Limestone Calcined Clay Cement: Opportunities and Challenges

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Abstract Limestone calcined clay cement (LC^3) is being developed as a low-carbon alternative to conventional cements. The cement has the potential to reduce CO_2 emissions by up to 30%, at the same time, demonstrating a higher performance in many types of exposure conditions. Being a conservative industry, the introduction of a new cement is a challenging process with many technical, commercial, psychological and political hurdles. Additionally, it is understood that the solutions for the reduction of CO_2 emissions will be varied and will depend on various factors such as the availability of raw materials, the environmental conditions and the construction practices. It is, therefore, important to ensure that the engineering properties of concretes produced using any cement are well understood and that right type of cement is used for the right application. This article discusses the challenges that need to be overcome for the introduction of LC^3 and the applications where the cement is especially at an advantage or disadvantage.

Keywords Limestone calcined clay cement · Chloride · Carbonation · Economy · Workability

1 Introduction

Limestone calcined clay cement, or LC^3, has been developed as a low clinker alternative to conventional cements such as ordinary Portland cement (OPC) and Portland pozzolanic cements (PPC). Being a ternary cement that relies on the combined action of two supplementary cementitious materials (SCMs), calcined clay and limestone, the cement achieves similar mechanical properties as conventional cements despite the relatively lower clinker factor of 50% or less [1–3]. The cement also promises

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to reduce CO_2 emissions by as much as 30% compared to OPC. More details on the performance and the development of the cement can be found elsewhere [4]. Still, the acceptance of a new cement faces many hurdles due to the relatively conservative nature of the construction industry. Given the high risks involved, the demonstration of the usability, strength and durability of any new cement is important before it can be used for construction. Additionally, since the market potential of any new product is difficult to establish beforehand, the large investments required to start producing a new product may be difficult to justify. This article discusses the opportunities offered by the development of LC^3 as a new cement and the challenges being faced for its introduction to the market.

2 Opportunities

2.1 Technical Opportunities

From the results that have been obtained this far, it is apparent that LC^3 offers many technical benefits over the conventional cements. First, it has been shown that LC^3 develops its strength faster and is less sensitive to poor curing. This can be advantageous not only in precast applications, but also in site concreting applications since the faster removal of formwork would reduce cost and increase construction speed. Additionally, reduced curing durations will help in reducing the consumption of water, which is becoming more and more a precious resource. The presence of limestone in LC^3 also helps in improving the cohesion of mixes, which is especially useful for the production of self-compacting concrete.

The lower alkalinity of the cement will also be beneficial in preventing alkali silica reaction and in the consumption of reactive aggregates, especially in areas where non-reactive aggregates are difficult to obtain. Due to the nature of the composition of the cement, the resistance to sulphate attack also increases. The reduced permeability and sorptivity of concrete using LC^3 also make the cement suitable for use in foundations and locations that are susceptible to capillary rise of water from the ground. The lower heat of hydration of the cement, compared to OPC, also makes it suitable for application to mass concretes.

Perhaps the most important strength of LC^3 is that it offers a four-component system, which can be engineered to obtain different types of cements. For example, the gypsum content in the cement and the kaolinite content in the clay can be used to control the setting time and early strength development of concrete, making it suitable for application to repair applications. The calcined clay to limestone ratio and the clinker content can also be modified to control the heat of hydration.

2.2 Commercial Opportunities

Apart from various technical opportunities, LC^3 offers a variety of economic opportunities for the production of cement and concrete. The first opportunity comes from the quality of raw materials to be used. The clay that is calcined for blending in LC^3 contains around 50% to 60% kaolinite and is of a quality that cannot be used for other applications such as for the production of ceramics, paints, etc. It has been shown that pure clays that are used for such applications are less suitable in terms of workability and reactivity of LC^3 [4]. Additionally, clays with iron contents that are too high to allow the use of the clay in such applications can also be used in LC^3. The clays used in LC^3 should not be confused with fertile or agricultural soils. Given the requirements in composition, fertile agricultural soils cannot be used for the production of LC^3. Clays that are suitable for LC^3 are known to be present in large quantities, either as rejects from mines that produce purer kaolinitic or china clays, or around the areas where such pure clays are mined. This offers a unique opportunity for the consumption of such clays and the reduction of mine wastes.

The limestone that is grounded into LC^3 also offers an interesting economic opportunity for the consumption of limestones that have too low calcium content for the production of clinker or other applications. It has been shown that since the reactivity of carbonates in LC^3 is relatively low, lower grade limestones are also suitable [4]. It has also been shown that impurities such as quartz and clay minerals in the limestone do not negatively impact the performance of the cement. What is, perhaps, the most interesting opportunity for the cement industry is that limestones containing dolomite, which cause unsoundness in cements, and even pure dolomite, can be used in LC^3. Since limestone which is blended or grounded into LC^3 is not calcined, any dolomite present in it is not converted to periclase, which is known to react slowly and expand, causing unsoundness. In fact, studies have shown that LC^3 blends containing dolomite may be more robust under various conditions [5, 6]. LC^3, therefore, provides a unique opportunity for the consumption of rejected limestones from the mines of the cement companies.

