Prepublished copy

Nature Environment & Pollution Technology

This is a peer-reviewed prepublished version of the paper

Review Paper

Potential of Agro-Industrial Wastes to Adress Environmental Challenges-A Review

Anshul Nikhade[1]†, Devendra Padole[2], Sameer Algburi[3], Monali Wagh[4], Harshal Nikhade[4], Ahmed M. Abdulhadi[5], Hasan Sh. Majdi[6], Adel Hadi Al-Baghdadi[7] and Prajakta Waghe[8]

[1]Department of Civil Engineering, Karmaveer Dadasaheb Kannamwar College of Engineering, Nagpur, India

[2]Structural Consultant, Struct Design, Nagpur, India

[3] Al-Kitab University, Kirkuk 36015, Iraq

[4]Department of Civil Engineering, Yeshwantrao Chavan College of Engineering, Nagpur, India

[5]Al-Safwa University College, Kerbala, Iraq

[6]Department of Chemical Engineering and Petroleum Industries, College of Engineering, Al-Mustaqbal University, 51001 Hillah, Babylon, Iraq

[7]Al-Mustaqbal University, 51001 Hillah, Babylon, Iraq

[8]Department of Chemistry, Yeshwantrao Chavan College of Engineering, Nagpur, 441110, India

†Corresponding author: Anshul Nikhade; anshulnikhade1986@gmail.com

ORCID IDs of Authors- Anshul Nikhade - 0000-0002-1794-2315, Devendra Padole - 0009-0003-4736-4901, Monali Wagh - 0009-0002-1856-0500, Harshal Nikhade - 0009-0002-2122-574

Key Words	Sustainable construction, Agricultural waste, Industrial waste
DOI	https://doi.org/10.46488/NEPT.2026.v25i02.B4333 (DOI will be active only after the final publication of the paper)
Citation for the Paper	Nikhade, A., Padole, D., Algburi, S., Wagh, M., Nikhade, H., Abdulhadi, A.M., Majdi, H.S., Al-Baghdadi, A.H. and Waghe, P., 2026. Potential of agro-industrial wastes to adress environmental challenges-A review. *Nature Environment and Pollution Technology*, 25(2), B4333. https://doi.org/10.46488/NEPT.2026.v25i02.B4333

ABSTRACT

In an effort to decrease carbon emissions from the cement industry, many authors investigated into different materials for construction which utilized agro-industrial waste as an alternative for cement. This study's potential relative with conventional materials for construction with regard to of environmental aspects was reviewed and assessed in this article. In accordance with the research, these eco-friendly waste-based materials for construction would lead to 32% decreased greenhouse gas emissions. These materials additionally provide a unique opportunity to deal with the interlinked issues of climate change and resource shortages while simultaneously achieving environmentally friendly construction products.

INTRODUCTION

From the last three decades, global issues like population explosion, rapid urbanization and industrialization growing consumerism, increasing energy need; and exponentially impact on issues like environmental pollution, depletion of reserved fossil fuels, the security of energy, mounting solid waste generation; needs sustainable attention(Venkata et al. 2018). These issues lead to an increase in carbon footprints all over the world, which results in significant variations in climate change. This emission of anthropogenic CO_2 into the environment is a major challenge to the world. The generation of this hazardous CO_2 is mainly due to: a) the combustion of biomass and fossil fuels; b) deforestation and other land- use changes. c) the cement industry. The cement industry is the third largest source of anthropogenic CO_2 after fossil fuels and land-use change (Andrew 2018).

Now-a-days cement industries are under scrutiny because of the large amount of anthropogenic CO_2 they emit into the atmosphere. Cement production contributes about 5-7 % of the global loading of anthropogenic CO_2 into the atmosphere(Chen et al. 2010). In 2019, approximately 1.6 Gt of anthropogenic CO_2 was emitted due to decomposition of carbonates in the production of cement clinker, while 0.9 Gt of CO_2 was emitted from the combustion of fossil fuels to produce the heat required by global cement industries(Jackson et al. 2018). Besides these, the production of cement is a highly energy consuming process. For the manufacture of cement clinker, approximately 4 GJ of energy and 0.85 tonnes of CO_2 are required, as well as 3.00 kg of NO_2, 1.5 kg of SO_2, and 0.23 kg of particulate matter released into the atmosphere(SSEF 2013). Additionally, extracting the huge amounts of raw materials like limestone not only consumes high energy but also results in the deforestation of land. It is complicated to figure out the exact area of land destroyed for cement production because the issue is complex and there is a lack of precise data that distinguishes cement manufacturing from other activities like land development or mining. However, based on the pattern of excavation limestone which is main raw material in manufacturing of cement can help to figure out the approximate area deforest for the manufacturing of cement. As per world resource institute, probable estimate of all mining activities, including the production of cement, destroy about 0.5 and 1 million hectares forest annually worldwide(Stanimirova et al. 2024). In India, from 2018 and 2023, 18,847 hectares of forest land have been cleared for mining activities, including the extraction of limestone(Pandey et al. 2023). Furthermore, the cement industry's extraction of virgin nonrenewable materials emits hazardous solid waste into the environment(Mehta 2001).

In developing countries like India, an increasing population, growth in urbanisation and rapidly changing technologies boost agriculture and industrialization sectors, which results in India being the second fastest growing economy after China in 2019. On the other hand, this uplifting nation’s economy leaves millions of tones of solid waste derived from agriculture and industrial waste behind, causing serious problems related to environmental pollution. The globe is currently dealing with a shortage of natural resources(Wagh et al. 2025; Waghe et al. 2023). As per Pappu et al. 960 million tons /year solid waste are generated in India every year, contributing around 350 MT of organic waste from the agriculture sector and 290 MT of inorganic waste from the industrial and mining sectors(Pappu et al. 2007).

It is very urgent to a) reduce the emission of anthropogenic CO_2 from cement industries and b) consume the accumulated waste generated due to different agricultural and industrial activities. Carbon dioxide (CO_2) emissions that have been brought on by human activities are termed as anthropogenic CO_2 emissions. Cement industry anthropogenic CO_2 emissions contribute for around 7–8% of global CO_2 emissions, which makes it the biggest contributor of greenhouse gas emissions. These emissions originate from the energy and chemical processes used for manufacturing cement(Zhang 2024). **Figure 1** reveals the various agricultural and industrial waste which are used as a supplementry cementitious materials. Efforts are being made for the utilisation of these unwanted solid wastes into usable raw materials for various sustainable uses. Many researchers have succeeded in developing value-added products using these solid wastes. This helps to resolve environmental and solid waste management problems and also reduces the dependency on crude non-renewable resources, which are dwindling day-by-day. Studies that were published to compensate for both issues and come together into novel, eco-friendly, sustainable construction products are reviewed in this paper. **Figure 2** shows the cluster network visualisation produced with study article keywords.

