30 s, followed by another mixing for 60 s with a high speed.

Monopotassium phosphate, whose amount is equivalent to 2.5, 5, 10 wt.% of BOF steel slag, was first mixed with BOF steel slag powder in a mixer at a low speed for 30 s to obtain a homogenous distribution. Water was then added to the dry mixture with a water to solid ratio (BOF steel slag plus monopotassium phosphate) of 0.2. Mixing for 30 s with a low speed, subsequently manual homogenization for another 30 s and then mixing for 60 s with a high speed was applied to obtain the monopotassium phosphate-activated BOF steel slag paste. The fresh BOF steel slag paste was cast into

foam molds (40×40×160 mm) and then covered with plastic film before demolding. Due to the various setting time, the samples with 5 wt.% and 10 wt.% can be demolded after 24 hours while the samples with 0 wt.% and 2.5 wt.% need to be demolded carefully after 7 days to ensure sufficient hardening. Afterwards, the pastes were demolded, covered with the foil, and cured in the air at ambient temperature until the testing age. The 7-days and 28-days compressive strength was determined according to EN 196-1, in three replicates for each composition.

The samples described here are based on the amount of monopotassium phosphate added, as MKP0, MKP2.5, MKP5, MKP10 for 0, 2.5, 5, 10 wt.% of monopotassium phosphate dosage, respectively.

Dipotassium phosphate, whose amount is equivalent to 1, 2 and 3 wt.% of BOF steel slag, was first added to the water to ensure a homogenous dispersion prior to the mixing. The water to solid (BOF slag + DKP) ratio is 0.18. The BOF steel slag powder was first mixed with dipotassium phosphate solution at a low speed for 30 s and then subsequently manually homogenized for another 30 s, followed by another mixing for 60 s with a high speed to obtain the dipotassium phosphate-activated BOF steel slag paste. The fresh BOF steel slag paste was cast into foam molds (40×40×160 mm) and then covered with plastic film before demolding after 3 days to ensure sufficient hardening. Afterwards, the pastes were demolded, covered with the foil, and cured in the air at ambient temperature until the testing age. The 7-days and 28-days compressive strength was determined according to EN 196-1, in three replicates for each composition.

The samples described here are based on the amount of dipotassium phosphate added, as DKP0, DKP1, DKP2, DKP3 for 0, 1, 2, 3 wt.% of DKP dosage, respectively.

Dipotassium phosphate-activated BOF steel slag specimen and the corresponding reference BOF slag specimen were chosen for the test of carbonation resistance. After 28-days curing, the samples were placed in a CO₂ chamber with a CO₂ concentration of 20% and a relative humidity of 80% for 3 days and 14 days. The labels of the carbonated samples are based on the carbonation period. For instance, CDKP0-3d is the sample with 0 wt.% DKP after 3-days carbonation.

After the designed curing periods, the samples were crushed manually to pass a sieve of 4 mm and then immersed in isopropanol for 24 hours to eliminate hydration, followed by drying in an oven at 45°C until a constant mass. All dried samples were ground finely to pass a sieve of 68 μm and then stored in desiccators, using a drying agent (CaCl₂ pellets) and sodium hydroxide pellets as a CO₂ trap until further testing.

From the results of Table 4 and 5 it can be seen that a significant improved carbonation resistance and a controllable leaching behavior of heavy metals, in particular of vanadium and chromium, before and after carbonation has been found.

From the results of Table 6 it can be seen that DKP2 results in a reduction in porosity occurs for the DKP2 sample following carbonation (CDKP2). The addition of DKP also results in a considerable lower porosity both before and after carbonation compared to samples having no addition of dipotassium phosphate (DKP0).

From the results of Table 7 it can be seen that in accordance with the invention the addition of a phosphate compound, in this case dipotassium phosphate (DKP), at increasing levels it promotes the dissolution and hydration of C_2F and C_2S . With increasing presence of DPK the amount of C_2F and C_2S decreases and the amount of amorphous increases after 28-days hydration. Similar trends have been found for monopotassium phosphate (MKP) and tripotassium phosphate (TKP).

In a similar set up as set out above the compressive strength has been measured for a further series of samples having no phosphate compound (REF), or a defined amount of monopotassium phosphate (MKP), dipotassium phosphate (DKP), tripotassium phosphate (TKP), a mixture of MKP+DKP and of DKP+TKP. The amounts of phosphate compound(s) added are listed in Table 8 and the water to solid ratio is 0.18 for the samples comprising MKP, DKP, TKP or combinations thereof and 0.2 for the REF sample, and the results are shown in Fig. 12. The 7-days and 28-days compressive strength was determined again according to EN 196-1, in three replicates for each composition.

On basis of the above results and discussion it has been found that BOF steel slag can be activated with small amounts of a specific group of phosphate compounds, and preferably selected from the group consisting of monopotassium phosphate, dipotassium phosphate, tripotassium phosphate, or combinations thereof. From the results of Fig. 2 and Fig. 8 it can be seen that monopotassium phosphate and dipotassium phosphate can provide about the same compressive strength levels and where dipotassium phosphate requires a lower amount to be added to achieve about the same results. Similar or better results have been found for tripotassium phosphate (Fig. 12). A combination of dipotassium phosphate and tripotassium phosphate resulted in the highest compressive strength levels. And from the results of Table 3-5 it can be seen that dipotassium phosphate provides even better leaching results, at least for vanadium and chromium, compared to monopotassium phosphate. Similar results have been found for tripotassium phosphate.

The products obtained according to the present method provide adequate strength for the application as building materials with the addition of a specific group of phosphate compounds, and most preferably selected monopotassium phosphate, dipotassium phosphate, tripotassium phosphate, or combinations thereof.

The inventor also found a significantly improved carbonation resistance and a controllable leaching behavior of heavy metals, in particular of vanadium and chromium, before and after carbonation.

The above-discussion is intended to be merely illustrative of the present process and should not be construed as limiting the appended claims to any particular embodiment or group of embodiments. Accordingly, the specification and figures are to be regarded in an illustrative manner and are not intended to limit the scope of the appended claims. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the figures, the disclosure, and the appended claims. The mere fact that certain measures are recited in different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

Table 1. Mineralogical and chemical composition of the BOF steel slag.

Mineral compound	Content [wt.%]	Oxide	Content [wt%]
Brownmillerite	17.4	MgO	8.04
Magnetite	10.9	SiO ₂	13.8
C ₂ S	31.6	Al ₂ O ₃	2.44
Wuestite	21.1	CaO	39.5
Lime	0.5	P ₂ O ₅	1.67
Calcite	0.6	TiO ₂	1.45
Portlandite	1.2	V ₂ O ₅	1.05
C ₃ S	0.2	Cr ₂ O ₃	0.3
X-ray amorphous	16.5	MnO	4.4
		Fe ₂ O ₃	29
		SrO	0.02
		Na ₂ O	<0.2
		K ₂ O	<0.01
		GOI 1000	1.41

Table 2 Average chemical composition of the main phases in 28-days hydrated BOF steel slag.

