Sustainability, Agri, Food and Environmental Research, (ISSN:0719-3726),12(X),2024:
http://dx.doi.org/

Ferrock: carbon negative substitute for cement- a review.

Ferrock: sustituto de carbono negativo para el cemento: una revisión

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ABSTRACT

Cement is considered as one of the prominent building materials used for construction. It is considered as the second most used entity next to water in the world today. Though it has many significant advantages, it has a major disadvantage of CO_2 emission. For every ton of cement generated more or less eight ton of CO_2 is released to the atmosphere. Hence it is high time to find a substitute for cement. Ferrock is such a substitute which utilizes a variety of waste products to produce a versatile building material. It is a binder that is a blend of iron oxide powder, fly ash, lime powder, metakaolin and oxalic acid. This review mainly focuses on characteristics, advantages and application of ferrock in building construction.

Keywords: Ferrock, Carbon negative, waste management, cement substitute

RESUMEN

El cemento se considera uno de los materiales de construcción más destacados utilizados en la construcción. Actualmente se considera la segunda entidad más utilizada después del agua en el mundo. Aunque tiene muchas ventajas importantes, tiene una gran desventaja: las emisiones de CO2. Por cada tonelada de cemento generada se liberan a la atmósfera más o menos ocho toneladas de CO2. Por tanto, ya es hora de encontrar un sustituto del cemento. Ferrock es un sustituto que utiliza una variedad de productos de desecho para producir un material de construcción versátil. Es un aglutinante que es una mezcla de polvo de óxido de hierro, cenizas volantes, polvo de cal, metacaolín y ácido oxálico. Esta revisión se centra principalmente en las características, ventajas y aplicaciones del ferrock en la construcción de edificios.

Palabras clave: Ferrock, Carbono negativo, gestión de residuos, sustituto del cemento.

INTRODUCTION

Concrete is the most widely used construction material in the world, with current consumption of 1 m3 per person per year. Ordinary Portland cement (OPC) has traditionally been used as the binder material in concrete, however OPC has high embodied energy, with carbon dioxide equivalent (CO2-e), the measure used to compare the emissions from various greenhouse gases based upon their global warming potential, ranging from 0.66 to 0.82 kg of CO2 emitted for every kilogram manufactured. The contribution of the production of OPC is approximately 5–7% of global anthropogenic CO2 emissions. The key causes of high CO2 emissions arising from OPC manufacture have been attributed to: (i) calcination of limestone, one of the key ingredients, which leads to formation and release of CO2; and (ii) high energy consumption during manufacturing, including heating raw materials within a rotating kiln at temperatures greater than 14000C [1]

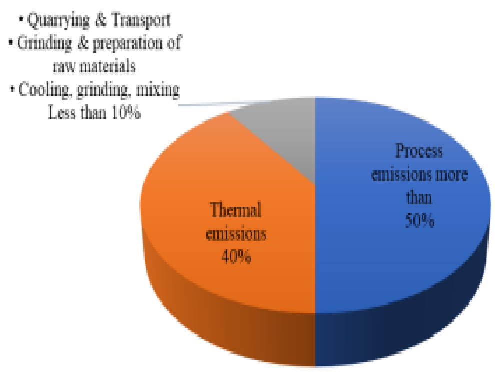

Figure 1: CO2 emissions in clinker production [5]

Anthropogenic emission of CO2 is accepted as being responsible for changes in global climate and it has potentially irreversible damaging impacts on ecosystems and societies [2] Alternative cements to OPC have been proposed to reduce greenhouse gas emissions. Blended cements, comprising OPC that has been partly substituted by supplementary cementitious materials (SCCs), are used as binders for concrete. [1] One such partial replacement for cement in concrete can be ferrock. Ferrock is made of 90% recycled materials such as iron powder, metakaolin, flyash, limestone and oxalic acid. The key ingredient in this is iron dust, a waste from iron mill which goes straight to the landfill as it's not recycled conventionally and the process of recovering iron from this powder is uneconomical. The iron dust reacts with carbondioxide and rust which creates an iron carbonate matrix to form ferrock while it dries [3]

