An economic analysis of the production of limestone calcined clay cement in India

Shiju Joseph, Shashank Bishnoi and Soumen Maity

An international study investigating the suitability of a new ternary blend of crushed limestone, calcined clay and Portland cement clinker (LC^3), has been ongoing for the last few years. While the larger study looks at various technical and environmental aspects of such a cement, the current article presents an economic analysis of the production costs of LC^3 in India, discussing scenarios where this cement can be economically viable to produce. The LC^3 technology was found to be economical with respect to Ordinary Portland Cement (OPC) in most situations and scenarios exist where LC^3 can be more economical to produce than fly ash based Portland Pozzolana Cement (PPC) in India.

Keywords: *limestone calcined clay cement; ternary cement; economy of production; capital investment.*

1. INTRODUCTION

In the year 2014, India produced around 280 million tonnes of cement, making it the second largest cement producer in the world, This figure is expected to double every 8 to 12 years during the coming decades [1]. While this growth is vital to the development of the Indian economy, there are concerns regarding the economic and environmental costs of this growth. Cement production already contributes to approximately 7% of the anthropogenic CO_2 emissions in India [2]. There are also concerns regarding the limited availability of clinker grade limestone in the country. Since late 1990s, fly ash has played an important role in cement production with around 70% of the cement being produced in India containing 25% to 27% of fly ash on an average [3]. While the Indian standards allow up to 35% fly ash content in Portland Pozzolana Cements (PPC) [4], the quality and local availability of fly ash prevents higher replacement levels. While replacement levels of up to 70% are allowed in Portland Slag Cements (PSC) [5], most of the blast furnace slag produced in the country is already used in cement and concrete [3].

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India was the first country to get a roadmap for sustainable development of the cement industry released by the World Business Council for Sustainable Development in association with the Indian cement industry [1]. This roadmap envisages average clinker factors in the range of 0.58 for the Indian cement industry to meet its emission targets. However, it is clear from the above discussion that this target can not be achieved through existing cements.

The Limestone Calcined Clay Cement (LC^3) is a new ternary blend cement recently developed in an international collaboration [6]. Pilot scale production trials of this cement have already been carried out in Cuba and India [7,8]. While these trials indicated encouraging mechanical properties of the cement, the commercial viability of the cement is still not well understood. This study presents an economic analysis of the industrial production of LC^3 in India, from the perspective of scenarios that already exist in the country.

2. BACKGROUND: INDIAN CEMENT INDUSTRY

The cement industry in India is over a 100 years old and due to its constant growth and high energy prices, uses the best available technologies in the sector [9]. Most of the large cement plants in India can be characterised as modern with efficient production processes and strict environmental norms. In the early 1990s, Ordinary Portland Cement (OPC) was the most widely produced cement in India, while PPC shared smaller portions of the market. Due to the increased availability of fly ash and new policies that allowed an easier incorporation of the material in cements, fly ash based PPC cornered around 70% of the share of the market with OPC and PSC taking approximately 20% and 10% of the market respectively [3].

Most of the clinker production units in India are located in seven clusters located around large limestone deposits. Large grinding units also have come up close to coal-fired thermal power plants near urban centres taking advantage of the easy availability of fly ash and high demand of cement in the area. A typical cement plant in India produces 1 to 3 million tonnes of cement every year. It has been reported that the cost of putting up such a cement plant in India is of the order of 100 to 300 million American dollars. While, due to the recent spurt in construction of new cement plants, the current capacity utilisation of the industry stands at around 70%, it is expected that more investment into the construction of new plants will be required to keep pace with the demand projected in the near future.

The typical cost of production of clinker in a large cement plant in India stands between 1,100 and 1,600 Indian Ruppes per tonne. While at most locations, fly ash is available at a cost of 300 to 800 Indian Rupees per tonne, including transportation to the cement plants, at some locations, the landed cost of fly ash can be as high as 1,200 Indian Rupees per tonne. The cost of cement in the market is in the range of 5,500 and 6,500 Indian Rupees per tonne. High excise and tax rates are often cited as the reason behind the price of cement in the market. More than 60% of the cement produced in India is sold in 50 kilogramme bags and is consumed in the housing sector.