Phase	Oxide											
	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	SO ₃	K ₂ O	CaO	TiO ₂	V ₂ O ₅	MnO	Fe ₂ O ₃
C2S MKP2.5	0.25	0.26	0.24	24.62	2.27	1.27	0	56.61	0.52	1.06	0	2.07
Wuestite/Magnetite MKP2.5	1.43	21.39	0	1.49	0.01	0.01	0.05	2.78	0.04	0.51	14.34	57.39
Brownmillerite MKP2.5	0.56	0.76	7.13	1.73	0.77	0.25	0.11	40.53	7.97	0.84	2.06	37.23
Hydration products MKP2.5	1.09	2.26	1.84	13.66	4.44	0.9	1.82	44.22	1.3	1.8	2.12	21.66
C2S MKP5	0.25	0.17	0.24	24.58	2.36	1.26	0	56.86	0.53	1.19	0	1.75
Wuestite/Magnetite MKP5	1.4	19.24	0	1.12	0	0.01	0.06	2.2	0.01	0.35	13.84	61.28
Brownmillerite MKP5	0.45	0.68	6.26	1.19	0.66	0.18	0.12	39.77	6.44	0.85	1.81	41.57
Hydration products MKP5	0.98	1.92	1.7	14.29	5.95	0.71	4.33	44.47	1.29	1.66	1.16	18.17
C2S MKP10	0.26	0.28	0.34	24.29	2.32	1.27	0.1	56.37	0.69	1.29	0	2.3
Wuestite/Magnetite MKP10	1.44	20.93	0	1.4	0	0.01	0.13	2.2	0.03	0.43	14.47	58.46
Brownmillerite MKP10	0.6	0.8	6.72	1.88	0.68	0.25	0.3	39.88	8.6	0.77	2.34	37.13
Hydration products MKP10	0.97	1.63	1.84	14.42	8.27	0.51	4.45	43.13	1.28	2.07	0.57	17.3

Table 3. Leaching of inorganic contaminants measured by one stage batch leaching test and the SQD limit values.

Parameter	Unshaped	MKP0	MKP2.5	MKP5	MKP10
	material (SQD)				
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Antimony (Sb)	0.32	0.005	0.002	0.005	0.004
Arsenic (As)	0.90	0.007	0.005	0.007	0.004
Barium (Ba)	22.00	0.251	0.519	0.425	0.030
Cadmium (Cd)	0.04	-	-	-	-
Chromium (Cr)	0.63	0.004	0.010	0.039	0.140
Cobalt (Co)	0.54	0.001	0.001	-	-
Coper (Cu)	0.90	0.001	0.001	0.002	0.003
Lead (Pb)	2.30	0.002	0.002	0.001	0.002
Molybdenum (Mo)	1.00	0.008	0.006	0.009	0.083
Nickel (Ni)	0.44	0.001	0.002	0.002	0.001
Tin (Sn)	0.40	-	-	-	-
Vanadium (V)	1.80	0.033	0.008	0.006	0.076
Zinc (Zn)	4.50	0.003	0.002	0.003	0.002

Table 4. Leaching of inorganic contaminants measured by one stage batch leaching test and the SQD limit values.

Parameter	Unshaped	DKP0	DKP1	DKP2	DKP3
	material (SQD)				
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Antimony (Sb)	0.32	0.005	-	-	-
Arsenic (As)	0.90	0.007	-	-	-
Barium (Ba)	22.00	0.251	0.008	0.008	0.010
Cadmium (Cd)	0.04	-	-	-	-
Chromium (Cr)	0.63	0.004	0.004	0.002	0.003
Cobalt (Co)	0.54	0.001	-	-	-
Coper (Cu)	0.90	0.001	-	-	-
Lead (Pb)	2.30	0.002	-	-	-
Molybdenum (Mo)	1.00	0.008	0.01	0.01	0.01
Nickel (Ni)	0.44	0.001	-	-	-
Tin (Sn)	0.40	-	-	-	-
Vanadium (V)	1.80	0.033	<0.001	<0.002	<0.001
Zinc (Zn)	4.50	0.003	-	-	-

Table 5. Leaching of inorganic contaminants measured by one stage batch leaching test and the SQD limit values.

Parameter	Unshaped				
	material	CDKP0	CDKP1	CDKP2	CDKP3
	(SQD)				
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Antimony (Sb)	0.32	-	-	-	-
Arsenic (As)	0.90	-	-	-	-
Barium (Ba)	22.00	0.004	0.351	0.225	0.228
Cadmium (Cd)	0.04	-	-	-	-
Chromium (Cr)	0.63	0.024	0.003	0.002	0.002
Cobalt (Co)	0.54	-	-	-	-
Coper (Cu)	0.90	-	-	-	-
Lead (Pb)	2.30	-	-	-	-
Molybdenum (Mo)	1.00	0.01	0.01	0.01	0.01
Nickel (Ni)	0.44	-	-	-	-
Tin (Sn)	0.40	-	-	-	-
Vanadium (V)	1.80	9.578	0.011	0.012	0.005
Zinc (Zn)	4.50	-	-	-	-

Table 6. The porosity of DKP activated BOF steel slag before and after carbonation.

	DKP0	DKP2	CDKP0	CDKP2
Porosity (%)	40.73	23.98	24.75	20.53

Table 7. The phase composition of DKP activated BOF steel slag samples after 28-days hydration.

	Wuestite	Magnetite	C2F	C2S	Lime	Portlandite	Calcite	Katoite	Pyroaurite	Hydroxalcite	Apatite-like minerals	Amor
DKP0	19.8	6.3	15.5	36.2	1.0	0.7	0.7	2.7	0.8	0.9	0.0	15.5
DKP1	16.2	6.0	6.2	21.3	0.7	0.6	0.4	8.8	0.1	1.9	0.7	37.1
DKP2	14.5	6.8	4.5	15.4	0.6	0.8	0.2	14.1	0.3	1.6	0.9	40.1
DKP3	15.1	7.0	4.4	14.2	0.5	1.9	0.6	17.5	0.2	1.4	2.3	34.9

Table 8. Sample mix proportion in wt.% of zero, MKP, DKP, TKP, and mixtures.

Sample	MKP (wt.%)	DKP (wt.%)	TKP (wt.%)
REF	0	0	0
M	2.2	0	0
MD	1.1	1.4	0
D	0	2.8	0
DT	0	1.4	1.7
T	0	0	3.4

CLAIMS

1. A method for activating Basic Oxygen Furnace (BOF) steel slag minerals comprising a step of adding an activator to the Basic Oxygen Furnace (BOF) steel slag minerals, wherein the activator is a phosphate compound selected from the group consisting of: monopotassium phosphate, monosodium phosphate, monoammonium phosphate, dipotassium phosphate, disodium phosphate, di-ammonium phosphate, tripotassium phosphate, trisodium phosphate, tri-ammonium phosphate, or a combination thereof.
2. A method according to claim 1, wherein the activator is a phosphate compound selected from the group of: monopotassium phosphate, dipotassium phosphate, tripotassium phosphate, monosodium phosphate, disodium phosphate, or a combination thereof.
3. A method according to claim 1 or 2, wherein the activator is monopotassium phosphate in a range of up to 15 wt.%, preferably in a range of 0.10 to 15 wt.%, and more preferably 0.10 to 10 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals.
4. A method according to claim 1 or 2, wherein the activator is dipotassium phosphate in a range of up to 10 wt.%, preferably in a range of 0.10 to 10 wt.%, and more preferably 0.10 to 5 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals.
5. A method according to claim 1 or 2, wherein the activator is tripotassium phosphate in a range of up to 10 wt.%, preferably in a range of 0.10 to 10 wt.%, and more preferably 0.10 to 5 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals.
6. A method according to any one of claim 1 to 5, wherein the Basic Oxygen Furnace (BOF) steel slag minerals is milled in such a way that a median grain size of Basic Oxygen Furnace (BOF) steel slag minerals is at most 25 microns, preferably at most 20 microns.
7. A method according to any one of claims 1 to 6, wherein the Basic Oxygen Furnace (BOF) steel slag minerals comprises of: 10 – 30 wt.% brownmillerite, 0 - 15 wt.% magnetite, 25 – 60 wt.% C_2S , 10 – 30 wt.% Mg-Wuestite 0 – 20 wt.% C_3S , and 0 - 6 wt.% free- CaO .

