Effect of Binders on the Properties of Concrete – A Review

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Abstract
There is a need for alternative materials which will partially or fully replace cement used in concretes and mortars without affecting the quality and other desired properties. The blending of cement with supplementary cementitious or non-conventional material is vital in low-cost construction; these materials are referred to as binders or pozzolanas. The binders discussed in this study are; Ordinary Portland cement, Fly ash, ground granulated blast furnace slag, silica fume, metakaoline and Cassava peel ash. The properties considered in the study were grouped into fresh properties, mechanical properties and durability properties. Findings from this study reveals that cassava peel ash, metakaoline, ground granulated blast furnace slag, fly ash and silica fume enhance the workability of fresh concrete when added as blended material. These binders also enhance the compressive, tensile and flexural strength of concrete when administered optimally. Ordinary Portland cement has poor acidic attack resistance and weak resistance to extreme temperature thereby putting its durability on doubt. Cassava peel ash, metakaoline, ground granulated blast furnace slag, and Fly ash tend to exhibit reasonable durability properties even at adverse conditions such as acidic attack. This study reveals that these binders which are waste products can be used to enhance durability and mechanical properties of concrete. Rather than these binders been discarded, they can be used in concrete production thereby promoting the sustainability of the environment.

Keywords: Binders, concrete, durability, mechanical properties, waste material.

Introduction

Concrete is one of the most commonly used construction materials in civil engineering practice and construction works around the world, there's great dependency on concrete (Olafusi *et al*., 2015). It is the world's most widely used construction materials because of its durability properties, concrete is a multipurpose construction material (Serdar *et al*., 2019). Concrete is readily available, relatively cheap, flexible to handle and can be formed into any desired shape and any desired form (Anejo & Damen, 2014). In a broad sense, concrete is made from the combinations of cementitious material (cement, lime, pozolanas), aggregates (fine and/or coarse) and water. However it can also accommodates some additives and/or admixtures added to the basic constituents to diverge the properties of the concrete when it is green or hardened (Anejo & Damen, 2014) .

Concrete exhibits quite acceptable properties that are required of a construction material and due to its flexibility, it can be mixed with other constituent elements which makes it more adaptable (Mamoon & Mondal, 2019). The properties of concrete can be grouped into fresh or green properties which are properties exhibited by concrete from its mixing state to the time it start solidifying, this behavior is generally termed as workability which is used to describe its cohesiveness and consistency (Suryawanshi *et al*., 2015).

The materials used in concreting tend to alter the properties of concrete, be it coarse, fine or the binders. That is to say, properties of the concrete are dependent on the type of constituent used in the concrete mix (Wallevik, 2009). Binders play one of the key roles in a concrete mix, it's the material that holds other constituents together. A binder is any material either liquid or solid that holds or draws other materials together to form a cohesive whole mechanically; chemically, by adhesion or cohesion. In a clearer sense, binders are liquid matter that harden by a chemical or physical process and bind fibres, filler powder and other particles added into it (Strijov, 2020).

The new trend that have emerged in construction materials research area is to find out the material with a good concession between the usage performances on one hand, and the durability and sustainability on the other hand (Aubert et al., 2019). It is against this backdrop that this review was embarked upon, the study covers mainly, literatures written within the last ten years, the study also considered the most commonly used binders based on findings from previous researches. These commonly used binders are fly ash, ground granulated blast furnace slag, metakaoline, cassava peel ash and silica fume. They are all regarded as industrial waste product.

Chemical Composition of Binders

The chemical composition of materials is commonly determined using the X-ray fluorescence (XRF) method. This approach involves the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays. The elemental chemical analysis results which gives the oxides composition of ordinary Portland cement, ground granulated blast furnace slag, fly ash, silica fume and rice husk ash as reported in previous work is depicted in Table 1.

