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Use of Steel Slag and/or Air Pollution Control Devices Dust as Filler in the Manufacture of Fly Ash Bricks

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Abstract:

Conventional bricks made of clay are the basic component used for construction proposes around the world.Waste materials like Fly ash, steel slag and APCD dust have adverse impacts on human health and is a cause of concern. For environmental protection and sustainable development, there is a need to explore the use of such waste materials in manufacturing of fly ash bricks. The present study focussed on the assessment of use of steel slag and/or APCD dust as fillers in fly ash bricks in order to increase strength of bricks and to facilitate the use of steel slag or APCD dust which are considered to be hazardous wastes. The test bricks manufactured from steel slag, APCD dust and fly ash used in different proportions were subjected to tests including water absorption and compressive strength. Results showed significant decrease in water absorption up to 17% and increase in compressive strength up to 12 N/mm^2 with 21% of steel slag in fly ash brick. APCD dust was also varied from 5 to 20% but due to its very fine size, it was unable to bond strongly enough with rest of the mixture, resulting in higher water absorption rate of 24.53%. As the fly ash possess good pozzolonic properties similar to cement, studies revealed that steel slag also possess comparable properties with those of natural aggregates and therefore it can be effectively used as filler in fly ash bricks.

Keywords — **Fly ash bricks, Steel slag, APCD dust, Compressive strength, Water absorption**

Introduction

In India, approximately 180 billion tons of common burnt clay bricks are consumed annually, which requires approximately 340 billion tons of clay ***(Sivalingam N., 2011).*** Soil erosion, emission from coal burning or fire woods and deforestation are the serious problems posed by brick industry. Fly ash is being accumulated as waste material in large quantity near thermal power plants, thus, creating serious environmental pollution problems. All fly ash contain significant amounts of Silicon dioxide (SiO_2), Aluminium oxide (Al_2O_3), Iron oxide (Fe_2O_3), Calcium oxide (CaO), and Magnesium oxide (MgO) however, the actual composition varies from plant to plant depending on the quality of coal burnt and the type of burner employed. Fly ash also contains trace elements such as mercury, arsenic, antimony, chromium, selenium, lead, cadmium, nickel, and zinc ***(Feng et al., 2011).*** The utilization of fly ash as main raw material in the manufacture of bricks has not only created ample opportunities for its proper and useful disposal but also help in environmental pollution control to a greater extent in the surrounding areas of power plants. The manufacture of fly ash bricks is a commercially and technically established technology. Fly Ash bricks can be extensively used in all building constructional activities similar to that of common burnt clay bricks. The fly ash bricks are comparatively lighter in weight and stronger than common clay bricks ***(Pawar et al., 2014).***

Steel slag exist as solid waste during melting of steel scrap from the impurities and fluxing agents, which form the liquid slag floating over the liquid crude iron or steel in arc or induction furnaces, or other melting units. The use of such materials not only result in conservation of natural resources, but also helps in maintaining good environmental conditions by effective utilization of these wastes material ***(Sarkar et al., 2010).*** The physical, chemical and mechanical properties of steel slag and the steel slag concrete were studied by few researchers ***(Kothai et al., 2014)*** and revealed that its properties are comparable with those of natural aggregates. The mechanical properties of hardened concrete incorporated with steel slag showed a better result when compared to conventional concrete. ***(Saravanan et al., 2015)***

APCD dust is made up of solid particles predominantly larger than those found in colloids and capable of temporary suspension in air or other gases. It is produced by crushing or burning of organic or inorganic materials. Generally, they are over 20 μ in diameter, although some are smaller. Most of the APCD dust particles settle to the ground as dust fall, but particles 5 μ or smaller tend to form stable suspensions ***(Rao et al., 2011)***.