Limestone makes the majority of the raw material used to produce cement in India. Since Indian limestones generally contain relatively higher levels of siliceous impurities, little to no clay is used in the production of grey clinker in India. As limited amounts of natural gypsum are available in India, cement plants widely use phospho-gypsum and marine gypsum. Some plants also import high-purity natural gypsum from Oman, Iran, Bhutan, etc.

Most plants use the dry process and consume coal, pet coke and lignite as fuels for the rotary kilns, precalciners and captive power plants that supply electricity to the plants. Waste heat recovery (WHR) is commonly used to produce electricity in the plants and the exhaust gases are at temperatures as low as 80°C. A variety of grinding systems such as ball-mills and vertical roller mills are in use for the grinding of the product. While fly ash is generally interground with clinker and gypsum at most plants, some plants use dry air blending systems.

3. APPLICATION OF LC^3 TECHNOLOGY TO THE INDIAN CEMENT INDUSTRY

The application of the LC^3 technology to the Indian cement industry would require the identification of locations where raw materials required for the cement are easily available. A typical LC^3 blend would contain between 40% to 50% clinker, 15% to 20% crushed impure limestone, 30% to 40% of calcined clay and up to 5% of gypsum. It has been seen that clays with around 50% kaolinite content and limestone with as low as 30% CaO content can be used in LC^3.

Sufficiently large quantities of raw materials of the quality that have been demonstrated to satisfactorily perform in LC^3 [6,8] are known to be available in India [10]. Limestones with calcium oxide content of 37%, one with 8.7% MgO content, have already been used in trial productions in India. Such low purity limestones, which cannot be used in the production of clinker, are easily available in the mines being operated by the cement companies. The Indian Bureau of Mines reports the availability of over 2.7 billion tonnes of high-kaolinite content china clays, currently being used for the production of paper, paints and ceramics in India. These clays are known to be available at least in 22 states in India, including Gujarat, West Bengal, Jharkhand, Kerala, Rajasthan, Assam and Meghalaya [10]. Deposits of materials with lower kaolin contents in the range of 50%, which have been found to be suitable for use in LC^3 are expected to be much larger than those of high-purity china clay.

Since the current production of calcined clay in India is limited to a few million tonnes per year of high purity kaolin products, the production of LC^3 in India will require setting up of new mines, larger scale calcination units and transportation logistics to take calcined or uncalcined clays to cement plants. However, as it has been demonstrated that LC^3 can contain over 50% by weight of a mixture of calcined clay and crushed limestone, giving a cement that performs at least as well as OPC, the capacity of cement plants can be increased by reducing the clinker factor.

This article analyses various scenarios of the production and use of the LC^3 technology. Since it is understood that at all locations where good quality clay is easily available, the cost of production of LC^3 will always be economical with respect to OPC. Only a comparison with PPC is therefore carried out here. Special cases such as white cements, where the cost of production of clinker is much higher than the cost of production of grey cement clinker and value added products, where lower level of clinker replacement may be carried out to achieve higher early strengths, high chloride resistance, etc. are also not covered in this article.

4. PARAMETERS AND DATA

The main parameters that affect the cost of LC^3 production are the availability of clay, the cost of its beneficiation, calcination and transportation in addition to the clinker production and grinding costs. The economy of the production of LC^3 with respect of OPC and PPC would additionally depend on the cost, availability and quality of fly ash. This implies that the commercial viability of the production of LC^3 would depend on the location of a cement plant and the technology being used for the production of the cement. For this reason, instead of calculating the absolute cost of LC^3 production, the relative cost of LC^3 to PPC production was calculated under various scenarios.

The data for the calculations was obtained from the cement industry. It has been assumed that the same fuel, as used in the production of clinker, will be used in the calcination of clay. The energy and cost of calcination of clay has been assumed to be approximately 50% of the energy and cost of the production of clinker. It is assumed that the same fuel is used in the calcination of clay and in the production of clinker. A summary of the data used in this study is summarised in the discussion below.