8. A method according to any one of claims 1 to 7, wherein the Basic Oxygen Furnace (BOF) steel slag minerals comprises of: 35 - 60 wt.% CaO, 10 - 17 wt.% SiO₂, 15 - 35 wt.% of Σ Fe Oxides, 1 - 5 wt.% Al₂O₃, 1 - 13 wt.% MgO, 0 - 4 wt.% P₂O₅, 0 - 2 wt.% TiO₂.
9. A method according to any one of claims 1 to 8, further comprising a step of adding water to the mixture of activator and Basic Oxygen Furnace (BOF) steel slag minerals to obtain a steel slag mixture.
10. A method according to claim 9, wherein a water to solid ratio is at most 0.25, preferably at most 0.22, and preferably at least 0.10, wherein solid refers to the amount of Basic Oxygen Furnace (BOF) steel slag minerals.
11. A method according to any one of claims 1 to 10, comprising a step of further adding one or more solid additions selected from the group comprising sand, gravel, and lime stone.
12. A method according to any one of claims 9 to 11, further comprising the step of:
 - mixing the Basic Oxygen Furnace (BOF) steel slag minerals, activator, water and optional solid additions to obtain a steel slag mixture;
 - applying the steel slag mixture in a mould;
 - curing the steel slag mixture to obtain a building product.
13. A building product obtained by the method according to claim 12 having a 7-day compressive strength of at least 20.0 MPa.
14. The building product according to claim 13 having a 28-day compressive strength of at least 35.0 MPa, and preferably of at least 40 MPa.
15. The building product according to claim 13 or 14, wherein the leaching properties for vanadium and chromium are within the limits of the Dutch Soil Quality Decree.
16. The building product according any one of claims 13 to 15, wherein the leaching properties for vanadium and chromium after subsequent carbonation are within the limits of the Dutch Soil Quality Decree.

17. A premix kit for obtaining a building product comprising BOF steel slag minerals and an activator in the form of a phosphate compound selected from the group of monopotassium phosphate, dipotassium phosphate, tripotassium phosphate, monosodium phosphate, disodium phosphate, or a combination thereof, and wherein the phosphate compound ranges between 0.10 and 15 wt.%, preferably between 0.10 and 10 wt.%, and more preferably 0.10 to 5 wt.%, of BOF steel slag minerals.

18. Use of phosphate compound selected from the group monopotassium phosphate, dipotassium phosphate, tripotassium phosphate, or a combination thereof as activator for BOF steel slag minerals in the production of building products and to reduce the leaching of at least vanadium and chromium within the limits of the Dutch Soil Quality Decree, and wherein the total amount of monopotassium phosphate is in a range of 0.10-15 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals, and for dipotassium phosphate to total amount is in a range of 0.10-10 wt.%, and preferably 0.10 to 5 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals, and for tripotassium phosphate to total amount is in a range of 0.10-10 wt.%, and preferably 0.1 to 5 wt.%, based on the amount of Basic Oxygen Furnace (BOF) steel slag minerals.

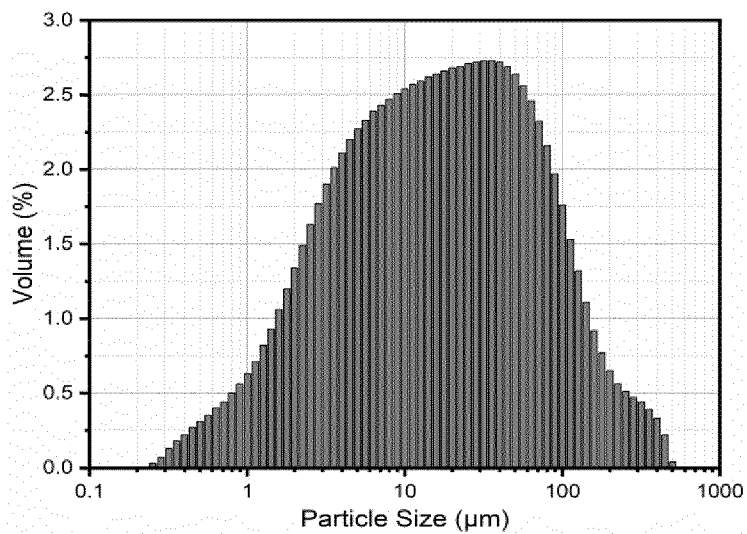


Fig.1(a)

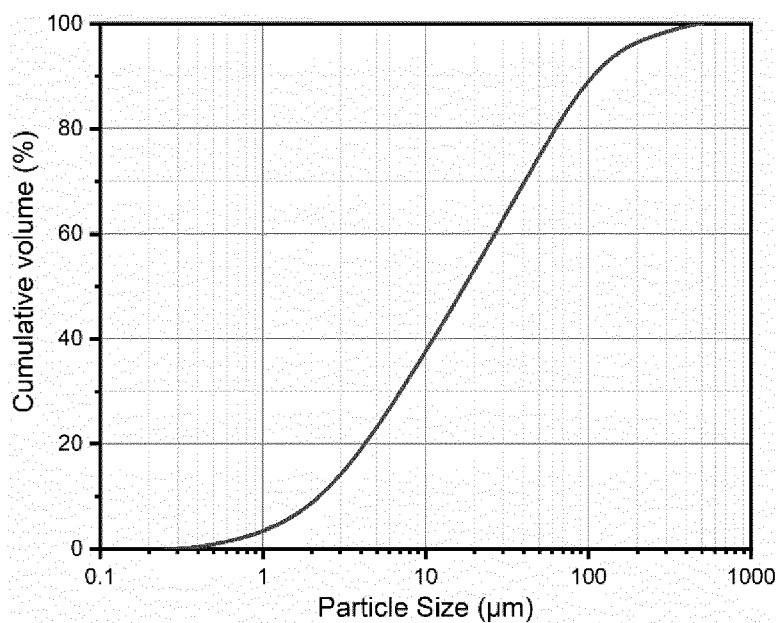


Fig.1(b)