Globally, the production of fly ash in India is at the top with 112 MT/yr. followed by China 100 MT/yr., USA 75MT/yr., Germany 40 MT/yr., UK 15 MT/yr., Australia 10 MT/yr., Canada 6 MT/yr., France 3 MT/yr., Denmark 2 MT/yr., Italy 2 MT/yr. and Netherlands 2 MT/yr. But, the utilization rate the trends get reversed with 100% utilization by Netherlands, Italy and Denmark, 85% utilization by France, Australia and Germany followed by Canada 75%, USA 65%, UK 50%, China 45% and India at the last spot with only 38% utilization ***(Dwivedi et al., 2014)***. Bricks whose solid ingredient of 100% fly ash are 28% lighter than clay bricks and possessed compressive strength higher than 40 MPa ***(Kayali, 2005),*** some fly ash bricks were produced by using fly ash, water & chemical additives such as plasticiser, Carboxymethyl Cellulose (CMC) and $CaCl_2$ in small quantities ***(Nawza, 2013; Senapati, 2011)***. Fly ash might improve the compressive strength of bricks and make them more resistant to frost ***(Lingling et al., 2005).*** Use of around 25% of fly ash instead of cement helps in gaining effective resultant end products in terms of durability, workability, permeability and density. It has been analysed that black coal fly ash was mainly used in research studies as it contains less impurities than brown coal fly ash ***(Gamage et al., 2011).***In India, the current production of clay brick exceeds 100 billion bricks a year. Under such circumstances fly ash brick is technically acceptable, economically viable and environment friendly solution. It has been reported that in order to produce 2 billion fly ash bricks per year, it would consume about 5 million tonne of fly ash /year, yielding a net saving of around Rs. 20 crores per annum ***(Dwivedi et al., 2014)***. Full utilization of generated fly ash in India, will provide employment potential for 3000 people. ***(Patil et al., 2013)***

Steel Slag is being used extensively for various applications across the world including USA, the European Union, Brazil, Australia and China. Australia utilizes more than 60 to 70 % the steel slag that it generates. On an average, China use 40-50% Europe use 80%, US and other developed countries use 70-80 % of steel slag. In India, slag utilisation is less than 20% ***(FICCI, 2014).*** Masonry brick made by utilizing steel slag showed higher bulk density values than the commercial bricks. Water absorption values for all masonry brick groups were either comparable to or slightly higher and the compressive strength results after 28-days of curing were also higher than commercial bricks ***(Kornay et al. 2001).*** The replacement of cement by steel slag developed lower strength at all ages compared to Portland cement, and the strength of the cementitious pastes decreased with increasing slag content ***(Kourounis et al., 2007).*** The replacement of common natural aggregate with carbonated granulated steel slag aggregate showed significant improvement in the compressive strength and volume stability with drop in water absorption, porosity and free calcium oxides ***(Pang et al., 2015).*** The replacement of conventional aggregates by steel slag aggregates in various concrete grade assessed and results indicate that with the increase in proportion of steel slag the strength of aggregates also increased but after 75% replacement of sand as steel slag, slightly decrease in strength was observed but still it is higher than 0% replacement without any adverse effect on the strength of concrete ***(Pajgade et al., 2013).***

The dedicated literature indicates that most of the research in the field of fly ash bricks lies with natural aggregates as filler materials. There was limited research in the utilization of steel slag or APCD dust as filler in fly ash bricks/blocks. Some reports discussed the utilization of fly ash in bricks but it is very low in comparison to global trends.The utilization of steel slag in construction sector is very low, as there is no interest shown by industries in taking initiative toward this area. The use of steel slag as filler in the manufacture of fly ash bricks needs to be explored. In the field of APCD dust utilization in fly ash bricks, no research findings are available. Thus, its use needs to be assessed. So, the current study aimed at the assessment of use of steel melting furnace slag and/or APCD dust as filler in the manufacture of fly ash bricks for attaining superior properties of synthesized bricks/blocks.

1. Materials & Methods

1.1 Materials:

Fly ash used in the study was collected from Thermal Power Plant, Roopnagar and used as such. Steel slag and APCD dust were collected from Induction furnace unit, Mandi Gobindgarh. Ordinary Portland cement of grade 53 was used as binder.

1.2 Methodology employed in Brick manufacturing

The manufacturing process of Fly ash bricks/blocks requires fly ash, steel slag, APCD dust and lime/ cement to be mixed in a suitable proportion. The manufacturing process involves pan mixing, conveying the mixture to moulds, moulding, drying and curing. The manufactured bricks were of size 230x110x75mm. Different ranges of Fly Ash 35-70%, steel slag 21-45% and APCD dust 5-20% were used in the manufacturing of bricks. Table 3.1 shows all the compositions used for bricks manufacturing. Curing time of 15 - 21 days were given to the manufactured bricks.