Table 1: Chemical composition of binders

Oxides	OPC	GGBS	Fly ash	Silica fume	RHA
CaO	67.2	34.0	3.5	0.1	0.8
SiO_2	22.3	35.5	53.7	96.0	93.4
Al_2O_3	4.4	15.4	28.1	0.1	0.2
MgO	1.0	9.4	0.8	0.2	0.4
TiO_2	0.2	1.2	-	-	-
Fe_2O_3	3.4	1.0	11.6	0.6	0.2
MnO	0.1	0.9	-	0.2	-
K_2O	0.6	0.9	-	0.4	2.0
Na_2O	0.2	0.2	0.8	0.1	0.1
SO_3	0.6	2.5	0.4	-	0.2

Effect of Binders on the Properties of Concrete

Workability

From the results of the compacting factor test conducted on samples of cement-Cassava peel ash blended concrete at various percentage replacements with 0.6 water binder ratio. It was observed that the slump and compacting factor values reduces as the CPA was increased. This shows that more water is needed to achieve better workable mix. It is observed that the percentage replacement level of cement with CPA did not have any appreciable influence on the densities of the test specimens of the blended concrete. This may be attributed to the lower specific gravity of the CPA which was much lower than that of cement (Olatokunbo *et al.*, 2018).

The standard values of slump required for the different working conditions shows that the concrete remains stable in the range of very low to low workability (Oladipo *et al.*, 2013). This means they can be applied on road vibrated by mechanical power operated machine and hand operated machine in accordance with the provision of the -BS 4550 method of testing cement British Standard Institute London (Neville and Brooks, 1987). In other words, the concrete embedded with CPA up to 50 percent constituent is still stable and could be acceptable in most concrete work in building industry.

Quareshi et al. (2014), carried out research on the effect of fineness of ordinary Portland cement (OPC) (ASTM type 1) on the workability of high strength concrete. Six OPC samples of fineness ranging from 1525 to 3741cm^2/g each weighing 15kg were prepared. Slump and compacting factor tests were carried out to determine the workability. The slump test according to figure 1 shows that the slump increases with increase in fineness up to 2500 cm^2/g and remains constant up to 3400cm^2/g and afterward, it then increases with increasing fineness. The compacting factor test also shows an increase in workability with increase fineness according to figure 2.

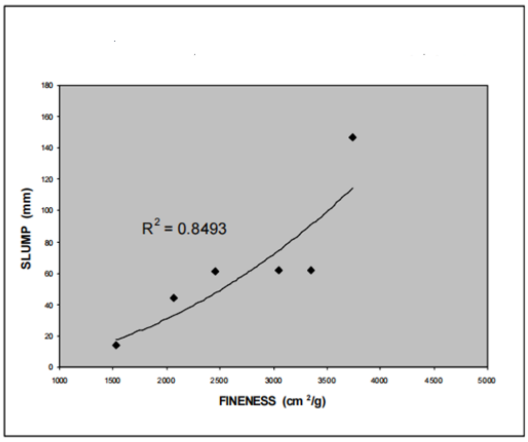

Figure 1: Fineness of cement on slump

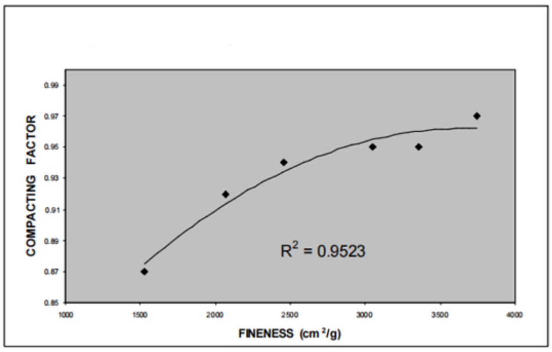

Figure 2: Fineness of cement on Compacting factor

Adam, (2021) carried out a research on the effect of blending Ordinary Portland Cement (OPC) type class 42.5N with fly ash (ASTM Class F) on the workability of self-consolidating concrete (SCC). Three different total binder content levels of 400, 460, and 520 kg/m3 were adopted. For each total binder content level, one Powder-Type SCC mix (SCC-P), one Admixture-Type SCC mix (SCC-A), and one Combined-Type SCC mix (SCC-C) were prepared. In addition to the three SCC mixes, one NVC mix was made for the sake of comparison. Two different chemical admixture types were utilized in the study. Naphthalene Sulphonate superplasticizer (SP) was incorporated to improve workability and flowability, while modified polycarboxylate viscosity modifying admixture (VMA) was used to control bleeding and limit segregation of fresh concrete. It was observed that all investigated SCC mixes achieved the required flowability, viscosity, passing ability, and segregation resistance, additionally; it was observed that there were no signs of neither bleeding nor segregation during slump flow testing of all SCC mixes. Table 2 shows the results of the slump flow test, L-Box test and sieve segregation test.