Unless otherwise mentioned, the composition of LC^3 is assumed to be 50% clinker, 30% calcined clay, 15% crushed limestone and 5% gypsum. The compsition of PPC is assumed to be 60% clinker, 35% fly ash and 5% gypsum, while that of OPC has been considered to be 95% clinker and 5% gypsum. The delivered cost of limestone at the plant is assumed to be Rs. 200 per tonne, while that of lower grade limesone is assumed to be Rs. 100 per tonne. The cost of coal is assumed to be Rs. 8000 per tonne and gypsum to be Rs. 1800 per tonne.

5. ECONOMY OF PRODUCTION OF LC^3 IN AN INTEGRATED CEMENT PLANT

5.1 Effect of cost and transportation of fly ash

At most PPC producing plants, the main factor affecting the cost of production of cement is the variable cost of fly ash. In this analysis the cost variable of fly ash is coupled with the distance between the source of fly ash and clay from the cement plant. The results of the analysis are shown in Figure 1. The y-axis in this figure is the ratio of the estimated cost of production of PPC to the cost of production of LC^3. LC^3 will be commercially viable when this ratio is at least 1.0. The x-axis in this figure shows the difference of the distance from the source of fly ash from the distance to the source of usable clay. The results show that, e.g. when the purchase cost of fly ash is Rs. 200 per tonne and fly ash is transported 100 km more than the clay by road, the additional cost of calcination of clay will be compensated by the cost of transporting fly ash and the reduced clinker content. In this calcualtion it is assumed that the cost of transportation by road is Rs. 2.5 per tonne per km.

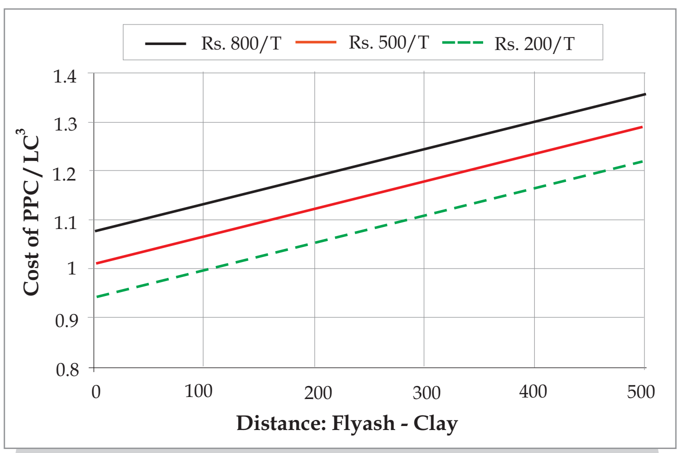

Figure 1. Effect of distance of fly ash and clay sources and the cost of fly ash on the commercial viability of LC^3

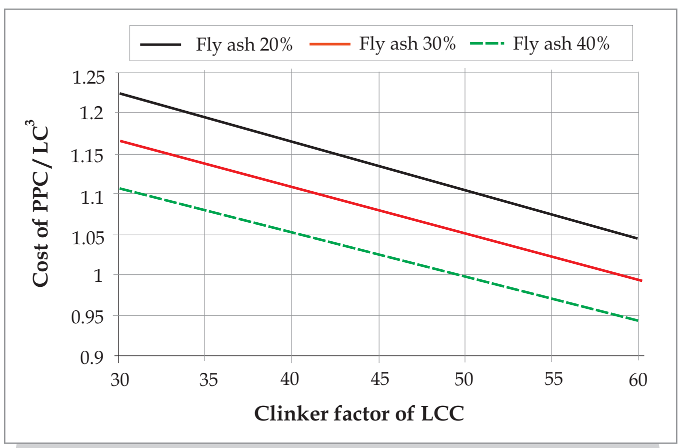

Figure 2. Effect of clinker factor in cement on the commercial viability of LC^3

5.2 Effect of quality of fly ash

Although PPC is allowed to contain up to 35% of fly ash in India, the actual fly ash content depends on the quality of flyash and the composition of the clinker. Finer fly ashes with higher amorphous content and low unburnt carbon content are considered to be of higher quality [11]. At locations where good quality fly ash is not easily available, the fly ash content in PPC would be lower. Similarly, at locations where higher quality clay is available, a lower clinker factor would be possible in LC^3. Figure 2 shows the effect of the clinker factor on the relative economy of producing LC^3. In this calculation, the cost of fly ash is assumed to be Rs. 500 per tonne and both the clay and the fly ash are assumed to be located at the same distance from the cement plant.