Table 2.1: Different composition of Bricks

Sample Code	Materials Used (%)
Composition-1 (C-1, Brick)	FA*-50%, AD*-20%, SS*-25%, C*-5%
Composition-2 (C-2, Brick)	FA*-50%, AD*-20%, SS*-23%, C*-7%
Composition-3 (C-3, Brick)	FA*-50%,AD*-20%,SS*-21%, C*-9%
Composition-4 (C-4, Brick)	FA*-55%, AD*-15%, SS*-21%, C*-9%
Composition-5 (C-5, Brick)	FA*-55%,AD*-15%,SS*-23%, C*-7%
Composition-6 (C-6, Brick)	FA*-60%,AD*-10%, SS*-22%, C*-8%
Composition-7 (C-7, Brick)	FA*-60%,AD*-10%,SS*-21%, C*-9%
Composition-8 (C-8, Brick)	FA*-65%, AD*-5%, SS*-21% ,C*-9%
Composition-9 (C-9, Brick)	FA*-45%, SS*-45%, C*-10%
Composition-10 (C-10, Brick)	FA*-70%, SS*-21%, C*- 9%
Composition-11 (C-11, Brick)	FA*-35%, WL*-16%, SS*-30%, S*-15%, C*-4%

FA- Fly Ash, SS*- Steel Slag, AD*- APCD dust, WL*- Wet Lime, S*- Sand& C*- Cement*

2.3 Testing of Bricks/Blocks

Synthesised bricks were tested for compressive strength and water absorption.

2.3.1 Compressive Strength Test

The purpose of conducting this test is to check the load at which the brick fails. The testing was done according to Indian Standard Code IS-3495 (Part-I):1976. Any unevenness observed in the bed faces was removed by grinding to provide two smooth and parallel faces. The specimen was immersed in water at room temperature for 24 hours. The specimen was removed and any surplus moisture was drain out at room temperature. Cement mortar (1:3) was prepared to fill the frog and all voids in the bed faces. The prepared specimen was stored under jute bags for 3 days. After three days, the specimen was removed and any traces of moisture were wiped out. The areas of two horizontal faces were measured. The specimen was placed with flat faces horizontal and mortar facing upward between two plywood sheets and centre carefully between plates of testing machine. The load was applied axially at a uniform rate of 14 N/mm^2 per minute till the failure occurs and the maximum load at failure was noted. The compressive strength (N/mm^2) of the specimen was calculated Maximum load at failure in N divided by average area of the bed in mm^2.

2.3.2 Water Absorption Test (24-hours Immersion Cold Water Test)

This test was done according to Indian Standard Code IS-3495 (Part-II):1976 [16]. The specimen was dried in a ventilated oven at temperature of 105-115°C till it attained substantially constant mass and thereafter, cooled to room temperature and its weight (M_1) was obtained. Completely dried specimen was immersed in the clean water at a temperature of 27 ± 2°C for 24 hours. The specimen was removed and traces of water were wiped with damp cloth. The weighing (M_2) was noted within 3 minutes after the specimen has been removed from water and water absorption (percent by mass) was calculated.

2.4 Heavy metal Analysis

Effluents from water absorption test were tested to assess the presence of heavy metals (iron, lead, zinc, etc.). Testing of the samples was done by APHA 22nd. Edn.3111B. Sample was digested with concentrated HNO_3 (2 ml in 50 ml sample) and thereafter, the digested sample was analyzed for metals in Atomic Absorption Spectrometer (AAS)/ Microwave Plasma Atomic Emission Spectrometer (MP-AES).

2. Results and Discussions

In the manufacturing of fly ash bricks of size 230x110x75mm, the replacement of conventional filler materials has been explored with steel slag and APCD dust. This section presents the results of water absorption and compressive strength of especially manufactured bricks. Each composition was tested in batch of four bricks of same composition and average result has been reported.