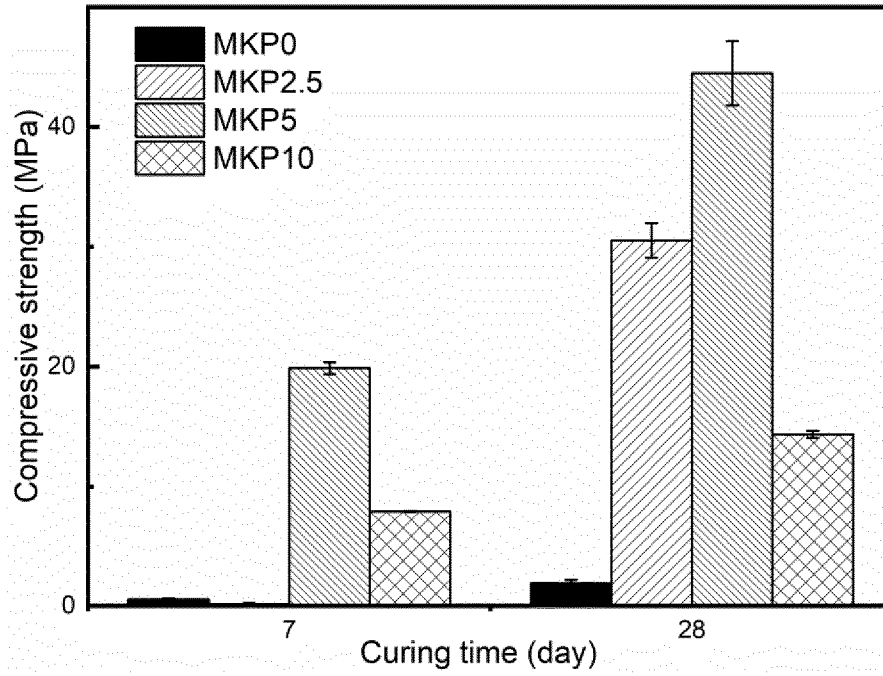


Fig. 2

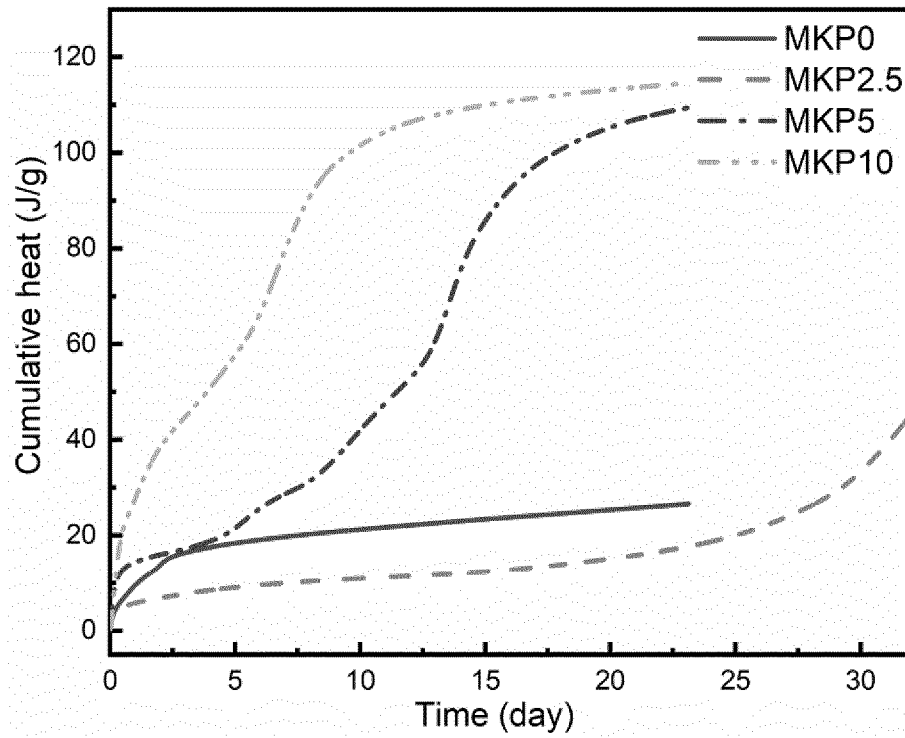


Fig. 3(a)

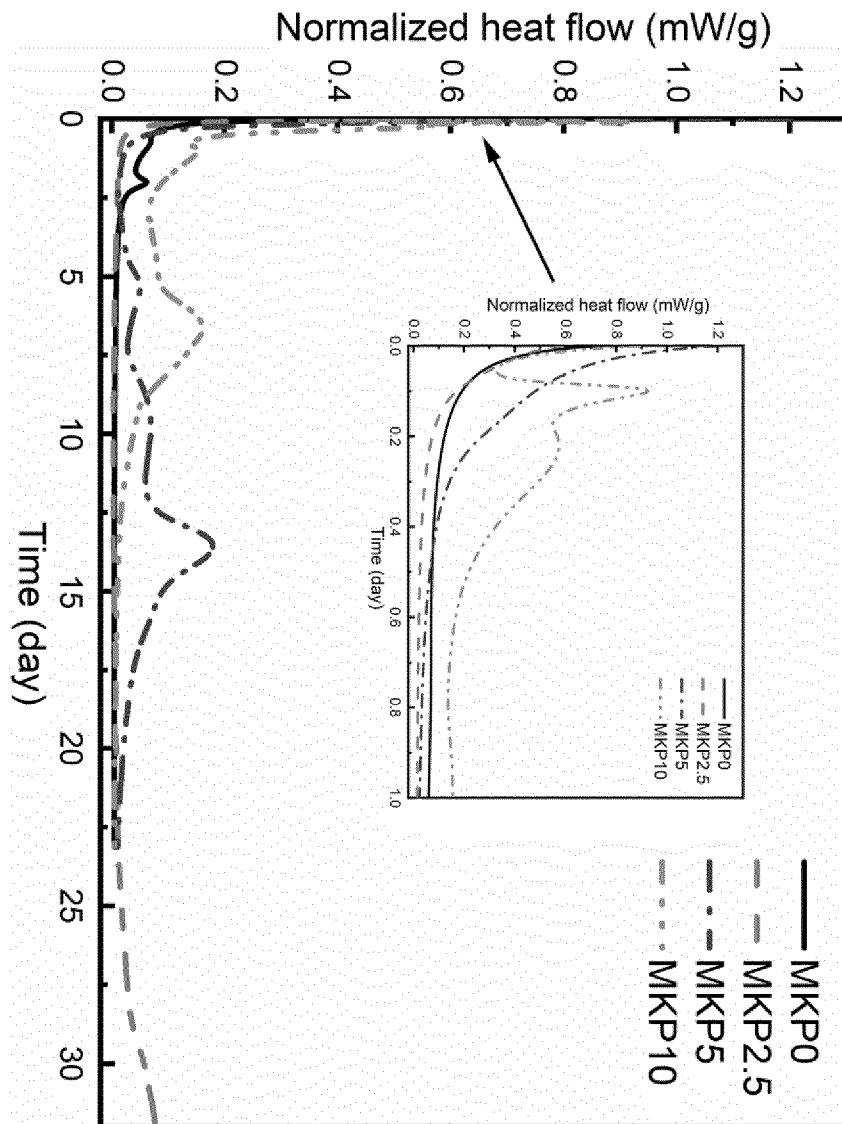


Fig. 3(b)