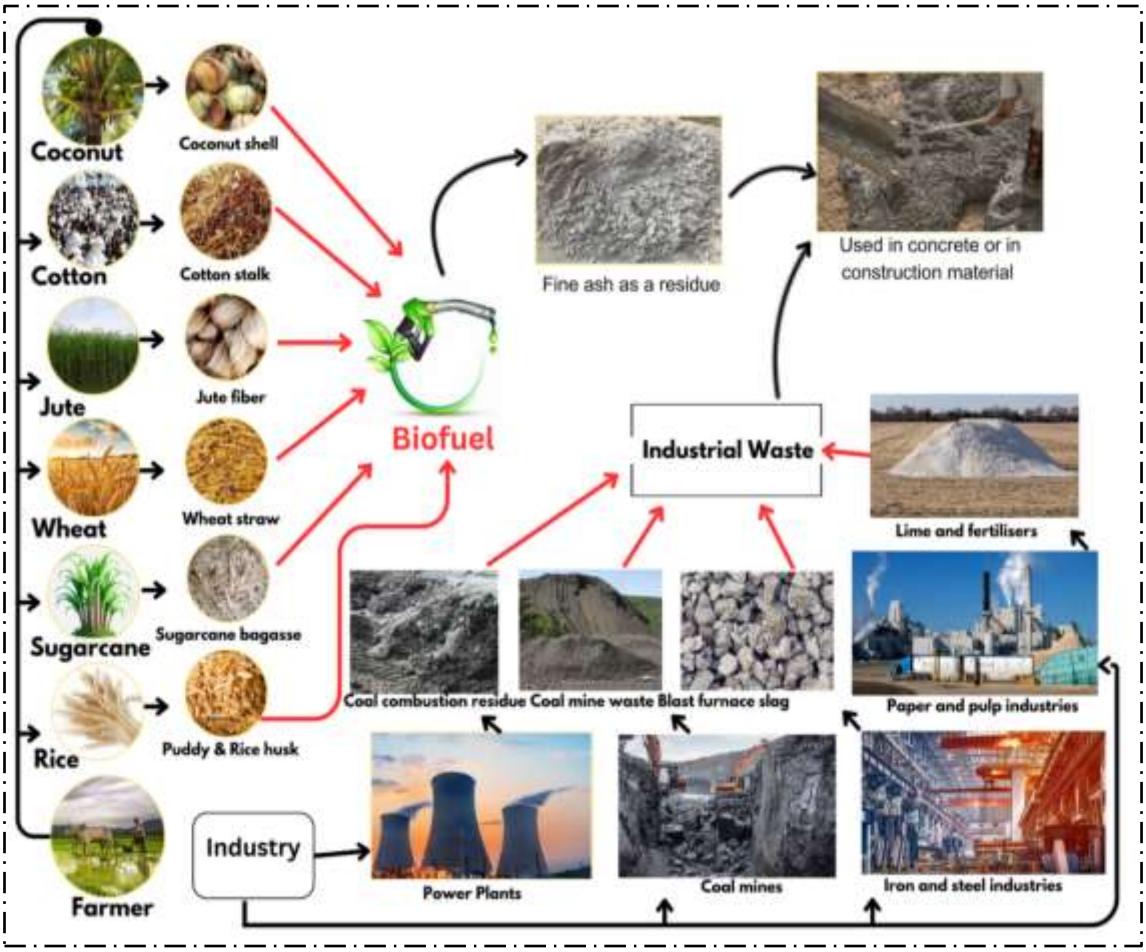

Figure 1 Agricultural and Industrial waste as Supplementry cementitious materials

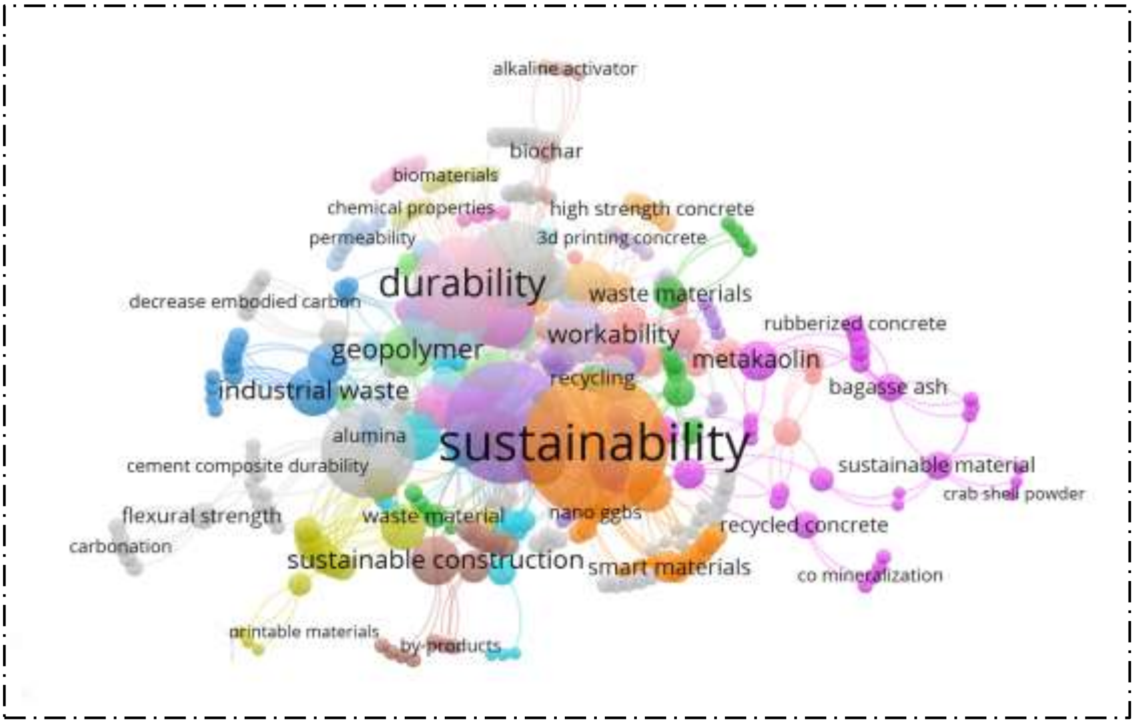

Figure 2 Cluster network visualisation produced with study article keywords

2. CEMENT DEMAND

2.1 Global Cement Demand

Cement has become one of the important commodities produced by more than 150 countries across the globe(Sharma 2017). Generally, the economic growth of a country is predicted by the growth of cement consumption in that country, and with the development of the economy, the production and consumption of cement are increasing every year. After 1990, the global consumption of cement accelerated drastically due to the rapid development of China(Andrew 2018). The demand for cement in the top ten countries - China, India, the United States, Vietnam, Indonesia, Iran, Turkey, Russia, Brazil, and Egypt - is studied and graphically represented, it has been observed that 65–70% of global cement is produced by China itself. The compound annual growth rate (CAGR) of global cement demand has increased by 5% from the year 2002 to 2019. The global cement demand in 2019 is almost two times greater than the demand in 2002 and four times greater than the demand in 1990(Armstrong 2018). It is forecasted that the demand for cement will reach up to 18000 Mt by the year 2050(Aprianti et al. 2015). In **Figure 3**, the worldwide cement demant is shown. **Figure 4** displays the demand for cement by the top 10 Countries. The demand for cement in 2019 by China, India, and the rest of the globe is depicted in **Figure 5**.

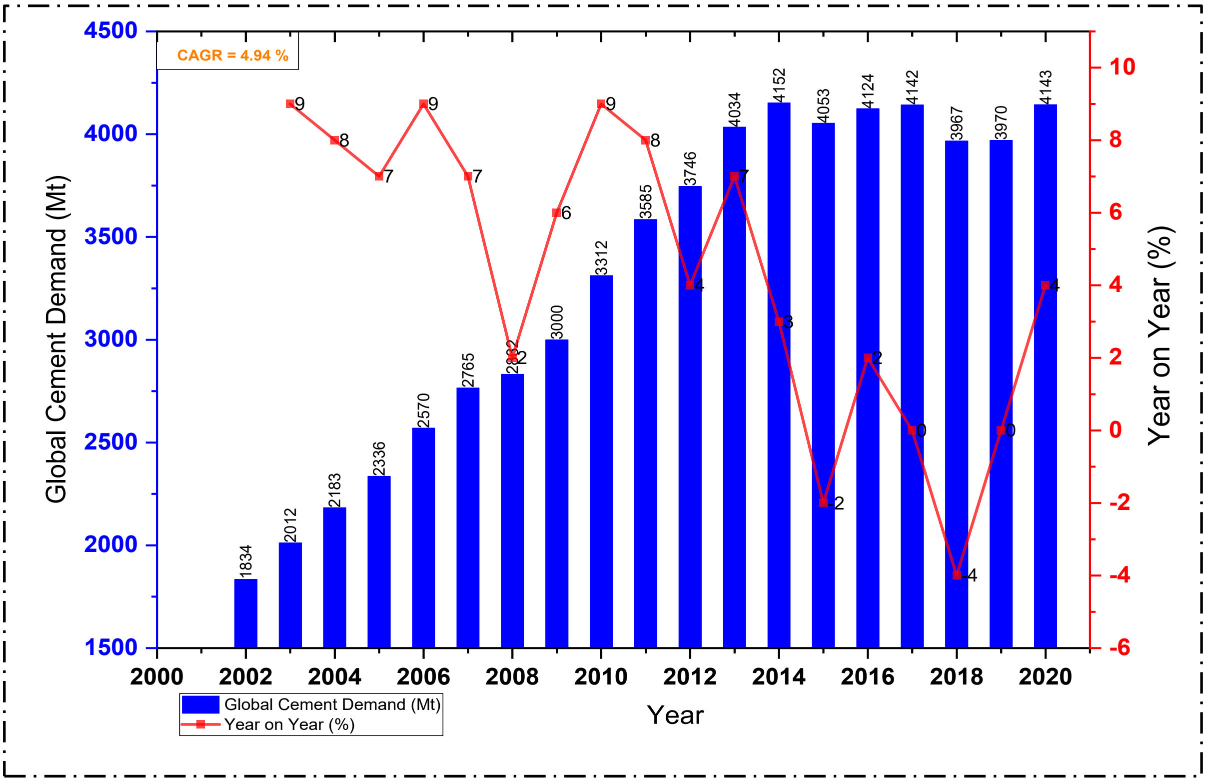

Figure 3- Global Cement demand (Sharma 2017) (Armstrong 2018) (IBEF 2019) (IBEF 2020) (Hargreaves 2013)