6. ECONOMY OF PRODUCTION OF LC^3 IN A GRINDING UNIT AND A READY MIX CONCRETE PLANT

The economy of producing LC3 in a grinding unit where clinker is obtained from the market depends the most on the cost of clinker obtained from the market. The scenario analysed here is where a cement griding unit may have easy access to calcined clay at a cost of Rs. 1000 to Rs. 3000 per tonne, the cost of clinker is Rs. 4000 per tonne. Four different scenarios, as listed in Table 1 were analysed.

A comparison of the effect of the cost of clacined clay on the economy of production of LC^3 is shown in Figure 3.

Similar economics are expected at ready mix concrete plants where a blend of Limestone Clained Clay (LC^2) is used as a pozzolana in place of fly ash and is mixed with cement purchased from the market.

7. OTHER BENEFITS

While it is relatively easier to calculate the production costs of LC^3, other benefits are harder to quantify. For example,

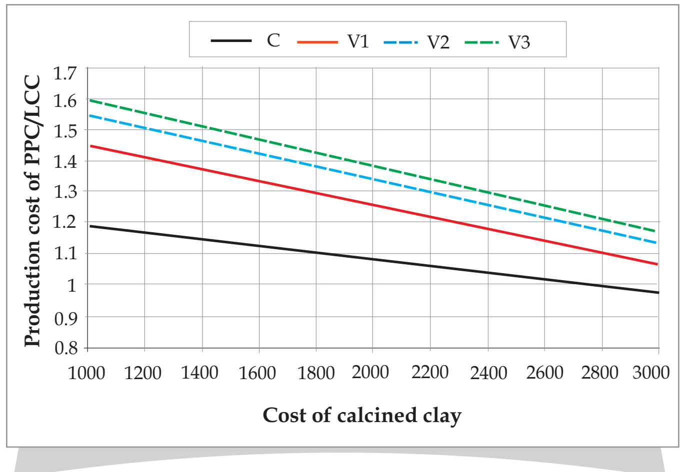

Figure 3. Effect of cost of calcined clay, composition of PPC, composition of LC^3 and cost of fly ash on the commercial viability of producing LC^3

the conversion of a plant from PPC to LC^3 would increase the production capacity due to the reduced clinker consumption, without significant additional capital investment. Additionally, the reduced consumption of clinker grade limestone per tonne of cement and the consumption of lower grade limestone would increase the life of limestone mines.

Limestone Calcined Clay (LC^2) blended pozzolana can also be produced for sale to ready-mix plants and grinding units, where, when used at lower replacement ratios of 15% to 30% of OPC, the strength of concrete can be increased and the permeability reduced. This would make LC2 a replacement for the more expensive silica fume and metakaolin.

The economics of the production of LC^3 could be further affected if there is a cost associated with the emission of CO_2. For example, in scenarios where carbon credits have a significant value, or where policies that promote low