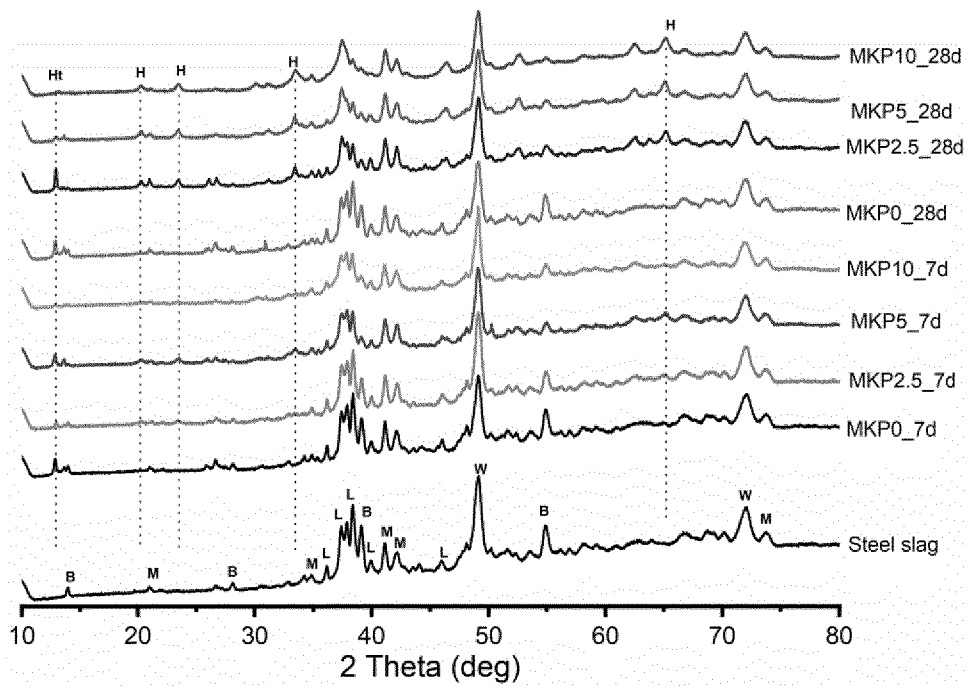


Fig. 4

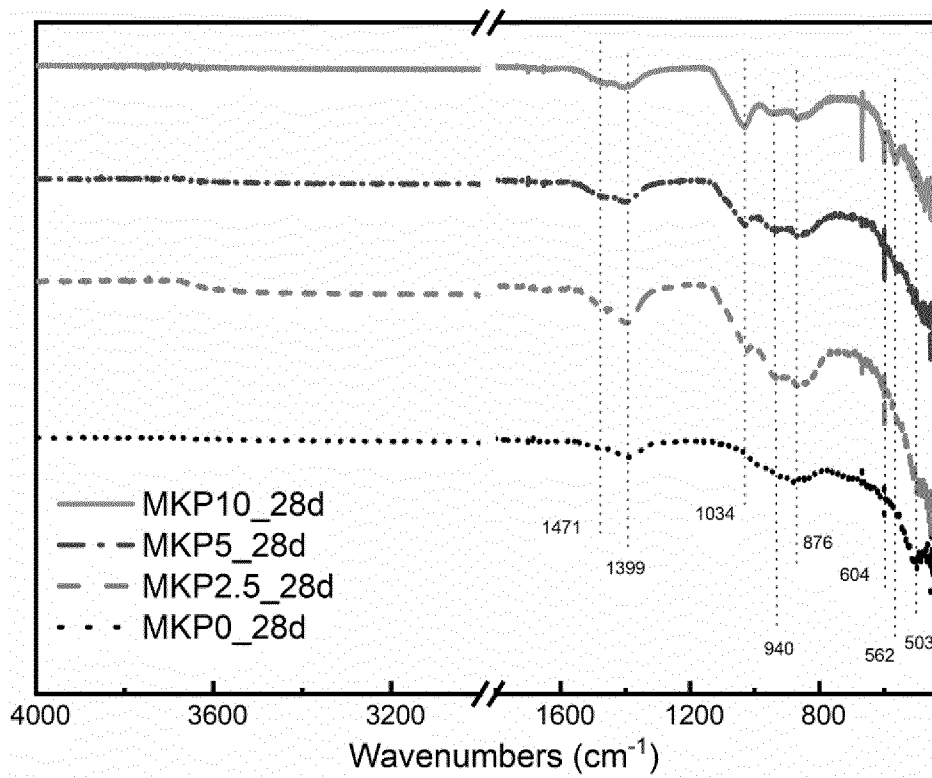


Fig. 5

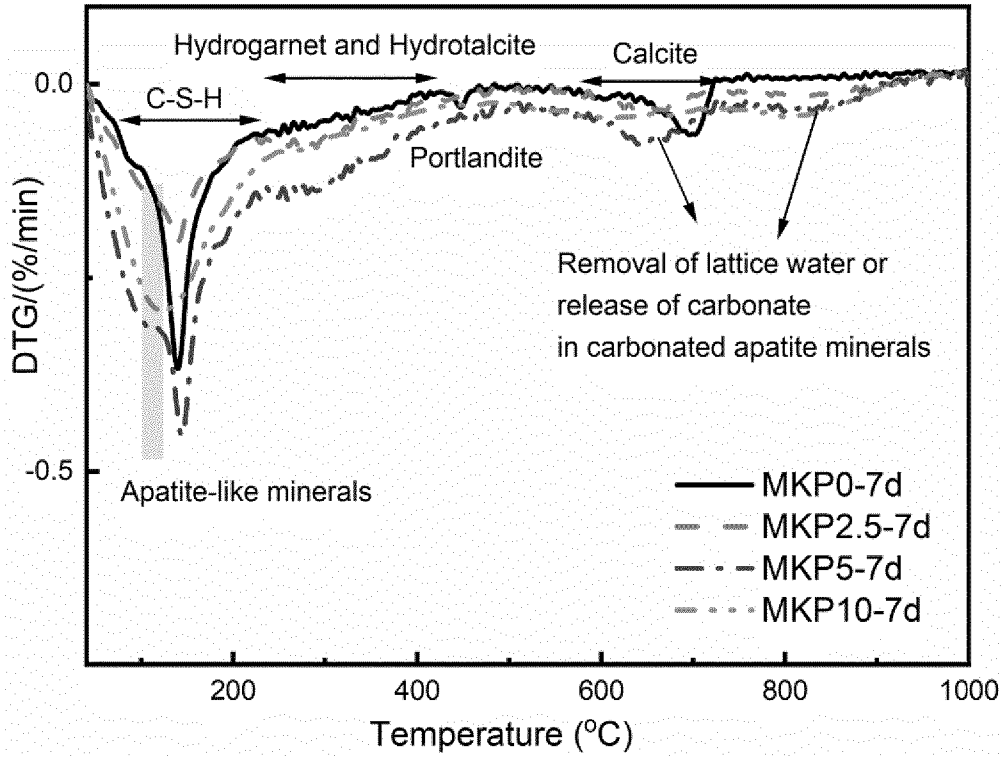


Fig. 6(a)