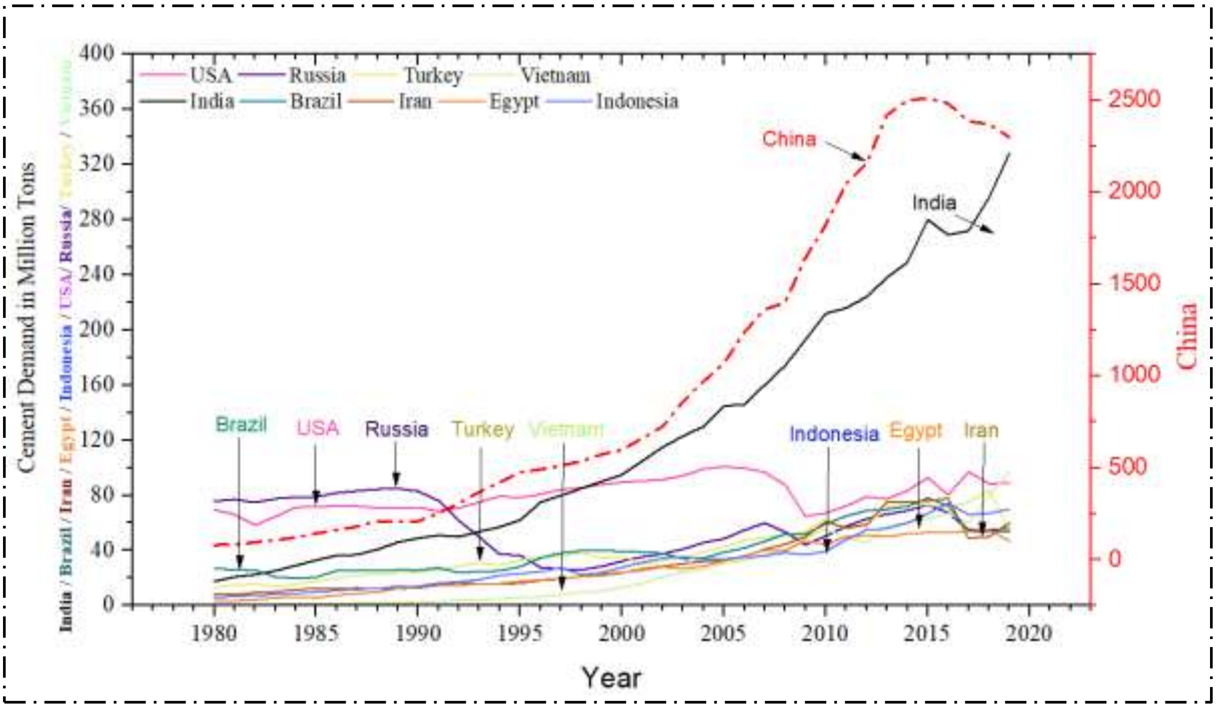

Figure 4 Cement demand by top 10 Countries (Sharma 2017) (Armstrong 2018) (IBEF 2020) (Hargreaves 2013)

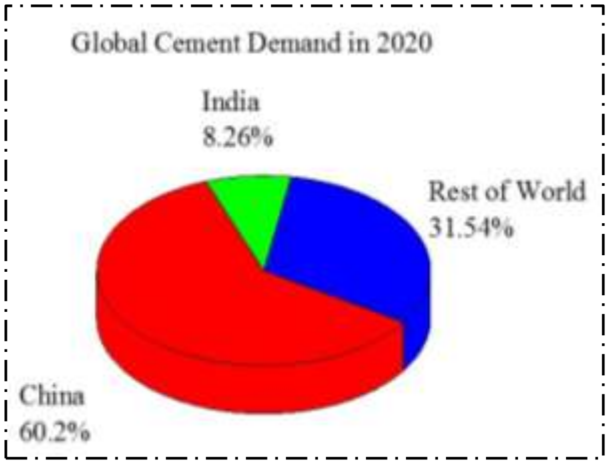

Figure 5 Demand of cement by China, India and rest of world in the year 2019 (Sharma 2017) (Armstrong 2018) (IBEF 2020) (Hargreaves 2013)

2.2 Cement Demand in India

India is the second largest cement producer in the world after China(Bahurudeen et al. 2017) (Balogun et al. 2016) (Rajya Sabha 2011). The immense geographical size and immense population demand in India involve more infrastructure and industrial development, pushing the production of cement more effectively every year. Hence, after agriculture, construction is the second-largest industry in India(Kulkarni 2012). The demand for cement in India increased from 146 million tons to 375 million tons from the financial year 2006 to 2023, with a CGAR of 5.7 percent. It is forecasted that the demand will reach 400 million tones by the year 2025 and 700 million tons by the year 2050. The current cement production capacity of India is approximately 500 million tons per annum and it is predicted that it may be increased to 50 million tons by the year 2025 to meet the domestic growth of the country(Armstrong 2012)(IBEF 2019). The serious issue behind increasing consumption is due to the unrestricted growth of the population, the modernization of industrial development, and unrestricted consumption of natural resources, and secondly, due to a lack of awareness to adopt sustainable practises in the country. **Figure 6** illustrates India's cement demand.

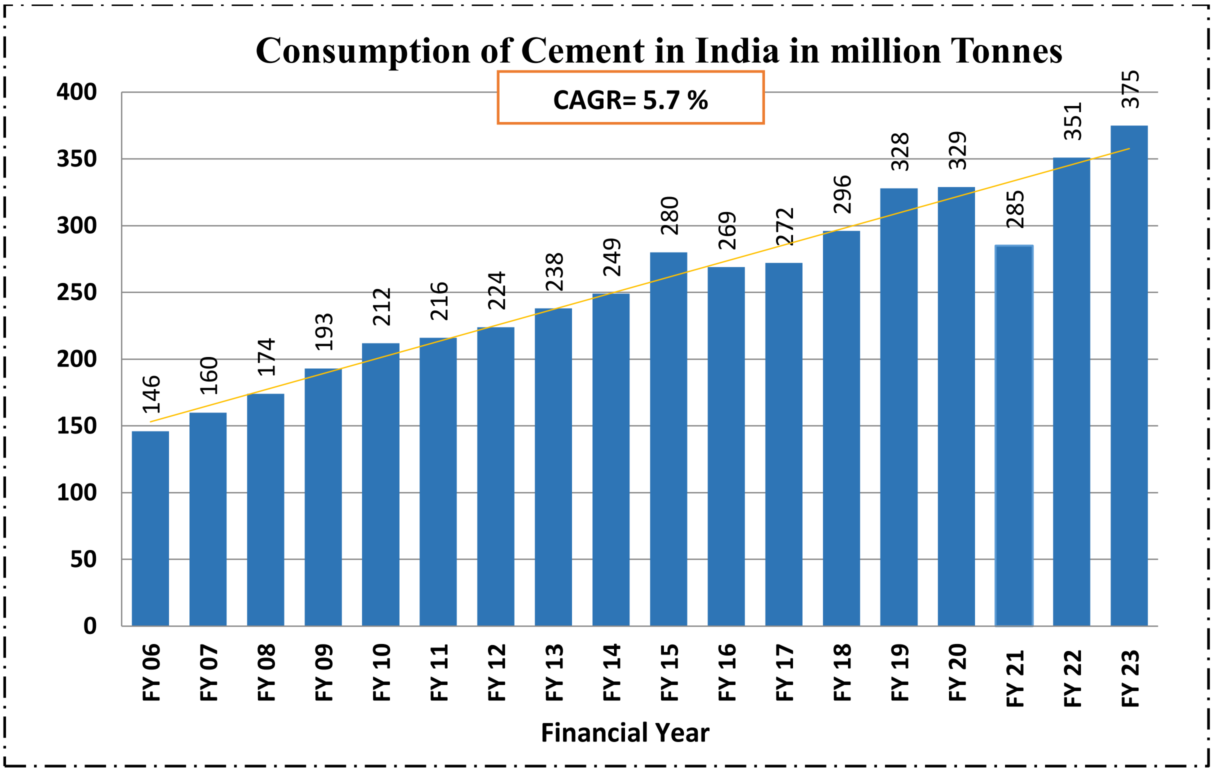

Figure 6- Demand of Cement in India (Sharma 2017) (Armstrong 2018)(IBEF 2020) (Hargreaves 2013)

The cement industry is the third largest source of anthropogenic carbon dioxide emissions, after oxidation of fossil fuels and deforestation(Andrew 2018). Cement production accounts for approximately 5–7% of global anthropogenic CO_2 loading into the atmosphere (Chen et al. 2010). In 2019, approximately 2.5 Gt of anthropogenic CO_2 was emitted, out of which, 1.6 Gt was emitted due to the decomposition of carbonates during the production of cement clinker, while 0.9 Gt of CO2 was emitted from the combustion of fossil fuels to produce the heat required(Jackson et al. 2018). The chemical reactions involved in the calcination process of limestone, or $CaCO_3$, which decompose into oxides of calcium oxide and CO2 at high temperatures, as well as the combustion of fossil fuel in the kiln to generate a temperature above 1000°C, are primarily responsible for the emission of hazardous CO_2 into the environment. Besides these, CO_2 also evolved due to overall energy use in the extraction, transportation, and cementing of sites, electricity generation, etc.(Andrew 2018). Around 50–55 percent of CO_2 is released as a result of the limestone calcination process, 40–50% as a result of fossil fuel combustion, and 0–10% as a result of electrical energy consumption. In general, the production of 1 ton of cement emits 0.85 tons CO_2 along with 3.00 kg of NO_2, 1.5 kg of SO_2 and 0.23 kg of particulate matter(SSEF 2013).