Table 2: Properties of Fresh Concrete

	Slump Flow		L-Box	Sieve Segregation
	D, cm	T_{50}, s	Passing ability	Segregation ratio, %
NVC-1	7.0*	---	---	---
SCC-A-1	65.0	1.20	0.80	15
SCC-C-1	64.0	1.25	0.79	12
SCC-P-1	67.0	1.15	0.80	16
NVC-2	6.0*	---	---	---
SCC-A-2	65.0	1.10	0.82	17
SCC-C-2	66.5	1.16	0.82	18
SCC-P-2	67.0	1.30	0.79	18
NVC-3	7.5*	---	---	---
SCC-A-3	64.0	1.35	0.79	17
SCC-C-3	65.0	1.15	0.80	18
SCC-P-3	64.0	1.10	0.81	15

Compressive Strength

From the outcome of several studies carried out compressive strength seems to be the most popular evaluating parameter for concretes. This is due to the fact that it is the quality that access the load carrying capacity of a concrete mix. Despite the fact that a lot of binders are being considered overtime, to produce cheaper concrete, the compressive strength of concrete can not be compromised.

Table 3: Compressive Strength of Concrete using Silica fume and Fly ash as binder

Mix	Binder	Compressive strength (N/mm^2)	
		28days strength of silica fume	28days strength of Fly ash
M1	0	38.30	39.53
M2	5	41.29	40.95
M3	10	46.76	42.50
M4	15	47.3	39.36
M5	20	44.27	38.15

(Amudhavalli & Mathew, 2012; Kiran & Ratnam, 2014)

Table 3 presents the outcome of two different researches with similar mix design. Amudhavalli & Mathew, (2012) investigated the effect of silica fume on strength and durability parameters of concrete by partial replacement of cement with silica fume at 0, 5, 10, 15 and 20% levels. The compressive strength test was carried out conforming to IS 516-1959 to obtain compressive strength of concrete at the age of 28 days. The result indicated significant improvement in the compressive strength of concrete because of the high pozzolanic nature of the silica fume and its void filling ability. Similarly Kiran & Ratnam, (2014) performed similar experiment although with Fly ash and the result shows increase in strength gain too with the increase in Fly ash content, although with different optimum replacement levels, Silica fume had 15% optimum replacement while fly ash was 10% optimum replacement.

Slag mixes is also found to have better strength performance than the plain CEM I 42.5R mix at all ages, contrary to other studies at 20°C (Ogirigbo and Black, 2015) where early age strength development was found to be retarded with composite cements. The high temperatures here speed up the strength development. The reason is because hydration of slag in the presence of PC depends on the breakdown and dissolution of the glass slag structure by hydroxyl ions released during the hydration of PC (Ogirigbo & Inerhunwa, 2017), and this process is known to be accelerated at high temperatures (Escalante et al., 2001).

Furthermore; Suryawanshi et al., (2015) investigates the effects of Metakaolin & Super plasticizer on strength properties of M-35 grade concrete. The experimental program was designed to find the compressive strength of concrete by partially replacing the cement in concrete production. The replacement levels of cement by metakaolin are selected as 4%, 8%, 12%, 16% and 20% for constant water-cementitious material ratio of 0.43. For all mixes compressive strength is determined at 3, 7, 28 days for 150 X 150 X 150 mm size cubes. The experimental study shows that 12% replacement of cement by metakaolin gives higher strength.

Similarly, Sharbaf et al., (2017) investigated on the effects of water to binder (w/b) ratio and binder content on mechanical and durability properties of High Performance Concrete (HPC. Twelve combinations with w/b ratios of 0.3, 0.34, 0.38, and 0.42 and binder contents of 330, 440, and 550 kg/m^3 were made. The result of compressive strength tests after 7 and 28 days of curing indicated an increase with increase in binder content. Patel et al., (2015) researched on effect of binder volume on fresh and hardened properties of Self Compacting Concrete (SCC) and the study showed contrary outcome, this time around the compressive strength decreased as binder quantity increased. This may be due to decreased in aggregate volume in mix proportion. On increasing the binder, compressive strength was increased. Increased in compressive strength for higher binder volume may be due to very strong bond between aggregate and cement. For higher volume of binder quantity and lower water binder ratio, the strength of concrete cube was increased.