3.1 Variation of Fly Ash and steel slag

Fly ash is pozzolanic in nature, which help in attaining cementing properties so fly ash can replace large amount of cement products form different construction sectors. Fly ash has the potential of replacing conventional clay bricks because fly ash bricks are much more superior to conventional clay bricks. Moreover, the use of steel slag in fly ash bricks open new gateways for its utilization in construction sector and provide steel slag a new platform for replacing the conventional aggregates. In this study, the fly ash and steel slag was varied from 35-70% and 21- 45% respectively to assess the effect on compressive strength and water absorption of bricks. Results in Fig. 3.1 (a) & (b) depict that, as the proportion of fly ash was increased, there was improvement in the compressive strength and decrease in water absorption, respectively. The composition C-10 with 70% fly ash and 21% steel slag resulted in compressive strength of 11.21 N/mm^2 when compared to 3.5 to 5 N/mm^2 of conventional clay bricks. The water absorption for this composition was found to be 18.51% which is well below 20% required for a good brick. The high compressive strength of C-10 bricks may be attributed to the cementing properties of fly ash used in manufacturing bricks. Improvement in the compressive strength features the well build matrix in the manufactured bricks, which help other materials to make strong bonds with each other. As steel slag aggregates expected to have dense structure with minimum voids, so there was decrease in the permeability of bricks that result in lowering the water absorption. Previous studies also indicated that fly ash used in range of 40 to 70% improved the compressive strength of bricks. ***(Lingling et al., 2005; Pang et al., 2015).***

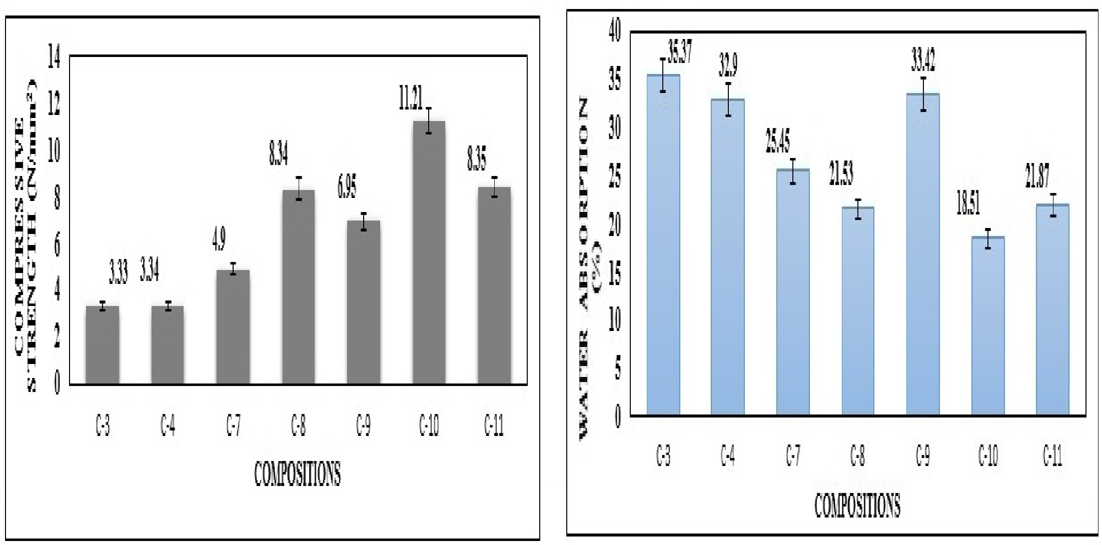

Figure 3.1: (a) Variation of Compressive Strength & (b) Water Absorption with different composition of Fly Ash

3.2 Variation of APCD Dust in Bricks

Air Pollution Control Devices (APCD) dust is a mixture of solid particles larger than colloidal particles. APCD dust is usually collected with the help of electrostatic precipitators and cyclone separators. The effective utilization of APCD dust is yet to be explored for its environmental friendly disposal. In this study, the APCD dust was varied from 5-20% in fly ash bricks to evaluate the effects on compressive strength & water absorption. Fig. 3.2 (a) & 3.3 (b) shows that with the increase in the amount of APCD dust there was decrease in the compressive strength and the maximum compressive strength of 8.34 N/mm^2 was observed with 10% APCD dust. The water absorption values of the bricks prepared with APCD dust were on higher side which is not desirable. Hence, composition C-7 with APCD dust of 10% showed better results with compressive strength and water absorption of 8.34 N/mm^2 and 24.53%, respectively. APCD dust have very fine structure which helps in filling the voids present in the bricks that results in increase in compressive strength, but due to very fine size of APCD dust particles, it was unable to bond strongly enough with rest of the mixture, resulting in higher water absorption.