Moreover, the production of cement involves high-energy-consuming processes. As per Ernst Worrell, et. al. [2001], around 2% of global primary energy and nearly 5% of global industrial energy is consumed by the cement industry alone. The kiln process consumes the most energy, and the grinding process consumes the most electricity(Worrell et al. 2001). The anthropogenic CO_2 emitted by China's cement industry is almost 80 percent greater than the rest of the world. The steep slope lines in **figure 7** represent China and India's abrupt emissions, whereas the remaining eight countries' emissions are very cautious. The reasons are obvious, due to the exponential increase in production and consumption of cement in these two countries. It is observed that global CO_2 emissions are rising abruptly, and it is very urgent to curb the emission of dangerous CO_2 into the atmosphere to maintain the integrity of the ecosystem.

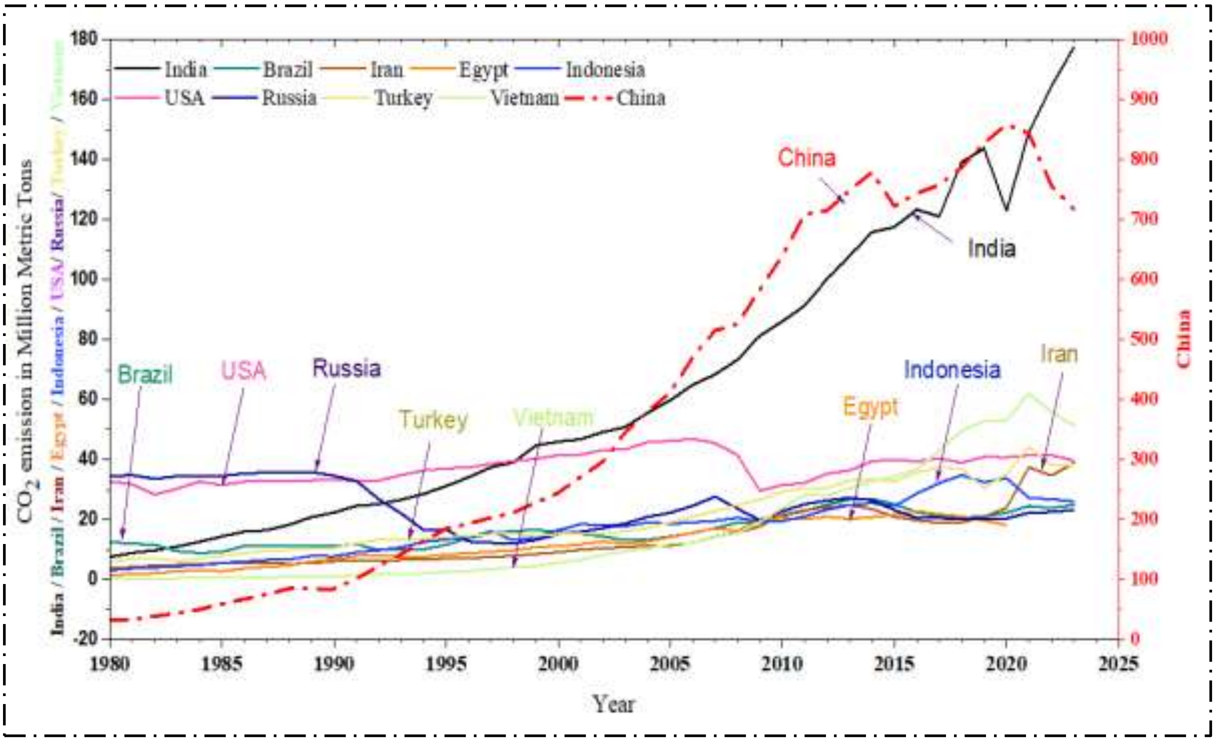

Figure 7 CO_2 emission by cement industries by top 10 Countries

Increasing CO_2 emissions put billions of people in danger. Already the terrible impact of 10ºC on global warming is being observed, which leads to many disasters all over the world. It will become very hard to imagine a low carbon world. Significant impact of rise in temperature are uninhabitable heat zones, sea-level rise, collapse of agriculture, mass extinctions, extreme weather(Jha and Dev 2024) It is urgent to shift our vision to other sustainable alternatives to achieve greater carbon emission reduction and to help solve our global environmental crisis.

Several authors assessed the environmental impact of the cement industry. Different studies identified the different remedials to control carbon emissions, which are: a) use of low carbon emission fuel, b) improvement of energy efficiency, c) carbon capture and storage, d) identification of alternate cementation blend(Salas et al. 2016). This paper explores the studies of the development of sustainable construction products using alternative cementation blends derived from agriculture and industrial rejects (Waghmare et al. 2025) and assesses their potential against conventional construction products. The most effective method to reduce energy consumption in buildings is to employ thermal insulation(Saleh et al. 2021). Artificial aggregates produced with sodium hydroxide with a molarity of 6.3 and sodium silicate with a molarity of 2.2 perform extremely well in aggregate tests examining specific gravity, water absorption, impact resistance, and abrasion(Kurzekar et al. 2024). Rubberized concrete's mechanical properties have been found to be equivalent with those found in conventional concrete(Agrawal et al. 2025). The advantage of partially replacing expanded polystyrene separators and barriers (EPS) for fine aggregates in concrete is that it can contributing to pollution management(Khurge et al. 2025). By minimizing dependency on natural aggregates and reducing adverse environmental impacts, incorporating refractory brick sand to concrete blends could serve as a potential option to promote sustainable building methods and protect human health and the environment(Kumar et al. 2025).

3. UTILIZATION OF AGRICULTURE & INDUSTRIAL WASTE AS AN ALTERNATE CEMENTITIOUS MATERIAL

In emerging countries like India, rising urbanization and population expansion, and rapidly changing technologies boost agriculture and industrial sectors, which results in India being the second most rapidly expanding economy after China in 2019. On the other hand, uplifting the nation’s economy leaves millions of tons of solid waste derived from agriculture and industrial waste behind, causing serious problems related to environmental pollution. Approximately 960 MT/year of solid waste is generated in India, contributing around 350 MT/year of organic waste from the agriculture sector and 290 MT/year of inorganic waste from the industrial and mining sectors(Pappu et al. 2007).

3.1 Agricultural Waste

In India, approximately 200 million hectares of land is covered for agricultural use (Venkata et al. 2018). Major crops like rice, sugarcane, wheat, tea, jute, groundnut, cotton, coconut, etc. generate agriculture waste like paddy and rice husk, sugarcane bagasse, wheat straw, jute fiber, cotton stalk, coconut shell, vegetable waste, etc. The approximate annual generation these wates are rice husk 22MT(Sen et al. 2024), sugarcane bagasse 27.2MT(Nikhade et al. 2025), wheat straw 145.44 MT(Sen et al. 2024), Jute stalk 3MT(Martin et al. 2024) Groundnut shell 0.11 MT(Sarkar et al. 2023) Cotton stalk 29.4 MT(Manna et al. 2024), Coconut husk 2.2 MT (Sarkar et al. 2023).This waste is used in the form of fodder and firewood called biofuel, which is utilised to generate electricity and other industrial thermal activities, which leaves a significant amount of fine ash as a residue (Bisht and Ahmed 2018) (Madurwar. et al. 2013; Wagh and Waghe 2022). An agricultural byproduct is produced in considerable quantities in India (Wagh and Waghe 2022, 2024). Approximately 4.5 billion tons of solid waste per year is generated in Asia alone, and 600 MT per year is generated by agriculture alone.

3.2 Industrial and Mining Waste

India generates around 290 Mt/year of industrial non-hazardous inorganic solid waste (Pappu et al. 2007). Thermal power plants generating coal combustion residues (CCR) are the leading major generators of industrial solid waste, followed by coal mine waste derived from coal mines, blast furnace slag derived from iron and steel industries, and lime and fertilisers derived from paper and pulp industries(CPHEEO 2000). The solid waste generated by non-ferrous industries, such as red mud and spent spot lining from aluminium industries; slag, dross, sludge, slime, mill scales, flue dust, and so on from copper industries; leach residue, zinck tailing, -cake, jarosite residue, and so on from zinc industries; and ISF slag, BF slag, and so on from lead industries(Agrawal et al. 2004). The compressive strength of concrete improved with the incorporation of silica nanoparticles but decreased with the addition of polystyrene granules(N. Saleh et al. 2023).The Imperial Smelting Furnace (ISF) process, which extracts zinc and lead simultaneously from their combined ores, produces ISF slag, a non-metallic byproduct. It may contain tiny quantities of heavy metals such as zinc, lead, cadmium, and arsenic, but its primary components are silicates and oxides produced from gangue minerals and fluxes(Łaźniewska-Piekarczyk et al. 2024).