The accepted reaction steps for this process are:

$Fe + 2CO_2 + H_2O \rightarrow Fe_{2+} + 2HCO_3- + H_2$

$Fe_{2+} + 2HCO_3- \rightarrow FeCO_3 + CO_2 + H_2O$

The net reaction then is:

$Fe + CO_2 + H_2O \rightarrow FeCO_3 + H_2$

One of the unique qualities of ferrock is that it absorbs more CO2, (a highly toxic gas) than it creates, unlike cement. This results in "carbon negative" process which helps to trap greenhouse gas. It can also be observed that valuable hydrogen gas is formed during the formation process. The formation of hydrogen gas as a by-product of ferrock production represents an intriguing opportunity for further applications of this material, especially as the energy industry looks for alternative sources of fuel. The clean-burning nature of hydrogen gas positions it as one of the leading fuels to aid the transition away from fossil-fuel energy sources. [4]

Figure 2: Ferrock [10]

MATERIALS

Ferrock is a binding material which was mainly introduced as the cement replacement. Thus, in order to obtain the binding property for the product, materials similar to cement were used and trails were done in order to obtain the same. Major constituent of ferrock is the iron powder which is obtained from the wastes of steel industries and mines which in-turn does a waste management and it doesn't sum up on to the carbon dioxide content in the atmosphere during its manufacturing process. The iron powder being used is ferrock is taken from the heaps of bag house dust waste of the shot blasting operations of steel and also electric arc furnace manufacturing process of steel. This component is not economically viable to recycle and thus it has been a landfill at great costs in the world Thus, using the minor ingredients such as metakaolin, fly ash, limestone and oxalic acid along with the major ingredient iron powder, ferrock was manufactured [5]

Table 1: Materials for Ferrock [6]

Materials	Percentage (by weight)
Iron oxide powder	60
Fly ash	20
Limestone Powder	10
Metakaolin	8
Weak Oxalic acid	2

Iron oxide powder: Major constituent of ferrock is the iron powder which is obtained from the wastes of steel industries and mines which in-turn does a waste management and it doesn't sum up on to the carbon dioxide content in the atmosphere during its manufacturing process [5] It is a by-product of shot blasting where the micro particles has become a threat to health while working on it and has ineffectual applicability. It is also obtained in the finishing techniques in the steel manufacturing industry. [4] Iron oxide particles are 10 times finer than cement particles. When added into a concrete mix, the iron oxide particlesactually surround and coat the cement particles. Iron oxide powder are found to be elongated and angular in shape. However, the large surface area helps it to provide greater reactivity. [6] Figure 3 shows SEM image of iron particles.

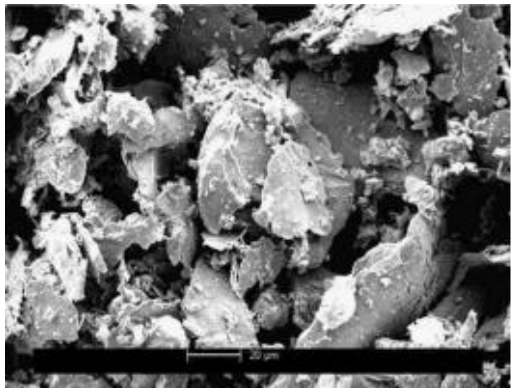

Figure 3: SEM image of iron particles. Scale corresponds to 20 µm [2]

Fly Ash: Fly ash is a by-product or a waste product; hence use of fly ash in concrete reduces CO2 and is thus environment friendly. It has good cold weather resistance and is a non-shrink material. Fly ash concrete has great workability as well and allows for a lower water-cement ratio similar slumps compared to the ordinary concrete. It reduces heat of hydration, cracks, permeability, bleeding. It is a cost-effective substitute for Portland cement.