Apart from the opportunity to utilise lower grade materials, LC^3 also offers the opportunity to reduce clinker content at locations where other suitable SCMs are either not available or are very expensive. Even in a country like India that has an overall abundance of fly ash, there are locations, such as in the north-east, that rely on fly ashes transported from several hundreds of km away, increasing their cost. The reduction of clinker factor achieved through the blending of limestone and calcined clay not only brings down the cost of the production of cement, but also allows a significant increase in the capacity of the cement plants with very small investment, without the need for installing new clinker production lines. This increase in capacity is advantageous even at locations where fly ash is available, since it is difficult to reduce clinker factors to levels possible with LC^3 by just using fly ash. A more detailed analysis of the factors that influence the relative cost of production of LC^3 can be found elsewhere.

Being different in performance from conventional cements, LC^3 also provides the opportunity to produce value-added cementitious products that can be used in niche markets. For example, the higher cohesion of the cement and its higher fineness may make it more suitable for plastering applications. It can also be used to produce lower cost binders for cement-based damp proof courses for brick walls. Given its high resistance to the flow of chlorides, the cement can be used for developing protective overlays for concretes exposed to marine conditions and groundwater.

The production of a blend of limestone and calcined clay as a pozzolanic material, also known as LC^2, for direct mixing in concrete also provides an opportunity for cement producers and ready-mixed concrete suppliers. LC^2 would provide concrete producers the flexibility to adjust the clinker content in concrete and would allow the production of specialised concretes depending on the application. The cost of production of concrete can also be reduced at locations where the supply of cement is difficult but suitable clays exist locally.

It can be seen from the above discussion that there are several commercial and technical opportunities that LC^3 offers.

3 Challenges

3.1 Technical Challenges

As is the case with any new product, there are many technical challenges that have to be overcome to allow the cement to be confidently used by engineers and the construction industry. The first challenge arises in the cement lacking a legacy of structures and experience that the conventional cements have. Although the relatively short life since the development of the cement has been significantly compensated by the vast research programme that has been implemented by a competent international research and application team, the results of accelerated durability tests are often not considered to be reliable by construction professionals. The first step in the acceptance of a new cement by the construction fraternity is the development of standards that permit its production and use. In the development and release of these standards, large committees of experts critically evaluate the performance of the cement and its suitability for use in structures. Confirmatory studies are often carried out by several research laboratories to validate results already available in the public domain. Although such testing work is important to ensure that the cement meets all technical requirements and the expectations of engineers, such work is often repetitive in nature, is costly and time consuming. Additionally, once the performance of the cement is established, it is difficult to obtain funding to repeat the same work in other laboratories. This is a major challenge that must be overcome by the cement industry, by making necessary investments so as to ensure timely and rigorous testing of the cement. However, given the absence of standards and the uncertainty involved in introducing new products in the market, such investments may be difficult. Government and investment agencies must therefore play a role at this stage.

From the technical studies that are available of LC^3, it can be clearly seen that the cement is not without its demerits. The first obvious demerit of the cement is its higher water demand and the associated higher water-reducing admixture demand. This is due to the high surface area of clays and the adsorption of the admixture on this surface, reducing their efficacy. As much as twice the doses of admixtures required for OPC are required for similar mixture designs produced using LC^3. This must be overcome by carrying out better concrete mix designs and through the development of more suitable admixtures. Given the high surface area of LC^3 and the cohesion that it provides to concrete, a reduction in the fine aggregate content in concrete will reduce the water demand. This would require a change of the thumb rules that are often used in the design of concrete mixes. In the case of admixtures, it is understood that a significant quantity of admixtures is adsorbed on the internal surface of the clays. Development of larger molecules that cannot adsorb on these surfaces would significantly reduce admixture dosage. From this point of view, it is also important to ensure that clays with high purities are either not used in the production of LC^3 or are used with higher limestone to calcined clay ratios. Since the majority of the increased water or admixture demand is due to adsorption on metakaolin particles, the reduction of the quantity of metakaolin in cement will reduce this demand. It has also been shown that LC^3 blends containing lower metakaolin contents react more, especially at lower clinker factors [4].

LC^3 is known as a cement that emits lower quantities of CO_2 during its production. This also means that LC^3 has a lower capacity to bind CO_2 and, therefore, does not pose a significant barrier to the reduction of pH through the process of carbonation [7, 8]. This reduction in pH has been shown to be accompanied by a coarsening of the pore structure of the cement and a reduction in its resistivity [9]. Similar behaviour has been observed in most other cements as well that have a low calcium content due to their low clinker content. This implies that the steel reinforcement in concretes produced using these low clinker cements will be at a high risk of faster corrosion depending on the conditions to which the structure is exposed. Exterior reinforced concrete elements that are exposed to intermittent rain and indoor elements that may be exposed to seepage of water from natural or man-made sources would be especially susceptible to carbonation-induced corrosion. Special measures are required to be taken to prevent the ingress of moisture into such reinforced concrete elements. While research on the possible use of water-proofing compounds and protective overlays is ongoing, relatively expensive measures to prevent premature corrosion of such elements would be required.