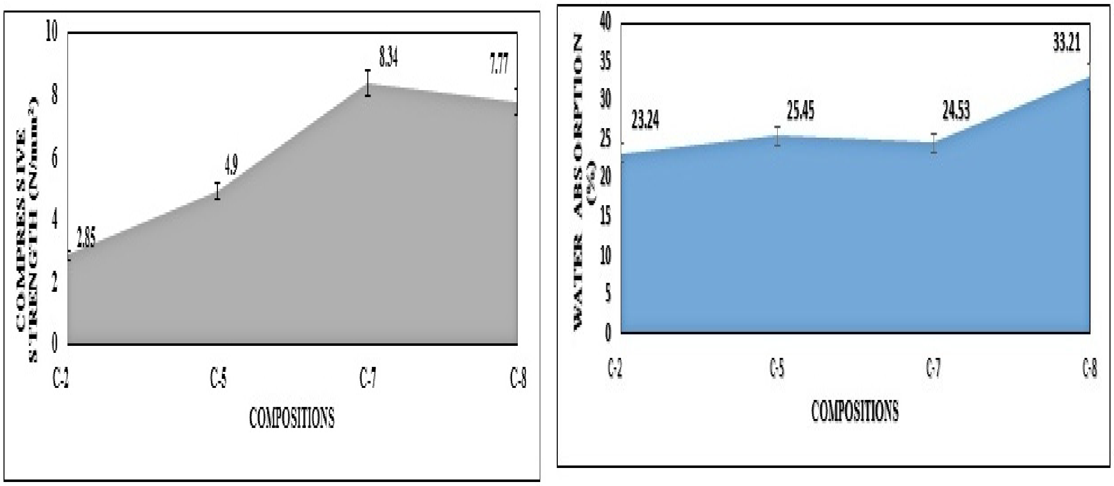

Figure 3.2 (a) & (b): Variation of Compressive Strength &Water Absorption with Different Composition of APCD Dust

3.3 Effect of pH

Bricks/blocks are the stepping stone of any structure; it has to deal with environmental conditions inside and outside the buildings. Rain water plays a very important role in bricks/blocks, therefore the effect of pH on bricks/blocks must be considered. As acid rain is one of the most common polluting phenomena these days, it can have very detrimental effects on infrastructures. In current study, the pH of water used in water absorption test was varied ranging from pH 5.0 to 9.0. Results presented in Fig 3.3 (a) &(b) showed insignificant effect of pH on the compressive strength or the water absorption. During the physical examination of bricks after water absorption test with different values of pH, the condition of bricks were good. So, the effect of pH on the synthesized bricks was not detrimental with change in pH.

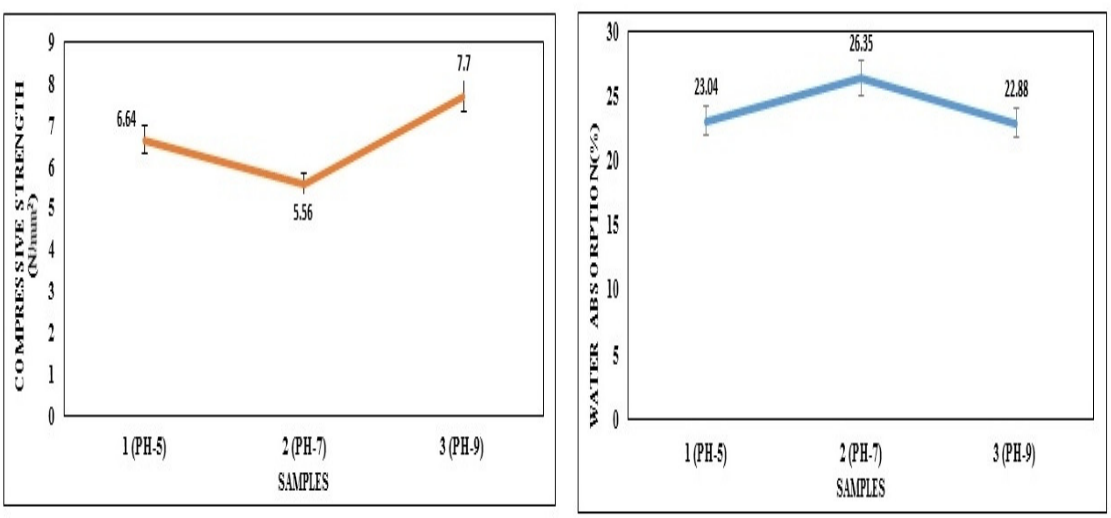

Figure 3.3 (a) & (b): Variationsin Compressive Strength & Water Absorption Test at Different pH Values