Limestone powder: Limestone powder is a by-product of the limestone quarry, and it has been used in cement-based materials. Addition of limestone powder provides easier grindability, reduced water demand, increased strength and less bleeding in concrete. Limestone due to its reactive nature provides nucleation sites for clinker hydration products, and reduces heat of hydration. Bending of limestone in cement will reduce the emission of CO2 and improve workability of cement. [6]

Metakaolin: Metakaolin is a high-quality pozzolanic material. Metakaolin is one of the most widely used admixtures these days. It helps concrete to obtain both higher performance and economy. It is produced from high Kaolin. Metakaolin consist of silica and alumina in an active form and as other mineral admixtures, it reacts with calcium hydroxide at room temperature and form calcium silicate hydrate-gel which increases the density of concrete and reduces porosity. [6]

Oxalic Acid: Oxalic acid is a weak acid and is reported to act as an accelerator for cement hydration reaction. This may also be helpful in the formation of a protective electrical double-layer film around the cement particle during gel state. [6]

As per the reaction equation iron dust reacts with CO2 and water to create Iron carbonate. Figure 4 shows the morphology of the reaction products observed on a fracture surface of the iron carbonate binder. The micro structure is heterogeneous, containing angular iron particles, spherical fly ash particles and porous reaction products. Reaction product film formation is observed on the surface of iron particles [2]

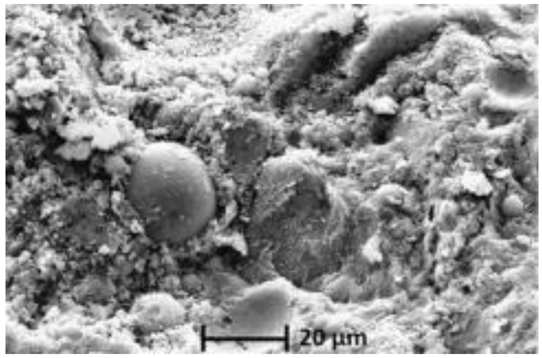

Figure 4: SEM images of Iron Carbonate binder [2]

TECHNICAL CHARACTERISTICS OF FERROCK

Besides its unique chemical properties as a carbon sink that emits valuable hydrogen gas as a byproduct, Ferrock additionally presents technical characteristics that have potential to make it a promising substitute for cement. Ferrock has similar functional properties in terms of its fresh-state behavior and workability. In addition, the iron-based binder requires a fractional amount of time to cure compared to OPC; 4 days of carbonation compared to the 28 days of hydration that is required for cement to cure. From the performance perspective, compressive and flexural strength tests show the pure paste (without aggregate) to be stronger than comparable samples of OPC. Research studies also show that the iron-based binder is chemically stable in marine environments and does not break down upon exposure to salt waters. [4]

STRENGTH PARAMETERS OF SPECIMENS INCORPORATING FERROCK

Concrete specimens made with partial replacement of cement with varying percentages of ferrock showed better strength. The compressive strength, split tensile strength and flexural strength for 4%, 8% and 12% ferrock concrete for 28 days are all higher than normal concrete of M20 grade. [3] Test results on the compressive strength, splitting tensile test and flexural strength has revealed that the 8% ratio of the ferrock cement has better results when compared to the other ratios. Hence 8% ratio will be optimum to be used in the construction industry [3] The Compressive strength, Flexural Strength and Split tensile strength of Ferrock Concrete is found to be 25.63%, 25.11% and 17.51% respectively, more than normal Mix of M20 grade. [8]

CURING OF SPECIMENS INCORPORATING FERROCK

Experiments were conducted to determine the effect of curing conditions on mechanical properties of a unique binder system that utilizes the carbonation of metallic iron powder for cementation properties. For the preliminary study, the specimens were kept in a 100% CO_2atmosphere for 3 days immediately after casting and demolding, and cured in air for 2 days before they were tested in uniaxial compression. No appreciable changes incompressive strengths were found after 4 days of carbon curing and 3 days of air curing. [9]