In the same manner Olatokunbo et al., (2018) investigated the effect of partial replacement of cassava peel ash with ordinary Portland cement at 5, 10, 15, 20 and 25%. The cassava peel ash was obtained by calcinations of cassava peel to 7000 c temperature. Cube samples of size 150 x 150 x150 were prepared for concrete grade 30 and cured in water for 7, 14, 28, 90, 120 and 180 days after which they were subjected to compressive strength, tensile strength, durability, porosity, water absorption, slump, compact factor and shrinkage tests. The results showed that partial replacement of 10 and 15% gave compressive strength comparable to the control with 0% replacement and optimum replacement of 10%. Osuide et al., (2021) embarked on similar studies and found that the strength of cement-CPA concrete is similar to those of normal concrete, especially at later age (56 days and above), when not more than 15% CPA is used and from the values of the compressive strength obtained, concrete made with unreplaced cement (control) at 28 days strength was not up to two times the value of the strength of concrete made with CPA replacing cement by 50% at 28 days which makes the strength acceptable, the findings also correlates with Oladipo et al., (2013).

Suzuki et al., (2020) carried out the compressive strength tests on the concrete incorporated with fly ash possessing various chemical composition, which are high and low calcium and the result shows that compressive strength of concrete with high calcium fly ash indicates a strong correlation with calcium content fly ashes also in the case of 10% and 20% replacement levels, the compressive strength exceeds that of concrete without fly ash even as early as on the 3rd day. Sabarish, (2019), also worked on partial replacement of cement with fly ash in concrete elements. The cement was replaced by fly ash accordingly in the range of 0% (without fly ash), 10%, 20%, 30% & 40% by weight of cement for M-25 and M-40 mix. These tests were carried out to evaluate the compressive strength after 28 days and split tensile strength after 56 days. The result indicated that compressive strength reduces when cement replaced fly ash. As fly ash percentage increases compressive strength and split strength decreases. Andreola et al., (2019) worked on the partial replacement of cement with fly ash and metakaolin with the purpose of reaching compressive strength closer to a bio- concrete containing only cement. Mixtures with partial substitution of 0, 40, 50, 60 and 70% of cement by mass were produced with a volumetric fraction of bamboo set as 40%. The compressive behavior of the bio-concretes was analyzed at 7, 28, 60 and 90 days. The results revealed that it was possible to reach between 60% and 90% of the reference strength, producing workable bio- concretes using binders with low CO2-emission.

Awodiji & Onwuka, (2016) re-investigated the compressive strength of ordinary Portland cement (OPC) concrete and lime concrete (LC) using five selected mix ratios. Materials used in concrete production were ordinary Portland cement, hydrated lime, granite chippings as coarse aggregates and river sand for fine aggregate. Optimum values of compressive strength recorded for OPC concrete at 7 days and 28 days of curing were 11.55N/mm2 and 26.96N/mm2 respectively. The results obtained showed that the compressive strengths at 90 days curing for LC are approximately half of the compressive strength values of OPC concrete at 28 days. Compressive strength values at 90 days for the LC were close to that of the 7 days strength values for OPC concrete. The compressive strength values of LC increased with increasing curing age which informs non-deterioration of concrete. Compressive strengths at 7 days curing of LC showed no results of strength gain.

Split Tensile Strength

Adam, (2021) researched on the effect of Binder Content on Properties of Different Self- Consolidating Concrete Types, the study used three different binder content levels of 400, 460, and 520 kg/m3. From the findings it was observed that with increase in the binder content the concrete also exhibited higher splitting tensile strength. However in a contrasting outcome Olatokunbo et al., (2018) on the effect of cassava peel ash on the tensile splitting strength, it was observed that in each case generally the tensile splitting strength decreases as the percentage of the CPA increased. The result in table 4 shows the increase in split tensile strength for the mix M3 to be 4.10N/ N/mm^2 and 4.95 N/mm^2 at 7 and 28 days respectively. The maximum increase in split tensile strength is observed at 10% replacement of silica fume. The optimum silica fume replacement percentage for tensile strengths was found to be a function of w/cm ratio of the mix. The optimum 28-day split tensile strength was obtained in the range of 5–10% silica fume replacement level.