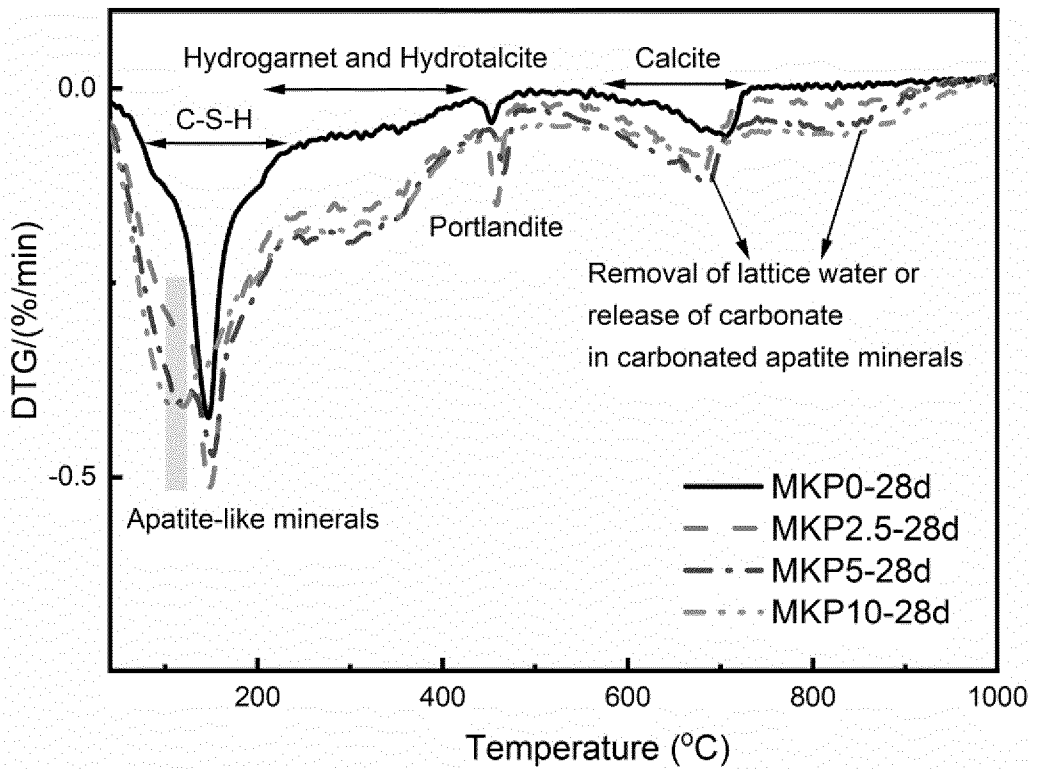
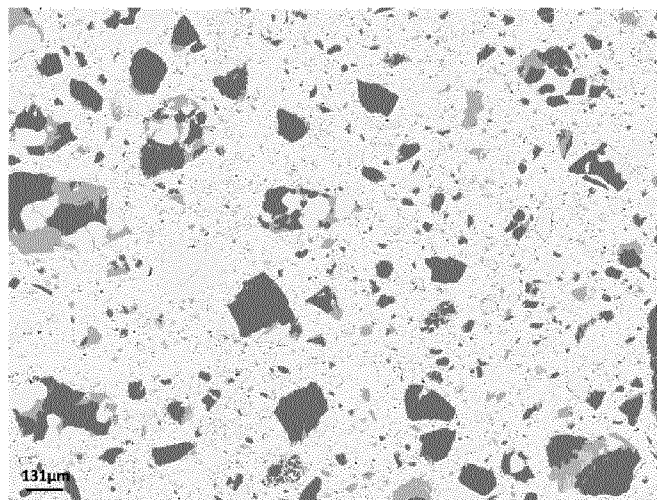
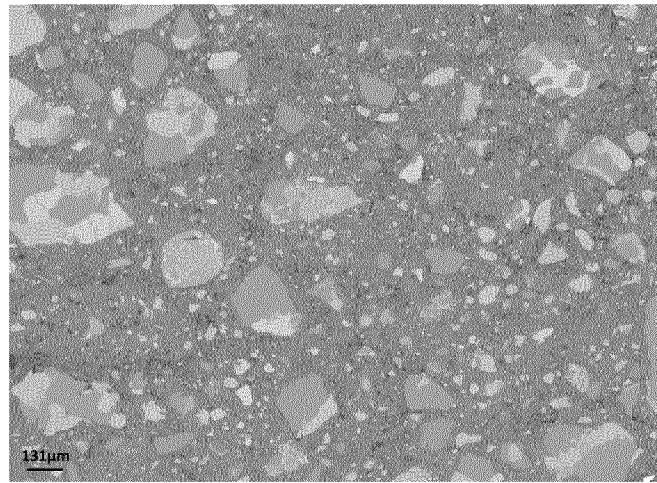


Fig. 6(b)



	Hydration products
	Wuestite/Magnetite
	Brownmillerite
	C2S
	Unclassified
	Porosity