3.4 Effluent from Water Absorption Test

During rainy seasons, bricks/blocks came in contact with water, if they possess traces of heavy metals in them, then they can induce heavy metals in surface run offs and may even contaminate the ground water. In the present study, the presence of heavy metals (Zn, Pb& Fe) in the effluent from water absorption test was assessed. It is evident from Fig.3.4 that the presence of heavy metals (Fe, Pb & Zn) were within the acceptable limits (Fe < 3mg/L, Zn < 5mg/L & Pb< 0.1 mg/L) which allows its safe discharge in the environment ***(The Environment (Protection) Rules, 1986).***

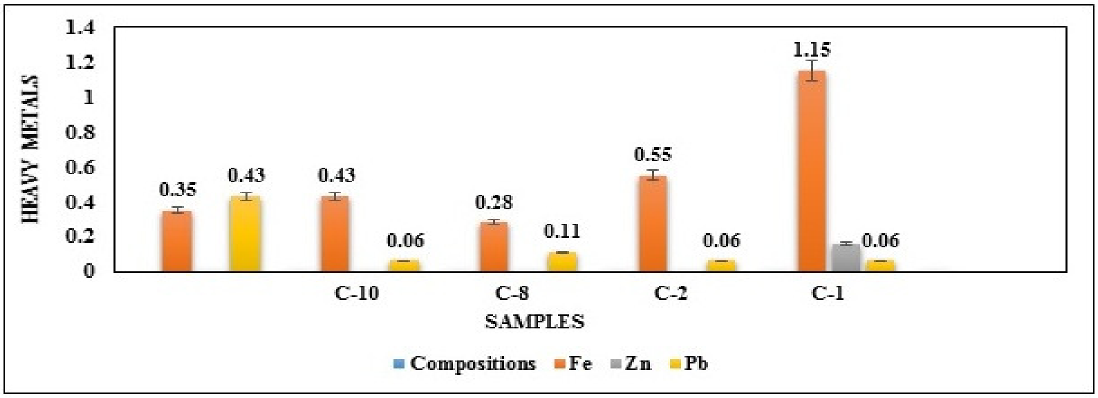

Figure 3.4: Presence of Heavy Metals in Effluent Samples after Water Absorption Test

3. Conclusion

The observations clearly indicate that the synthesized bricks made from fly ash and steel slag showed significant increase in compressive strength and lowering of water absorption when compared to conventional bricks. With the increase in the amount of steel slag, there was a decrease in the water absorption and increase in the compressive strength. The brick composition C-10 (Fly ash-70%, Steel Slag-21% & Cement- 9%) furnished good compressive strength of 11.21 N/mm^2 when compared to 3-5 N/mm^2 of conventional bricks. The water absorption of this composition was 18.51% which is well below 20% as required for a brick of good quality. With the increase in the amount of APCD dust, there was decrease in the compressive strength and the maximum compressive strength of 8.34 N/mm^2 was observed with 10% APCD dust. The bricks prepared with APCD dust were having water absorption of 31.8%, which is on higher side and is not desirable. Hence, brick composition C-7 with APCD dust of 10% gives the better results with compressive strength of 8.34 N/mm^2 and water absorption of 24.53%. The effect of pH was also investigated on bricks/blocks, by varying pH from 5.0-9.0 and the result revealed no significant alteration in the compressive strength or the water absorption. Even during the physical examination of bricks after water absorption test with different values of pH, the condition of bricks was found to be good. The effluent from the water absorption was also tested for the presence of heavy metal (Fe, Pb& Zn) and the results showed that the metals were found to be present under permissible range (Fe < 3mg/L, Zn < 5mg/L & Pb< 0.1 mg/L) and can be discharged safely into the environment. Hence, it can be concluded that the use of steel slag and APCD dust as a filler in fly ash bricks/blocks may prove to be beneficial for construction purposes as they are also cost effective and environmental friendly materials.

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