Table 4: Split Tensile strength of concrete with Silica fume

Mix	% silica fume	Split tensile strength (N/mm^2)	
		7 days	28days
M1	0	3.11	4.67
M2	5	3.65	4.80
M3	10	4.1.	4.95
M4	15	3.83	4.63
M5	20	3.65	3.98

(Amudhavalli & Mathew, 2012)

Durability

Acid Attack Resistance

The reaction of acids with concrete is as a result of conversion of calcium compounds into calcium salts of the attacking acid. The action of acids on cement paste is majorly on the components of the hardened cement paste. It is assumed that this action leads to a conversion of all the calcium compounds, un-reacted residue of C_3S and C_2S in cement grains, calcium hydroxide, calcium silicate hydrate, and calcium aluminate hydrate to the calcium salt of the attacking acid (Bakharev *et al.*, 2003). This reaction makes concrete structure to deteriorate. The percentage of loss in compressive strength was 11.91%, 8.18%, respectively according to Bakhrev *et al.*, (2003). Thus replacement of silica fume is found to have increased the durability against acid attack. This is due to the silica present in silica fume which combines with calcium hydroxide and reduces the amount susceptible to acid attack.

OPC concrete is more vulnerable than slag concrete to acid attack due to the differences in chemical and phase composition. The cement paste in OPC concrete is rich in calcium due to presence of residues of $C_2S$and C_3S, portlandite [$Ca(OH)_2$], and C-S-H with average Ca/Si ratio of 1.7. However the calcium-containing compounds in the cement paste react with the acetic acid, producing gel-like white cover, that contains calcium acetate, which is the product of chemical reaction of OPC paste with the acetic acid solute

ion. Calcium acetate is soluble it leaves the cement paste. Decalcified C-S-H and silica gel, another reaction product, have no structural properties. This result to, OPC concrete surface becoming softer and could be removed, thus, exposing the interior concrete layers to deterioration (Bakharev *et al.*, 2003).

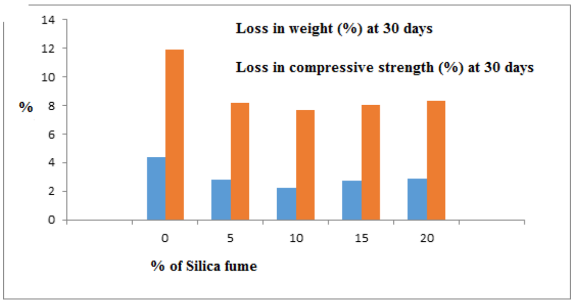

Figure 3: Effect of acid attack on weight and compressive strength of cubes (Amudhavalli & Mathew, 2012)

Khajuria & Siddique, (2014) investigated the effect of iron slag replacement of sand on the durability of concrete to sulphate attack, Magnesium sulphate ($MgSO_4$) solution of 50g/l was used to assess sul[illegible]ate resistance of concrete. Although iron slag was replacing sand, however it is possible that it could still retain some certain desirable properties when replacing cement too. The result indicated that iron slag was having better resistance to sulphate attack.

Kirubajiny *et al.* (2017) reported the durability aspects of fly-ash-based-geo-polymer concrete (FBGPC). A concrete culvert was cast and exposed to coastal environment for 6 years. FBGPC culvert was carbonated in the top slab 135 mm and leg 90 mm while OPC culvert reported maximum value of 10 mm and 20 mm respectively. Chloride resistance in the FBGPC was higher (2.5 times) compared to OPC in the coastal environment. Micro-structure test results affirmed the dissolutions of carbonation in FBGPC when exposed to the actual conditions, whereas leaching was detected in the normal concrete. Also, SEM/EDX images showed that the chloride was precipitated as a layer on the FBGPC. Micro-structure images shows higher sulfate penetration and no development of calcium silicate hydrate in the FBGPC. Based on the porosity test, the geo-polymer concrete recorded fine pores stuck between 1.25 and 25 nm diameter, while the pores in ordinary concrete ranges from 25 nm to 50,000 nm (Kirubajiny *et al*., 2017). Zhang *et al.*, (2016); Ye *et al.*, (2019) and Awoyera *et al.*, (2019) reported similar findings.