3.3 Availability of different agricultural and industrial waste

Details of the sources and availability of different agricultural and industrial solid waste generated in India are summarized in **Table 1** below.

Table 1 Solid Waste generation in India.

Sr. No	Solid waste	Source of Generation	Quantity (Million Tones per Annum)	Source / Author
a) Agriculture solid waste				
01	Bagasse Ash (BA)	Produced from the sugar industries	90	(Pappu et al. 2007)
02	Rice hull Ash (Rise Husk Ash)	By-product of rice production during milling	20	(Pappu et al. 2007)
03	Jute Caddies (Jute Fiber waste)	Obtained from Jute Industry	14.5	(Pappu et al. 2007)
04	Rice Wheat Straw	residues after wheat and barley grain	12	(Pappu et al. 2007)
05	Groundnut Shell	Leftover substance behind after groundnut seeds are extracted from their pods.	11	(Pappu et al. 2007)
b) Industrial waste				
01	Coal Combustion Residues (Fly ash)	Thermal power stations that use coal	176	(Surabhi 2017)
02	Cole Mine Waste	Coal Mines	60	(Pappu et al. 2007)
03	Lime stone wastes	Lime stone quarry's	50	(CPHEEO 2000)
04	Steel and Blast furnace	Conversion iron to steel	35	(CPHEEO 2000)
05	Iron tailing	Iron Ore	18	(Das et al. 2000)
06	Construction Waste	Construction Sites	14.5	(Pappu et al. 2007)
07	Marble Dust	Marble Industries	6	(Pappu et al. 2007)
08	Waste Gypsum	Gypsum Industries	6	(Pappu et al. 2007)
09	Phosphogypsum	Phosphoric acid plants, Ammonium phosphate	4.5	(CPHEEO 2000)
10	Red mud/ Bauxite tailing	extracting alumina from bauxite	4.71	(Patel and Pal 2015)
11	Lime Sludge	Obtained from fertilizer Industry	4	(Pappu et al. 2007)
12	Zinc Tailing	Waste obtained from mines	3	(Pappu et al. 2007)
13	Kiln dust	Cement plants	1.6	(CPHEEO 2000)
14	Brine mud	Caustic soda industries	0.02	(CPHEEO 2000)
15	Copper slag	byproduct of copper smelting	0.0164	(CPHEEO 2000)
16	Mica scraper waste	Mica mining areas	0.005	(CPHEEO 2000)
17	Alum Sludge	By-product of water treatment plants	0.08	(Owaid et al. 2018)

3.4 Physical and chemical characteristics of agricultural and industrial solid waste

In order to make use of industrial and agricultural solid waste materials with the raw material at different levels for developing sustainable construction products, the chemical composition of waste has been identified by many authors. **Tables 2–4** show a comparative analysis of the chemical properties of various agricultural and industrial solid wastes.

Table 2 Physical properties of agriculture solid waste

Agricultural waste	Mean particle size mu -m	Specific gravity	Blaine fineness (m^2/kg)	Source / Author
Bagasse Ash	66.9–107.9	1.9–2.4	--	(Aprianti et al. 2015)
Rise Husk Ash	5-70	2 – 2.2	350.0–376.8	(Aprianti et al. 2015)(Bisht and Ahmed 2018)
Wheat Straw Ash	--	2.31	--	(Biricik et al. 1999)
Palm Oil Fuel Ash	10.5	1.9–2.4	493.0	(Aprianti et al. 2015)
Groundnut Shell	--	2.10	--	(Nwofor and Sule 2012)

Table 3 Chemical properties of agriculture solid waste

Constitutions in %	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	SO_3	Na_2O	LOI	Source
Bagasse Ash	51.66 - 86.79	1.03-20.69	0.9-10.08	1-18.9	0.07-8.65	1.2-9.28	0.02-4.45	0.01-1.23	5.7-24.15	(Nwofor and Sule 2012)(James and Pandian 2017)(Bisht and Ahmed 2018) (Aprianti et al. 2015) (Madurwar. et al. 2014)(Bahurudeen et al. 2015) (Rukzon and Chindaprasirt 2012) (Rattanashotinunt et al. 2013) (Onyelowe 2012)(Rajasekar et al. 2018) (Bahurudeen and Santhanam 2015) (Zareei et al. 2018) (Rukzon and Chindaprasirt 2014) (S. Demis et al. 2014)(S Demis et al.2014)(Katare and Madurwar 2017)(Prusty et al. 2016; Wagh and Waghe 2024)
Rise Husk Ash	80.7-95.9	0.22-1.6	0.2-1.5	0.39-5.5	0.01-1.32	0.54-3.9	0.35-1.2	0.2-1.2	0.54-10.39	(Bisht and Ahmed 2018)(Aprianti et al. 2015) (Zareei et al. 2017) (Rukzon and Chindaprasirt 2014)

Wheat Straw Ash	19-20.6	4.31-6.14	2.4-3.72	62.9-63.65	1.29-18	0.82	2.55-3.24	0.14	1.42-3.1	(Biricik et al. 1999)(Jankovsky 2017)
Palm Oil Fuel Ash	55.5-66.9	1.6-9.2	1.4-5.7	4.9-12.4	3-4.5	5-7.5	0.2-0.5	0.1-0.8	6.6-10.1	(Aprianti et al. 2015)(S. Demis et al. 2014)(Sata et al. 2004)
Ground nut Shell	16.21-33.36	5.82-6.73	0.5-2.16	8.69-10.91	4.72-6.74	15.73-20.02	1.86-6.4	1.15-9.02	22	(Oriola 2010)(Duc et al. 2019)(H. Mahmoud 2012)

Table 4 Chemical properties of industrial solid waste

Constitutions in %	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	SO_3	Na_2O	LOI	Source
Coal Combustion Residues/ Fly ash	50.5-59.26	23.83-30.2	4-13.77	1.1-4.7	0.38-1.77	0.6-1.35	0.22-1.29	0.1-2.22	0.6-5.9	(Nath and Sarker 2011)(Kumar 2003)(Dana et al. 2005)(Zhao et al. 2014) (Sharma and Khan 2017)
Lime Stone waste	0.26-8.97	0.25-1.02	0.3-0.37	34.95-56.19	2.38-14.44	0.13-0.4	0.33-0.67	0.02-0.1	39.54-42.65	(Omar et al. 2012)(Sua-iam and Makul 2013)(Algin and Turgut 2008)
Blast Furnace Slag	35.35-41.2	14.3-19.15	0.6	32.7-36.56	2.99-7.33	0.9-1.29	--	0.81	0.21	(Dana et al. 2005)(Bayer Ozturk and Eren Gultekin 2015)
Iron Tailing	52.06-68.96	7.68-17.14	2.32-25.13	0.03-12.74	0.08-3.68	0.04-1.85	0.16	0.04-1.41	2.49-6.67	(Kuranchie et al. 2015)(Zhao et al. 2014) (Wang et al. 2016a)
Marble Dust	1.12-14.08	0.73-2.69	0.05-3.66	29.5-83.22	0.52-20.6	0.01-1.9	0.56	0.91-1.12	40.6-43.46	(Omar et al. 2012)(Aliabdo et al. 2014)
Red Mud	4-16	15-26	25.6-62.78	0.23-14.6	--	--	--	3-9	10-15	(Agrawal et al. 2004)(Patel and Pal n.d.)
Copper Slag	24.7-40.97	2.4-15.6	34.62-57.82	0.7-17.42	1-3.51	0.71	1.59	0.3-0.34	< 1	(Sharma and Khan 2017)(Marghussian and Maghsoodipoor 1999)
Lime Sludge	2-25	0.8-8	0.5-6	35-70	0.1-10	--	0.2-9	0.8-2	20-50	(Sahu and Gayathri 2014) (Prasanth et al. 2019)
Phosphogypsum	2.41-14.74	0.5-0.88	0.5-0.32	26.76-41	0.1-0.11	<0.22	36.97-44.67	0.13	18.9-21.06	(Lin. Yang et al. 2013)(Değirmenci 2008)

From **table 2**, **table 3** and **table 4**, it is observed that the solid wastes derived from various agricultural and industrial processes are rich in oxides and have potential to be used as a pozzolanic material for the production of construction products. Simultaneously, the fine particle size of this solid waste also acts as a micro filler material which helps to improve the strength of the product (Razak and Wong 2005) (Chusilp et al. 2009).