Fig. 7

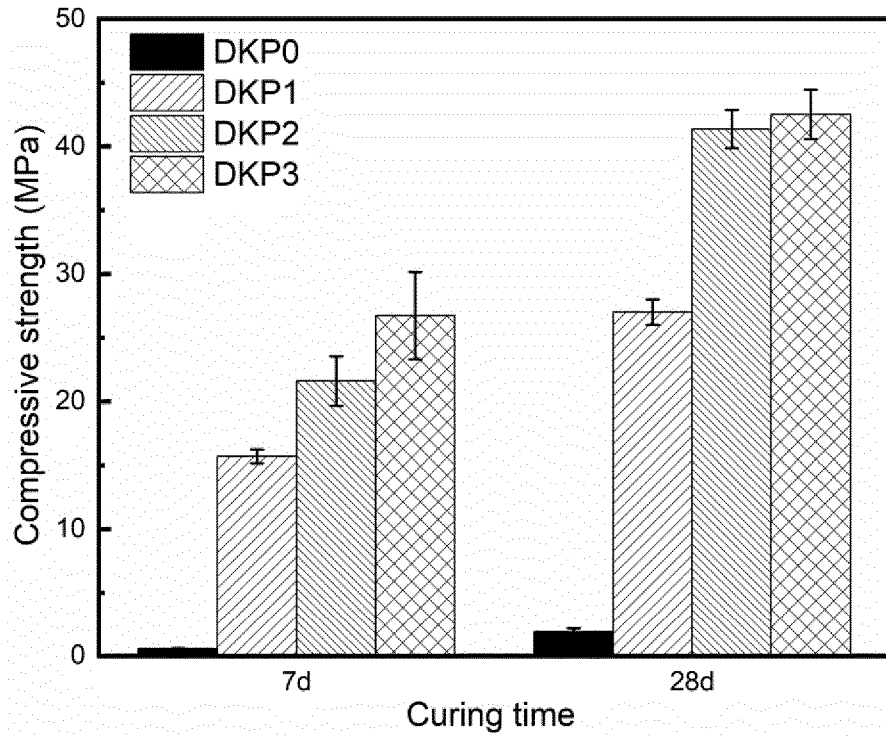


Fig. 8

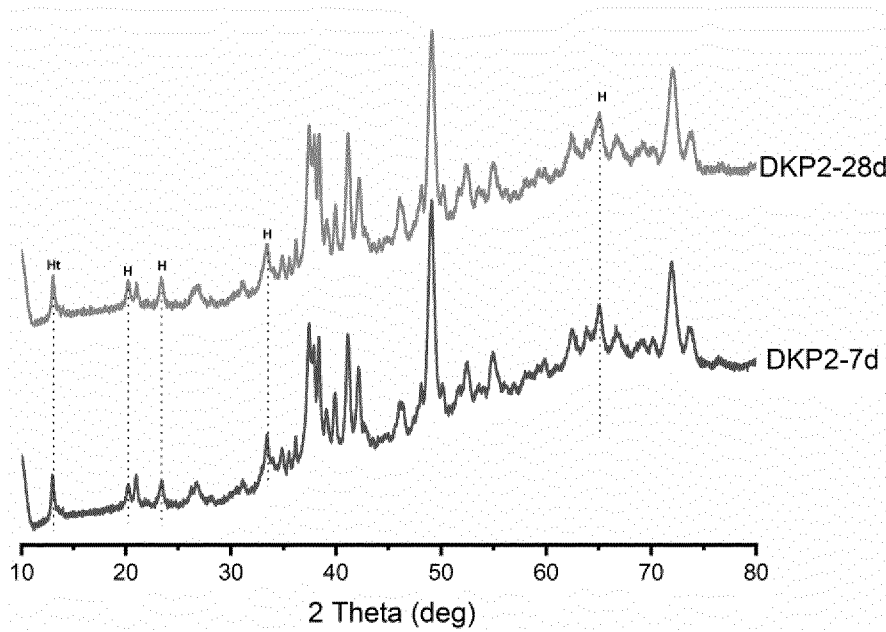


Fig. 9

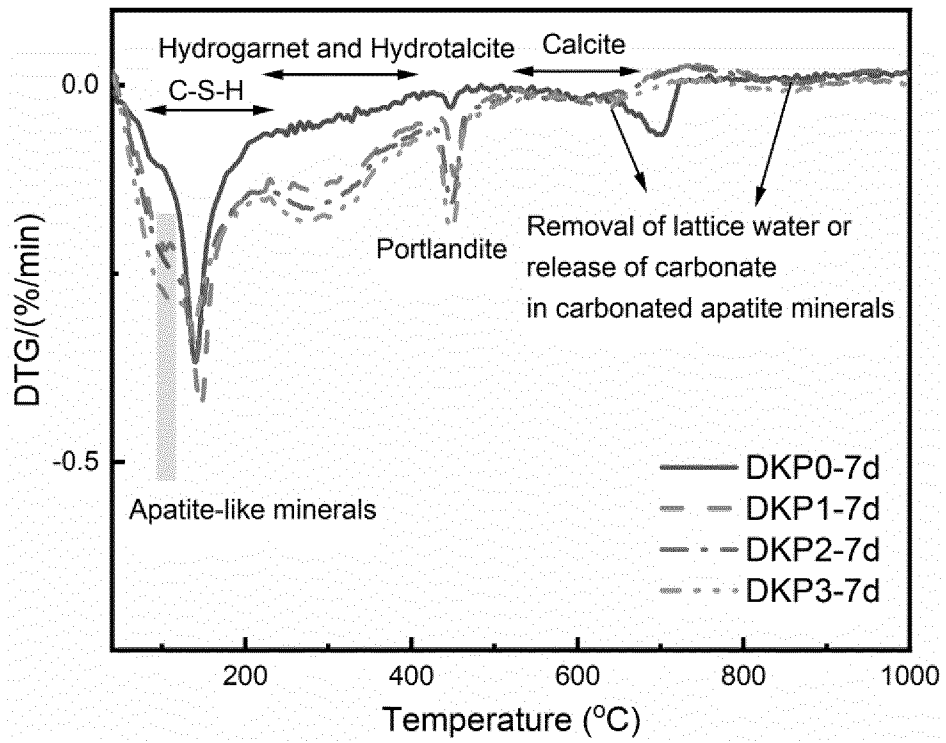


Fig.10 (a)

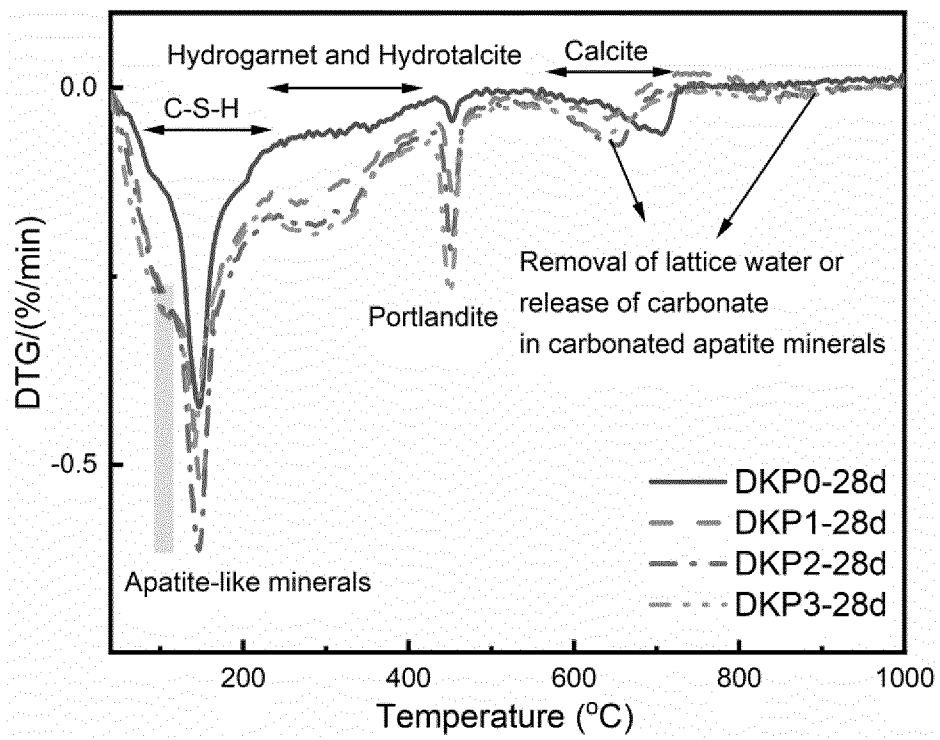


Fig. 10(b)