The upper limit of carbonation duration was determined by a thermogravimetric analysis. Variation in carbonation durations were made and experimentally tested starting from one day carbon curing which showed very low mechanical strength. Experiments were conducted with less carbon curing duration and higher air curing duration; however it was observed that air curing was effective only with the increase in carbon curing duration, as the average pore size decreased with increased carbonation duration. And, a significant increase in strength is observed for specimens carbonated for a longer duration and when the air curing time was increased. This is due to the fact that larger pores in initial days of carbonation exert less internal moisture pressure under compression test and thus loss of moisture in air curing after lesser carbonation duration doesn't have a larger effect on internal pressure and in turn on the compressive strength. In increased carbonation duration, pore size is reduced and thus more sensitive to compressive strength and loss of moisture during the air curing [10]

APPLICATIONS

The applications of ferrock can vary based on the coarse size of the aggregates added. Using a coarse-grit aggregate it may be used slabs, blocks, other pre-cast forms and general applications. By using fine aggregates, the material becomes very malleable and can be spread on like stucco, plaster or mortar. [4] Adding additional reinforcement, like rebar, allows for the construction of large full- sized structures. When cast in place, ferrock's shorter cure time allows for compressed project construction schedules, conserving capital resources. Ferrock is resistant to rust, oxidation, UV radiation, rotting and corrosion. Therefore, ferrock can be used for marine applications like breakwater, seawalls, piers, structural pilings, foundations and other structures exposed to seawater. Its environmental durability also makes its application in the manufacture of pipes that are typically used for water transmission and wastewater removal. Ferrock is not affected by the constituents of sewage water like hydrogen sulfide and sulfuric acid, which corrodes regular cement pipes. Further, since ferrock is less brittle compared to concrete, it enables better pipe-to-pipe connection and consequently there is less damage while aligning and installing sections [4].

ADVANTAGES

About 95% of ferrock components are recycled materials. In contrast to cement, which is made from chalk and clay, it absorbs carbon dioxide during manufacturing. Ferrock is chemically relatively inert, making it suitable for offshore projects. Economical for small projects. The main advantage of ferrock is eco-friendly as well as the formation of hydrogen gas as a by-product of ferrock production represents an intriguing opportunity for further applications of this material, especially as the energy industry looks for alternative sources of fuel. The clean-burning nature of hydrogen gas positions it as one of the leading fuels to aid the transition away from fossil-fuel energy sources. [7]

CONCLUSION

From the various literatures reviewed, following conclusions can be arrived.

•Ferrock is found to be an excellent substitute for cement. While using ferrock, 8 to 11% of CO2 emission is reduced and economical in construction, so it is carbon negative in nature.

•The composition of ferrock can be finalized as 60% iron powder, 20% fly ash, 10% metakaolin, 8% limestone, 2% oxalic acid in terms of rheological characteristics.

•Strength parameters are improved with addition of various percentages of ferrock. Test results on the compressive strength, splitting tensile test and flexural strength has revealed that the 8% ratio of the ferrock cement has better results when compared to the other ratios. Hence the test results reveal that the 8% ratio will be optimum to be used in the construction industry.

•The experimental studies on the curing process suggested that carbon curing of 4 days and air curing of 3 days gives the best result of ferrock blended concrete for better compressive strengths.

•It has various applications similar to normal concrete in buildings, bridges and other conventional uses of concrete. Due to its property of strength gaining in CO2 environments, it will be very useful in polluted sites of industrial zones.

•Ferrock can be used for marine applications like breakwater, seawalls, piers, structural pilings, foundations and other structures exposed to seawater as it is resistant to rust, oxidation, UV radiation, rotting and corrosion. Its environmental durability also makes its application in the manufacture of pipes that are typically used for water transmission and wastewater removal.

Ferrock is uneconomical for large projects such as roads and highways due to the limited supply of materials needed for its manufacture.

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Received: 30th March 2023; Accepted: 03th August 2023; First distribution: 01th November 2023.