4. UTILIZATION OF ALTERNATIVE CEMENTITIOUS BLEND FOR THE PRODUCTION OF SUSTAINABLE CONSTRUCTION MATERIALS

In the current situation of the degrading global environment and declining non-renewable resources, waste is one product that cannot be eliminated (Venkata et al. 2018). The residue generated during agriculture activities and industrial cogeneration processes appears to be a sustainable resource (Urade et al. 2024), addressing not only the pollution problem but also an economical option to develop green concrete. Green concrete is a sustainable alternative for conventional concrete which is designed to reduce the negative environmental impact and carbon footprint of construction materials. It uses sustainable techniques and supplies that minimize waste, conserve resources, improve durability, and lower CO2 emissions. Development process of green concrete includes selection of Supplementary Cementitious Materials, Recycled Aggregates, Alternative Binders, optimization of mix design, production, quality control, applications & performance monitoring(Sivakrishna et al. 2020).

Waste valorisation by enabling advanced technologies is one of the best alternatives to utilising renewable resources without having an impact on the environment (Venkata et al. 2018). Waste valorisation is the process of converting resources from waste into more valuable products—like chemicals, energy, or materials—rather of simply throwing these wastes. It is a fundamental concept in sustainable waste management and the economy of circularity(Varjani et al. 2021).Fortunately, this resource has beneficiary properties to boost during the pozzolanic reaction. Several researchers around the globe are engaged in obtaining fruitful and optimum consumption of wasteful materials from industries and agriculture to develop sustainable products. Waste but rich in silica, alumina, calcium oxide, and ferrous such as fly ash, bagasse ash, steel and lime stone sludge, blast furnace slag, groundnut shell, and so on, have been proven as cementation blends for making various construction materials such as ordinary and high strength concrete (Bahurudeen et al. 2015) (Duc et al. 2019) (Chowdhury et al. 2015)(Vejmelková et al. 2010)(Madurwar et al. 2015), paper mill residue(Raut et al. 2013) thermal insulating materials (Madurwar. et al. 2013), ceiling panels, particle boards or cement boards (Madurwar. et al. 2013)(Garg and Jain 2010), flooring and wall tiles (Oriola 2010) (Bayer Ozturk and Eren Gultekin 2015) etc, depending on their physical and chemical properties, these various solid wastes from various sources and generated at various temperatures either act as cementation blends (Rukzon and Chindaprasirt 2014) or as micro fillers (Pappu et al. 2007) (Razak and Wong 2005) (Chusilp et al. 2009). Fly Ash, Ground Granulated Blast Furnace Slag, Silica Fume, RHA, Metakaolin are used as SCM while Marble Dust, Stone Quarry Dust, Waste Glass Powder are used as micro filler in cementitious blend(Bheel et al. 2024)

Not only virgin waste but also chemically(Sada et al. 2013), mechanically or thermally (Rajasekar et al. 2018) treated waste can also be proved as effective use as a cementations blend in order to develop sustainable construction products. This established cementitious blend offers unique advantages to cope-up with the present environmental challenges. The implementation of sustainable construction practices can promote the circular economy model by transforming waste into valuable material and supporting revenue generation(Das et al.2025)

5. CONSTRUCTION PRODUCTS

5.1 Ordinary and High strength Concrete

Concrete is the product that uses the maximum percentage of cement with respect to the other construction products, and it has become a very essential construction material. With increasing concrete demand, the production and consumption of cement are also increasing exponentially. Furthermore, in comparison to ordinary concrete, the demand for high-strength or ultrahigh-strength concrete is increasing today to meet various construction challenges or requirements, such as long-span structures, tall structures, the use of pre- and post-tension technology, and so on, resulting in increased cement consumption.

Ordinary Concrete

Bahurudeen, et al [2015] produced blended concrete using SBA in different percentages. The compressive strength, durability, heat of hydration, and drying shrinkage of blended concrete were all examined. Compressive strength of 5, 10, 15, 20, and 25% SBA replaced blended concrete was investigated for 3, 28, and 56 days of curing. The resulting compressive strength is superior to control concrete up to a 20% replacement. Marginal decline was experienced for a 25% replacement after 28 days of curing. The durability of blended concrete was investigated using the rapid chloride penetration test, oxygen permeability test, chloride conductivity test, DIN water permeability test, water sorptivity test, and Torrent air permeability test. There was a significant reduction in permeability. Heat of hydration was assessed using an adiabatic calorimeter for 10 and 20% SBA replaced blended concrete and compared with where a marginal reduction of 20% was observed in heat of hydration for control concrete. There was a marginal reduction in the heat of hydration with a 20% replacement(Bahurudeen et al. 2015).Cement (OPC) is replaced with groundnut shell ash (GSA) to produce concrete. Principle materials; cement partially replaced with groundnut shell ash (GSA) varies from 0 to 40%. The compressive strength of GSA blended concrete was analysed, resulted 29% strength for 40 % replacement and 70 % for 10 % replacement as compared with control mix at 28 days of curing. Therefore, it is suggested to replace OPC with GSA up to 10% for sustainable construction and adequate strength work (Duc et al. 2019). Chowdhury, et al [2015] investigated wood ash (WA) blended concrete and also used soft computing models to predict strength parameters. The physical analysis of WA reported finer particle sizes. The characterization of WA was done using XRD, which resulted in WA containing amorphous silica. In this study, the authors evaluated the strength parameters of blended concrete prepared with WA blended cement in the form of strength properties. Test specimens were prepared using five different percentages of WA (5%, 10%, 15%, 18%, and 20%) with two different water-to-binder ratios, 0.4 and 0.45, were used for investigation and compared with control concrete specimens. The tasted result indicates that strength slightly decreases with the increase in percentages of WA as compared to control concrete. However, the strength obtained is greater than the targeted strength (Chowdhury et al. 2015).

High strength Concrete

Sumrerng Rukzon, et al [2014] investigated high-strength concrete using a binary or ternary blend of Portland cement with pozzolans. In this study, Portland cement was partially replaced with fly ash (FA) and ground bagasse ash (BA) or ground rice husk-bark ash (RB) at 20% and 40% by weight of cement. The chemical composition using XRF of FA, BA, and RB was analysed. Portland cement is replaced with either a single material or an equal weighted mixture of RB and FA; BA and FA were employed. Ten different concrete mix proportions were prepared using a superplasticizer (SP) to maintain high workability. Compressive strength, modulus of elasticity of concrete, porosity, corrosion resistance, and chloride penetration were determined. The compressive strength test was carried out for cylindrical specimens at the ages of 7, 28, and 90 days. The results showed that the early strength development of blended concrete is slightly less than control concrete, but the strengths of 40-FA, 40-RB, and 40-BA concrete evolved continually. at later stages. It is observed that, the strengths of 20-FA, 20-RB, and 20-BA concretes were superior to the control concrete. The Rapid Chloride Penetration Test (RCPT) was performed on samples, and the results showed that partial replacement of cement with an equal weighted blend portion of FA and RB; or FA and BA, improves concrete resistance to chloride penetration significantly, and this improvement increases as the blend replacement level increases. The resistances of corrosion of equal weighted ternary blended concrete, resulted ternary blended concrete were better than the control concrete or concrete with one pozzolan. (Rukzon and Chindaprasirt 2014). The high strength concrete is developed by using the combination of Metakaolin, RHA & Sugarcane bagasse ash (SBA) and the performance of concrete is under acidic environment is better as compared to control mix concrete(Nikhade and Nag 2022)(Nikhade and Pammar 2022). The light weight geomaterial is developed by using SBA, glass fibre & blast furnace slag(Nikhade and Lal 2022)(Nikhade et al. 2023)(Nikhade and Lal 2021)(Nikhade et al. 2024). In the development of Self compacting concrete, SBA and Metakaolin perform effectively together as a 15% cement replacement (Wagh et al. 2024).

Nath, et al [2011] developed high-strength blended concrete using high-volume Class F fly ash. Six mixes of 30% and 40% replacement of cement with fly ash (FA) were used to prepare the test specimen. To enhance the workability, a naphthalene-based superplasticiser was used. Compressive strength, drying shrinkage, sorptivity, and chloride permeability were measured in the blended and control concrete specimens. Cylindrical specimens of size 100x200mm for each replacement were tested at 3, 7, 28, 56, 91, and 210 days. It is observed that; earlier age strength decreases with the increase in percentage of fly ash as compared to control concrete. However, blended concrete gains more strength at later stages. 30% FA blended concrete shows better compressive strength as compared to 40% FA blended concrete. The effect on drying shrinkage of blended concrete was observed to result in less drying shrinkage as compared to control concrete. 40% FA blended concrete shows a slightly lower drying shrinkage effect as compared to 30% FA blended concrete. Also, blended concrete shows less sorption than that of the control mix, and it decreases further at six months. Blended concrete demonstrates superior resistance to chloride ion penetration at both 28 and 180 days. (Nath and Sarker 2011).

Gritsada Sua-iam. et al [2013] have produced self-compacting concrete (SSC) by employing increasing use of BA and limestone powder waste (LS) as a partial or complete replacement of fine aggregate. Mineralogical compositions of cement (OPC), BA, and LS were identified using XRD and SEM techniques. Nineteen batch formulations contained OPC, coarse aggregate, and river sand as a fine aggregate replaced by BA and LS in the amounts of 0, 10, 20, 40, 60, 80, and 100% by volume. With the help of a water reducing agent, the mixes were intended for a sump flow diameter of 70 + 2.5 cm. The physic-mechanical properties of developed self-compacting concrete were observed to result in 20% BA and 20% LS, which showed improved properties as compared to control SSC and achieved all the requirements as per recommendations (Sua-iam and Makul 2013).