Kirubajiny *et al.* (2017), also reported that slag mixes exhibited better resistance to chloride ion penetration than the normal concrete mix, especially at 90 days of exposure. This can be attributed to two factors. The first, being the pore structure, which was seen from the results of the penetration tests to be more compact for the slag mixes than the normal concrete mix. The second, being the chloride binding abilities of the mixes. Several studies (Cheng *et al*., 2005; Thomas et al., 2012 &Ogirigbo & Inerhunwa, 2017) have shown that slag blended concrete are denser than normal concrete mix. The test results for the rapid chloride penetration into cassava peel ash concrete specimens at 7, 28 and 90 days were 4400, 3650 and 2464 coulombs, respectively while that of normal concrete are 6650, 5608, and 2750 coulombs, respectively (Kirubajiny *et al.*, 2017). Olatokunbo *et al.*, (2018), also reported that, cassava peel ash concrete mixes produced lower permeability results at 7, 28, 90 days. It was observed that 15% had the highest resistance to acid attack. Which shows that it can serve as a suitable replacement if the right percentage is used. Durability and sulphric acid resistance improved considerably at 10% replacement of cement with cassava peel ash (Olatokunbo *et al.*, 2018).

Water Absorption

Zabihi-samani *et al.*, (2018) in their study observed that concrete with water absorption value less than 5% was recognized as a high quality concrete. From the study; water absorption of concrete incorporating FA ranged from 4.4-7.3%, 4.5-7.0%, 5.7-8.1% to 7.4-9.9% at the 20 ^{0}C, 400^{0}C, 600^{0}C and 800 ^{0}C, respectively. Concretes containing 0%, 30%, 50%, 70% FA resulted in less than 5% water absorption at the 20 ^{0}C. Similarly, the water absorption results of less than 5% were achieved for the concretes containing 0%, 30% fly ash at the 400^{0}C. According to these results, increase in temperature up to 800 ^{0}C leads to increase in water absorption value for all FA concretes. The values of the absorbed water indicated that 5% CPA cement replacement had the least amount of absorbed water while 25% had the most water absorption (Zabihi-samani *et al*., 2018).

Porosity

Zabihi-samani *et al*., (2018) mentioned that concretes incorporating high volume fly ash were exposed to 400^{0}C, 600^{0}C and 800 ^{0}C high temperatures. The highest value of porosity was recorded by concrete containing 90% FA at all temperatures while the lowest value of porosity was recorded by concrete containing 30% FA. Olatokunbo *et al.*, (2018) mentioned that, for cassava peel ash, porosity for the mixes, increases in values with increased cement replacement.

Drying Shrinkage

Olatokunbo *et al.*, (2018) reported that the CPA average particle size had a significant effect on the drying shrinkage of concrete. 20 % CPA addition in concrete mixture exhibited higher shrinkage value than the control. 15% CPA addition in concrete was comparable, while the shrinkage for 25% was lower compared to the control. The high fineness of CPA particle size increased the pozzolanic activity and contributed to the pore refinement of the CPA concrete paste matrix. Thus, it can be mentioned that the addition of micro-fine particles to concrete would reduce the drying shrinkage.

Conclusion and Recommendations

Based on several literature reviews considered in this study the following can be deduced:

Cassava peel ash, metakaoline, ground granulated blast furnace slag, fly ash and silica fume enhance the workability of a fresh concrete. The fineness of cement also helps to improve the workability of concretes in terms of flow ability.

Cassava peel ash, metakaoline, ground granulated blast furnace slag, fly ash and silica fume contributed to the compressive, tensile and flexural strength of concrete when administered optimally.

Ordinary Portland cement has poor acidic attack resistance along with minimal resistance to extreme conditions such as temperature thereby putting its durability in doubt.

Cassava peel ash, metakaoline, ground granulated blast furnace slag, Fly ash tend to exhibit a reasonable durability properties even at adverse conditions such as acidic attack.

Waste products such as Cassava peel ash, metakaoline, ground granulated blast furnace slag, fly ash and silica fume, rather than being discarded, can be used to enhance some properties of concrete.

Over reliance on Portland cement can be minimized if these binders that are bye products are fully utilized for construction purposes.

Environmental pollution can be reduced drastically if the waste materials are used for construction purposes thereby enhancing the sustainability of the Engineering industry.

In fact, cement manufacturing firms should consider incorporating some of these waste at the point of production to minimize the cost of production.

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