Table 1. Scenarios analysed for a grinding unit and a ready mix concrete plant

Scenario	Control (C)	Variation 1 (V1)	Variation 2 (V3)	Variation 3 (V3)
Composition of OPC	95% clinker, 5% gypsum	95% clinker, 5% gypsum	95% clinker, 5% gypsum	95% clinker, 5% gypsum
Composition of PPC	65% clinker, 30% fly ash, 5% gypsum	65% clinker, 30% fly ash, 5% gypsum	65% clinker, 30% fly ash, 5% gypsum	75% clinker, 20% fly ash, 5% gypsum
Composition of LC^3	50% clinker, 30% calcined clay, 15% limestone, 5% gypsum	35% clinker, 40% calcined clay, 20% limestone, 5% gypsum	50% clinker, 30% calcined clay, 15% limestone, 5% gypsum	50% clinker, 30% calcined clay, 15% limestone, 5% gypsum
Landed cost of fly ash	Rs.800/tonne	Rs.800/tonne	Rs.1500/tonne	Rs.800/tonne

carbon technologies exist, the reduced emissions from the production of LC^3 with respect to a PPC with 30% fly ash would yield added economic benefits. As an example, the CO_2 emissions from the production of different types of cement was calculated for one particular cement plant in India and compared in Figure 4. In this calculation, the emissions from the transportation of raw materials was neglected. However, at the moment, the effect of such policies on the economy of cement production is hard to quantify.

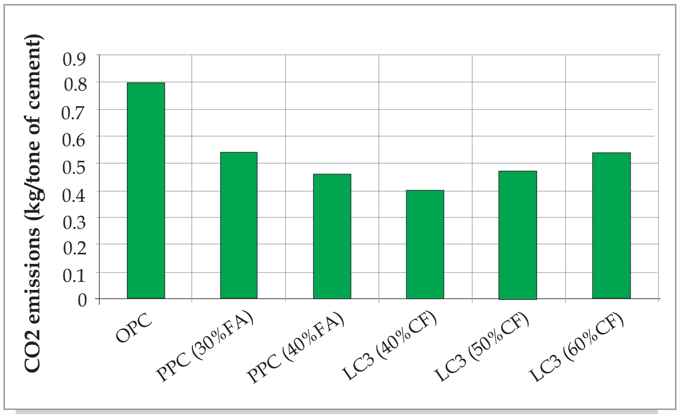

Figure 4. Estimated CO_2 emissions from production of OPC, PPC with different fly ash contents and LC^3 with various clinker factors

8. CONCLUSIONS

It can be seen from the above analysis that the production of LC^3 will be commerically viable with respect to PPC in scenarios where:

- The cost of fly ash is high,
- The quality of fly ash is low,
- Source of fly ash is located at a farther distance than the clay,
- The quality of clay available allows a lower clinker factor in the cement.

The LC^3 technology can be especially econimical in cases where LC^2 is used as a mineral admixture at a grinding unit or a ready mix plant. Such a mineral admixture would also be useful for improving the strength of concrete and reducing its permeability at low dosages. Additional benefits from the reduction of CO^2 emissions with respect to PPC can make the LC^3 technology especially attractive.

The analysis above shows that it is commercially interesting to carry out a deeper location-specific analysis of the feasibility of the LC^3 technology since it can co-exist with pozzolanic cements in scenarios already existing in the country.

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Shiju Joseph received his M.Tech in Civil Engineering from IIT Delhi and B.Tech in Civil Engineering from College of Engineering Trivandrum; is a PhD researcher at KU Leuven, Belgium. He has worked as a research scientist at IIT Delhi before he started his PhD. His research interests are modelling hydration and mechanical properties of cementitious systems, sustainable building materials

Dr. Soumen Maity holds a PhD in Materials Science from Central Glass and Ceramic Research Institute. He is working with TARA (Development Alternatives Group), New Delhi, leading the Innovation-Incubation-Multiplication value chain. His current sectors of interest are industrial waste utilization, resource efficiencies of small scale technologies, alternate building materials and technologies in producing them and water purification systems. He has also successfully transferred home grown Indian technologies to Asia and Africa supporting them in development process.

Dr. Shashank Bishnoi holds a Bachelors from IIT Kanpur; Masters from University of Tokyo; PhD from Ecole Polytechnique Fédérale de Lausanne, Switzerland. He is an Assistant Professor in the Department of Civil Engineering, Indian Institute of Technology Delhi. His areas of interest are experimental and numerical studies into hydration of cement and supplementary cementitious materials, sustainability, durability, repair and life-cycle costs of concrete structures.