5.2 Bricks

Madurwar, et al. (2014) have developed BA bricks using three principal raw materials: BA, quarry dust (QD), and lime (L). SBA was characterised using XRF, XRD, and particle size distribution; TGA and SEM techniques revealed rough surfaces with fine pores. The proportion of SBA and QD has been formulated to vary from 80–50% and 0–30%, respectively, with a constant 20% lime. 20 brick samples of each combination of size 23x11x8 cm3 were prepared and kept for 3 days for drying, followed by 7 and 7 days for wet curing and sun-drying, respectively. Physico-mechanical, functional, durability, and environmental tests were performed on brick samples. The optimum combination of 50% SCBA, 30% QD, and L 20% resulted in a 19.70% water observation with a 6.59MPa compressive strength. Moreover, developed brick is 40% lighter, shows lower thermal conductivity (k), and consumes 60% less energy than locally available conventional brick. The author finally concluded that the lightweight, energy-efficient brick is viable to solve environmental and solid waste management problems effectively and satisfy local construction demand (Raut et al. 2013).

Raut, et al. (2013) have investigated lightweight brick using (10–20%) OPC + (10–20%) rice-husk ash (RHA) + (70–80%) recycled paper mill residue (RPMR). PRMR and RHA were characterised by XRD, XRF, SEM, and the TG-DTA method. Thermogravimetric Analysis-Differential Thermal Analysis is commonly referred to as TG-DTA. This method for combined thermal analysis investigates the way a material changes both physically and chemically when heated, cooled, or maintained at a constant temperature. TG-DTA applications in Characterization of cement, ceramics, and polymers(Hosseinian et al. 2022).

It is observed that the silica content in RHA and RPMR contributes to pozzolanic reaction and acts as a cementitious material. The results show that brick made from cement, RHA, and RPMR is 50% lighter than conventional brick and has compressive strengths ranging from 11–15 MPa, which is five times higher than conventional clay bricks (Chowdhury et al. 2015).

Hegazy, et al. (2012) investigated brick (without clay) using water treatment plant sludge (WTP sludge) incorporated with Rice husk ash (RHA) and silica fumes (SF) for a different proportion of 25 or 50% individually. Bricks of each combination were burnt at 900ºC, 1000ºC, 1100ºC, and 1200ºC. XRD was used to characterise WTP sludge, RHA and SF. The major chemical composition observed in all raw materials is silica, which provides good strength in brick and is a good substitute for brick clay. The mix-proportion of 50% WTP sludge, 25% RHA, and 25 % SF stood for the optimum combination of brick produced from lime sludge incorporated with RHA and SF(Hegazy et al. 2012).

5.3 Mortar

Rukzon, et al [2013] developed a mortar using the three pozzolanic materials: FA, RB, and ground BA followed by OPC blended with single or double pozzolons in different percentages. Eleven different combinations of principle materials, FA (10, 20 or 40%) + RB (10, 20 or 40%) + BA (10, 20 or 40%) were prepared. The physical and chemical properties of the pozzolans were identified. Compressive strength and porosity tests for 7, 28, and 90 days and RCPT and Accelerated corrosion tests for 28 days were performed. Test results showed that employing ternary blends of CT, FA, and RB or BA outperformed binary blended mortar in terms of porosity. The mortar's RCPT increased significantly with the partial replacement of CT+FA, CT+RB, and CT+BA. The application of ternary blends of CT, FA, and RB/BA generated a mortar with good strength and resistance to chloride penetration (Rukzon and Chindaprasirt 2013).

Chindaprasirt et al [2013] investigated the RCPT of blended cement (OPC) containing palm oil fuel ash (POA), ground RHA, and fine fly ash (FA). With the aid of superplasticizer (SP), 10, 20 and 40 % of OPC were replaced with single or double pozzolan, followed by a constant w/c ration of 0.5. Compressive strength, RCPT, rapid migration test (RMT), and chloride penetration depth were measured after mortars were immersed in a 3% NaCl solution for 30 days. A mortar containing an equivalent amount of POA+ FA or RHA+ FA exhibited good strength and resistance to chlorine penetration. It also requires less superplasticizer than a standard OPC mortar.

5.3 Autoclaved Aerated Concrete

Chang-long Wang et al. (2015) developed autoclaved aerated concrete (ACC) using waste coal gangue (CGC) and iron ore tailings (ITOs). Waste Coal Gangue (CGC) are solid wastes, generated during the mining and washing of coal while the byproducts that remain after iron is extracted from ore during beneficiation are known as iron ore tailings(Jahandari et al. 2023).Seventeen different combinations of principal materials (CGC, ITOs, lime, cement, and gypsum) were prepared, followed by 0.06% aluminium powder and 60% water. The composition and morphology of AAC were analysed using differential scanning calorimetry, thermo-gravimetric analysis, XRD, and SEM. AAC, or autoclaved aerated concrete, is a lightweight precast construction material composed of cement, lime, silica, water, and aluminium powder. Morphology of AAC composed of Homogeneous distribution of air voids, Matrix of hydrated calcium silicate phases, Fine crystalline and amorphous phases, Low-density and porous structure(Kumar et al. 2022).

Test results showed that the bulk density and compressive strength of autoclaved aerated concrete samples were approximately 609 kg/m3 and 3.68 MPa, respectively, which achieved all the requirements as per recommendations. Many researchers have developed various environmentally friendly, sustainable, energy efficient construction products utilising optimum use of agricultural and industrial solid wastes summarised in **table 5**.

Table 5 -Average percentages of Agricultural and Industrial solid wastes use for development of different construction products.

A	Studies on Production of HIGH STRENGTH CONCRETE OR ORDINARY CONCRETE PREPARED by Replacing Cement with Agro-Industrial Rejects				
Sr. no	**Solid waste used**	**Raw material and its proportions in mix**	**Optimum Percentage of partial replacement of solid waste**	**Average**	**Reference**
01	Fly ash	OPC + Fly ash (30- 40 %)+ Sand + granite with naphthalene-based superplastizer	Fly ash - 40%	Average Fly ash – 33%	(Nath and Sarker 2011)
02	Fly ash + SBA + RHA	Portland Cement + Fly ash / Bagasse Ash / Rice husk-bark ash (20 and 40%) + Fine and Coarse Aggregate + superplasticizer	Fly ash - 20%		(Rukzon and Chindaprasirt 2014)
03	Iron Ore tailings + Fly ash	Cement + Iron Ore Tailings (20-100%) + Fly ash (35 %) + Silica Fume (15%) + superplasticizer	Fly ash- 35%		(Zhao et al. 2014)
04	Fly ash + Copper Slag	OPC + Copper Slag (0-100%) + Fly ash (40%)	Fly ash – 40%		(Sharma and Khan 2017)
05	RHA	Cement +Micro silica (10%) + RHA (0-25%)+ sand+ Gravel + Plasticizer	RHA -25 %	Average RHA- 20 %	(Zareei et al. 2017)
06	Fly ash + SBA +RHA	Portland Cement + Fly ash / Bagasse Ash / Rice husk-bark ash (20 and 40%)+ Fine and Coarse Aggregate + superplasticizer	Rice husk-bark ash - 20 %		(Rukzon and Chindaprasirt 2014)
07	RHA	OPC+ RHA(5 - 25%) + water reducing admixture	RHA - 15 %		(Sathurshan et al. 2021)
08	RHA	OPC+ RHA(10- 20%) + superplasticizer	RHA - 15 %		(Chopra et al. 2015)
09	SBA	OPC + SBA (10-30%) + Fine and Coarse Aggregate + superplasticizer	SBA- 30%	Average SBA - 21 %	(Rukzon and Chindaprasirt 2012)
10	SBA	OPC + Treated Bagasse ash + Silica fumes +quartz power +quartz sand+ steel fiber and superplasticizer	SBA- 15 %		(Rajasekar et al. 2018)