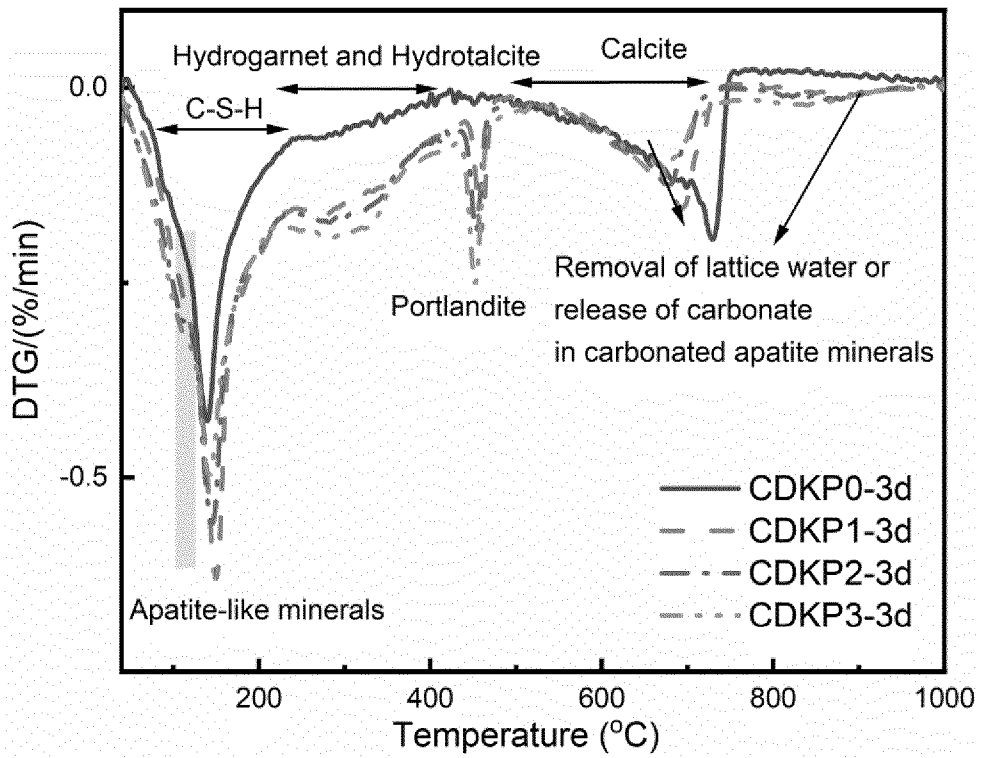


Fig. 11(a)

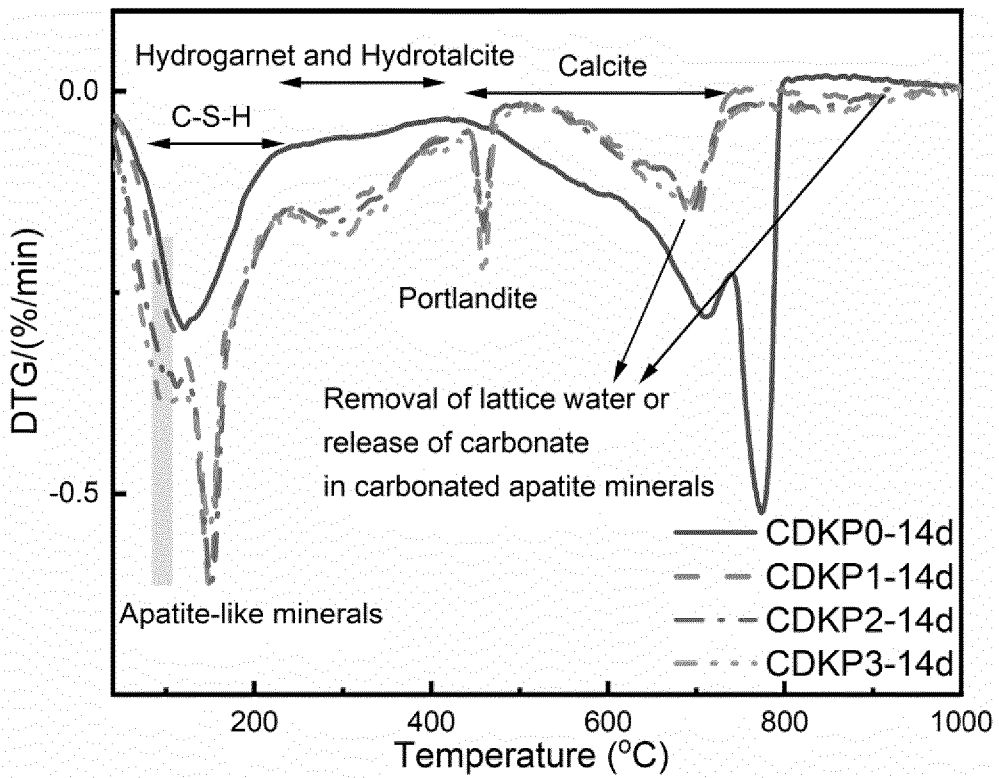


Fig. 11(b)

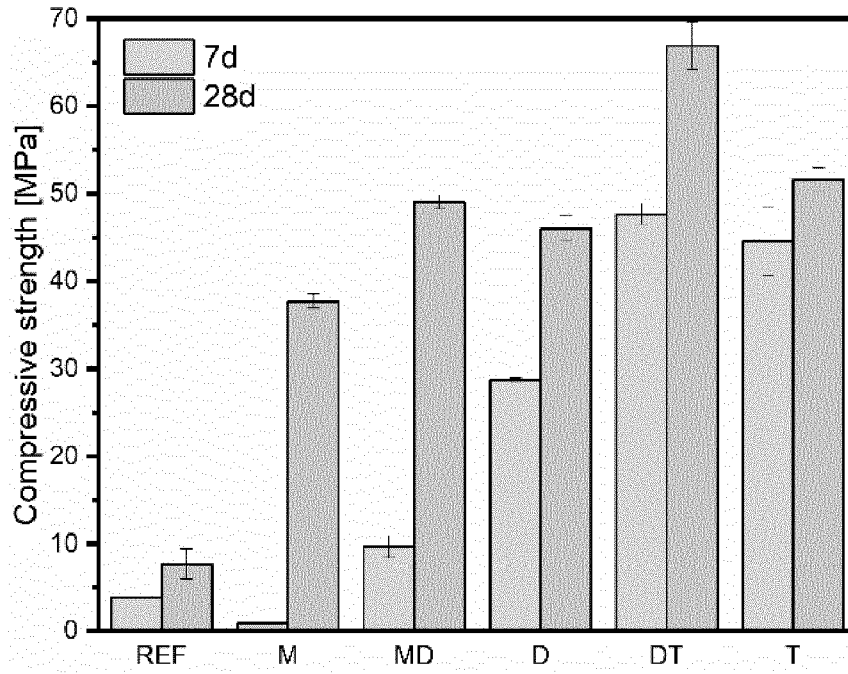


Fig.12

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/074148

A. CLASSIFICATION OF SUBJECT MATTER
INV. C04B28/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	<p>KAJA A.M. ET AL: "Hydration of potassium citrate-activated BOF slag", CEMENT AND CONCRETE RESEARCH., vol. 140, 1 February 2021 (2021-02-01), page 106291, XP093104289, US ISSN: 0008-8846, DOI: 10.1016/j.cemconres.2020.106291 the whole document</p> <p style="text-align: center;">-----</p>	1-18
Y	<p>US 5 553 670 A (COWAN KENNETH M [US]) 10 September 1996 (1996-09-10) cited in the application the whole document</p> <p style="text-align: center;">-----</p>	1-18

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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- "Y" document of particular relevance;: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search

Date of mailing of the international search report

22 November 2023

29/11/2023

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2023/074148

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5553670	A	10-09-1996	NONE