Laboratory studies have shown that concretes produced using LC^3 and exposed to temperatures higher than 40 °C during the first 12–24 h of hydration are likely to develop lower strength in the long term due to the formation of hydration products that are known to be less space-filling. This has been seen to occur in both isothermal and semi-adiabatic curing conditions. This may lead to a significant structural risk, since although concrete mixture design is carried out at lower standard temperatures that range from 20 to 30 °C, the concrete in field may be exposed to significantly higher temperatures depending on the climatic region and the casting conditions. Additionally, the coarsening of the microstructure while curing at higher temperatures would also reduce the durability of concrete. Although research on this subject is in a preliminary stage, it has been seen that LC^3 containing components with a certain composition may be more susceptible to a lower final strength development than others. Ensuring the right combination of materials to prevent a lower strength development in concrete is a challenge that must be overcome to allow a safe usage of the cement.

3.2 Commercial Challenges

The introduction of a new product to a market is always challenging. While one of the major strengths of LC^3 is that its use does not require special training and that it can be used almost in the same way as other conventional cements, it is also a challenge that the new cement will have to be marketed to consumers who are accustomed to conventional cements, without the opportunity to provide them additional training. Cost benefits are seen to be the most effective in inducing consumers to move to new products, and such cost benefits can only be provided in cases where the production cost of LC^3 is lower than the production cost of other cements.

One of the most important challenges for the production of LC^3 is locating, identifying and obtaining the rights to mine suitable clays. Since the composition of the clays that are the most suitable for use in LC^3 is significantly different from those used in most other applications, mapping of locations where they are available has not been carried out. Such a mapping is a large exercise where geologists collect samples from many locations on the surface and below using bore holes in order to determine the quality and the quantity of the minerals. This is an important hurdle for the production of LC^3 since significant investment is required in this process of prospecting, while the commercial suitability of production of LC^3 at a location can only be determined after the available quantities of suitable clays are established. Additionally, since these clays are significantly different from those usually sought by the cement industry, the geologists would require further training.

Although the cement industry is familiar with the technology required for the calcination of clays, the lower temperatures than those required for production of clinker and the difference in handling processes of the clays makes investment into new equipment necessary. Additionally, since the properties of the product, such as its hardness, fineness and cohesiveness, are different from the conventional cements, other handling equipment also requires modification. For example, ball mills that normally produce other cements would give larger throughputs of LC^3 due to the relatively softer nature of calcined clay and limestone. This would necessitate an increase in the capacity of the upstream and downstream handling systems. Given the lower temperature of calcination and the nature of the process, the options of using alternative fuels such as municipal solid wastes, rubber tires may not be available. Even the use of petcoke as a fuel, while keeping emissions within prescribed environmental norms, may be difficult. It may be noted here that cement plant manufacturers are in the process of developing equipment that may help in reducing the cost of calcination and allowing the use of alternative fuels. Additionally, plants that adopt LC^3 may continue to produce the other varieties of cements that they currently produce and may require the construction of new cement storage silos. Being a ternary cement, the number of materials that would be required to be tested would increase, and additional staff and testing equipment may be required for this. The difference in the production process of the cement would also necessitate retraining of staff. The investments required in the addition and modification of equipment and the retaining of staff may pose an important hurdle to the adoption of the cement.

Market factors pose an important challenge to the adoption of the cement. Since properties of the cement, such as the fineness, feel and colour, are likely to be different from the other conventional cement, the conservative nature of the market may slow down the adoption of the cement by the users. Furthermore, given the risks involved in introducing a new product to the market, the cement companies may also prefer to take a conservative approach to marketing the cement, reducing the rate of return on the investment required for its production. Widespread marketing and user awareness programmes would be required to allow a faster adoption of the cement.

Currently, fly ash and blast furnace slag are the most widely used SCMs in cement. Both are by-products of other industries and are available at a low cost, without the need for much further processing before the addition to cement. The added costs of drying and calcining the clays reduce the commercial attractiveness of LC^3, compared to other cements where low clinker factors can be achieved using slag and fly ash. Additionally, since most cement plants are located near limestone deposits so as to reduce transportation costs, the additional costs of transporting the clays to the plant are also likely to pose a challenge. Setting up of grinding units at locations where suitable clays are available may be an interesting option in many cases. A more detailed analysis of the influence of transportation costs can be found elsewhere [10]. At locations where LC3 becomes a more commercially attractive option than other blended cements, the risk of increasing environmental pollution through a reduction in the consumption of fly ash is also important to consider for policy makers. This, however, is likely to be a temporary scenario as most economies would move to sources of power other than coal.

4 Conclusions

This article discusses the opportunities and challenges faced for the introduction of limestone calcined clay cement as a commercial product. It can be seen from the discussion that while the cement offers many technical and commercial opportunities for the cement and construction industry, there are challenges to be overcome for its introduction into the market. The environmental benefits offered by the production of LC^3 have been demonstrated widely, and it is imperative that these challenges be overcome as soon as possible to maximise the benefit from producing a more environmentally friendly product. Since most of the challenges being faced by the cement are multifaceted in nature, researchers, consultants, policy makers and cement producers must work together to overcome these hurdles.

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