11	SBA + Lime stone waste	OPC + SBA + Lime stone waste + water reducing admixture	SBA- 20%		(Sua-iam and Makul 2013)
12	Fly ash + SBA +RHA	Portland Cement + Fly ash / Bagasse Ash / Rice husk-bark ash (20 and 40%)+ Fine and Coarse Aggregate + superplasticizer	Bagasse Ash - 20 %		(Rukzon and Chindaprasirt 2014)
13	SBA	OPC + SBA + Fine and Coarse aggregate	SBA -25 %		(Bahurudeen et al. 2015)
14	SBA	Cement + Sugarcane Bagasse (0-25 %) + Micro-silica(10%)	SBA -15 %		(Rukzon and Chindaprasirt 2014)
15	Palm oil Fuel ash	Cement + Palm oil Fuel ash + sand + coarse aggregate+ Silica fumes + superplasticizer	Palm oil Fuel ash 20 %	Palm oil Fuel ash 20 %	(Sata et al. 2004)
16	Copper Slag + Fly ash	OPC + Copper Slag (0-100%) + Fly ash (40%)	Copper Slag - 20 co %	Copper Slag - 20 %	(Sharma and Khan 2017)
17	Lime stone wastes	Cement + Lime stone wastes + Sand+ Aggregate + Super Plasticizer	Lime stone wastes -20 %	Average Lime stone wastes – 30%	(Kibriya and Tahir 2017)
18	SBA + Lime stone waste	OPC + SBA + Lime stone waste + water reducing admixture	Lime stone waste- 20%		(Sua-iam and Makul 2013)
19	Lime Stone waste + Marble powder	Cement + Lime stone waste (25, 50 and 75 %) + Marble powder (5, 10, 15%) + Superplasticizer	Lime Stone waste - 50%		(Omar et al. 2012)
20	Marble powder	Cement + Marble dust (0-15 %) +sand + coarse aggregate + Admixture	Marble powder -15%	Average Marble Powder -15%	(Aliabdo et al. 2014)
21	Marble powder + Lime Stone waste	Cement + Lime stone waste (25, 50 and 75 %) + Marble powder (5, 10, 15%) + Superplasticizer	Marble powder-15%		(Omar et al. 2012)
22	Construction Waste	Portland cements + Fly ash + Recycled Concrete Aggregate + Metacoline + superplasticizer	Construction Waste -20 %	Construction Waste -20 %	(Kubissa et al. 2017)
23	Groundnut Shell Ash	Cement + Fine and Coarse Aggregate + Groundnut shell (0-75%) +	Groundnut Shell Ash - 75%	Average Groundnut Shell Ash -75%	(Sada et al. 2013)
24	Groundnut Shell Ash	Cement + Fine and Coarse Aggregate + Groundnut shell (0-40%) +	Groundnut Shell Ash - 75%		(Duc et al. 2019)

B	**Studies on production of BRICK prepared by replacing cement with agro-Industrial rejects**				
Sr. no	**Solid waste used**	**Raw material and its proportions in mix**	**Optimum Percentage of partial replacement**	**Average**	**Reference**

			of solid waste		
01	Fly ash	Cement + fly ash, quarry dust and billet scale	fly ash = 50%	Average Fly ash- 60% ash- 60%	(Shakir et al. 2013)
02	Bottom Ash	Cement + Bottom Ash (70%- 90 %+ lateritic clayey soil + sand	Bottom Ash – 70 %		(Vinai et al. 2013)
03	SBA	SBA(90-50%) + quarry dust(0-40%) + Lime (10-30%)	SBA -50 %	Average SBA – 50%	(Madurwar et al. 2015)
04	SBA	SBA (80 -50 %)+ Quarry dust(0-30%) + Lime(20 %)	SBA -50 %		(Madurwar et al. 2013)
05	SBA	SBA (80 -50 %) + Quarry dust (0-30%) + Lime (20 %) + OPC	SBA - 50 %		(Madurwar. et al. 2013)
06	RHA	(10- 20 %) OPC + (10- 20 %) Rice - husk ash + (70- 80 %) Recycle paper mill residue	RHA – 20 %	RHA – 20 %	(Raut et al. 2013)
07	Wood sawdust + limestone powder	OPC + Wood sawdust and limestone powder (10–30%)	Wood sawdust -30 %	Wood sawdust -30 %	(Turgut and Murat Algin 2007)
08	Limestone Powder Waste +Waste Glass Powder	OPC+ Limestone Powder Waste +Waste Glass Powder	Waste Glass Powder =30 %	Waste Glass Powder =30 %	(Turgut 2008)
09	Recycle paper mills waste	OPC + Recycle paper mills waste (80- 95%)	Recycle paper mills waste = 80 %	Recycle paper mills waste = 80 %	(Raut et al. 2012)

C	**Studies on production of MORTAR prepared by replacing cement with agro-Industrial rejects**				
Sr. no	**Solid waste used**	**Raw material and its proportions in mix**	**Optimum Percentage of partial replacement of solid waste**	**Average**	**Reference**
01	Fly ash + rice husk-bark ash	fly ash (10-20%)+ rice husk-bark ash (10-20%)	fly ash – 20%	Average Fly ash – 21%	(Rukzon and Chindaprasirt 2013)
02	Fly ash + bagasse ash	fly ash (10-20%)+ rice husk-bagasse ash (10-20%)	fly ash – 20%		(Rukzon and Chindaprasirt 2013)

03	Fly ash	OPC+ Fly ash (25%)	fly ash – 25%		(Cho et al. 2019)
04	Fly ash	OPC+ Fly ash (10-20%)	fly ash – 20%		(Hsu et al. 2018)
05	Palm oil fuel ash + ground RHA + fine fly ash	OPC + palm oil fuel ash (20 and 40%) + ground RHA (20 and 40%) + fine fly ash (20 and 40%)	fine fly ash -20%		(Chindaprasirt and Rukzon 2008)
06	Bagasse ash	Cement + SBA (5-30%)	Bagasse ash - 20 %	Average Bagasse Ash = 23 %	(Amin and Ali 2011)
07	Bagasse ash	Cement+ bagasse ash (10- 40%)	Bagasse ash - 30 %		(Chusilp et al. 2009)
08	Fly ash + bagasse ash	Cement + fly ash (10-20%)+ rice husk-bagasse ash (10-20%)	bagasse ash - 20%		(Rukzon and Chindaprasirt 2013)
09	Fly ash + rice husk-bark ash	Cement +fly ash (10-20%)+ rice husk-bark ash (10-20%)	rice husk-bark ash – 20%	Average RHA – 20%	(Rukzon and Chindaprasirt 2013)
10	Palm oil fuel ash + ground RHA + fine fly ash	OPC + palm oil fuel ash (20 and 40%) + ground RHA (20 and 40%) + fine fly ash (20 and 40%)	RHA -20%		(Chindaprasirt and Rukzon 2008)
11	Palm oil fuel ash + ground RHA + fine fly ash	OPC + palm oil fuel ash (20 and 40%) + ground RHA (20 and 40%) + fine fly ash (20 and 40%)	Palm oil fuel ash - 20%	Palm oil fuel ash - 20%	(Chindaprasirt, et al. 2008)
12	Palm oil fuel ash	OPC + palm oil fuel ash (20 and 40%)	Palm oil fuel ash - 20%		(Rukzon and Chindaprasirt 2009)
D	**Studies on production of AUTOCLAVED AERATED CONCRETE prepared by replacing cement with agro-Industrial rejects**				
Sr. no	**Solid waste used**	**Raw material and its proportions in mix**	**Optimum % of partial replacement of solid waste**	**Average**	**Reference**
01	Iron Ore tailings + Coal gangue	Portland cement (10%)+ Iron ore tailing (20 -59 %) + Coal gangue (1-40 %) + Lime (25%) + Desulphurization gypsum (5%) + Aluminum powder (0.06%)	Iron Ore tailings - 40 %	Iron Ore Tailing - 40 %	(Wang et al. 2016)
02	Phosphogypsum + Blast furnace slag	Cement (15%) + Phosphogypsum (55%) + Blast furnace slag (0-35%) + Lime (3-15%) + Na_2SO_4 (1.6%) + Aluminum powder (0.074%)	Phosphogypsum -55%	Phosphogypsum - 55%	(Lin. Yang et al. 2013)
03	Iron Ore tailings + Coal gangue	Portland cement (10%)+ Iron ore tailing (20 -59 %) + Coal gangue (1-40 %) + Lime (25%) + Desulphurisation gypsum (5%) + Aluminum powder (0.06%)	Coal gangue - 20 %	Coal gangue - 20 %	(Wang et al. 2016)

04	Phosphogypsum + Blast furnace slag	Cement (15%) + Phosphogypsum (55%) + Blast furnace slag (0-35%) + Lime (3-15%) + Na_2SO_4 (1.6%) + Aluminum powder (0.074%)	Blast furnace slag -30%	Blast furnace slag -30%	(Yang et al. 2013)

From **table 5**, it is observed that various authors proved the successful replacement of cement with agro-industrial rejects for the development of different sustainable construction products. After long research by different researchers, solid waste is now treated as valuable feedstock and believed as supplementary cementation material up to a great extent in the correct proportion. Due to its enormous stock and fruitful composition, it is being considered as a potential resource for the future sustainable model. Employing engineering tools for resource recovery is gaining attention in the contest for a sustainable world. In the present era, India has the potential to digest a huge quantity of generated waste to develop value-added sustainable construction products. These waste-derived products eloquently address the majority of sustainable goals(Venkata et al. 2018). The average optimum replacement of different agro- industrial rejects for the development of blended concrete, bricks, mortar and Aerated Concrete is summarized and shown in **figure 8**.

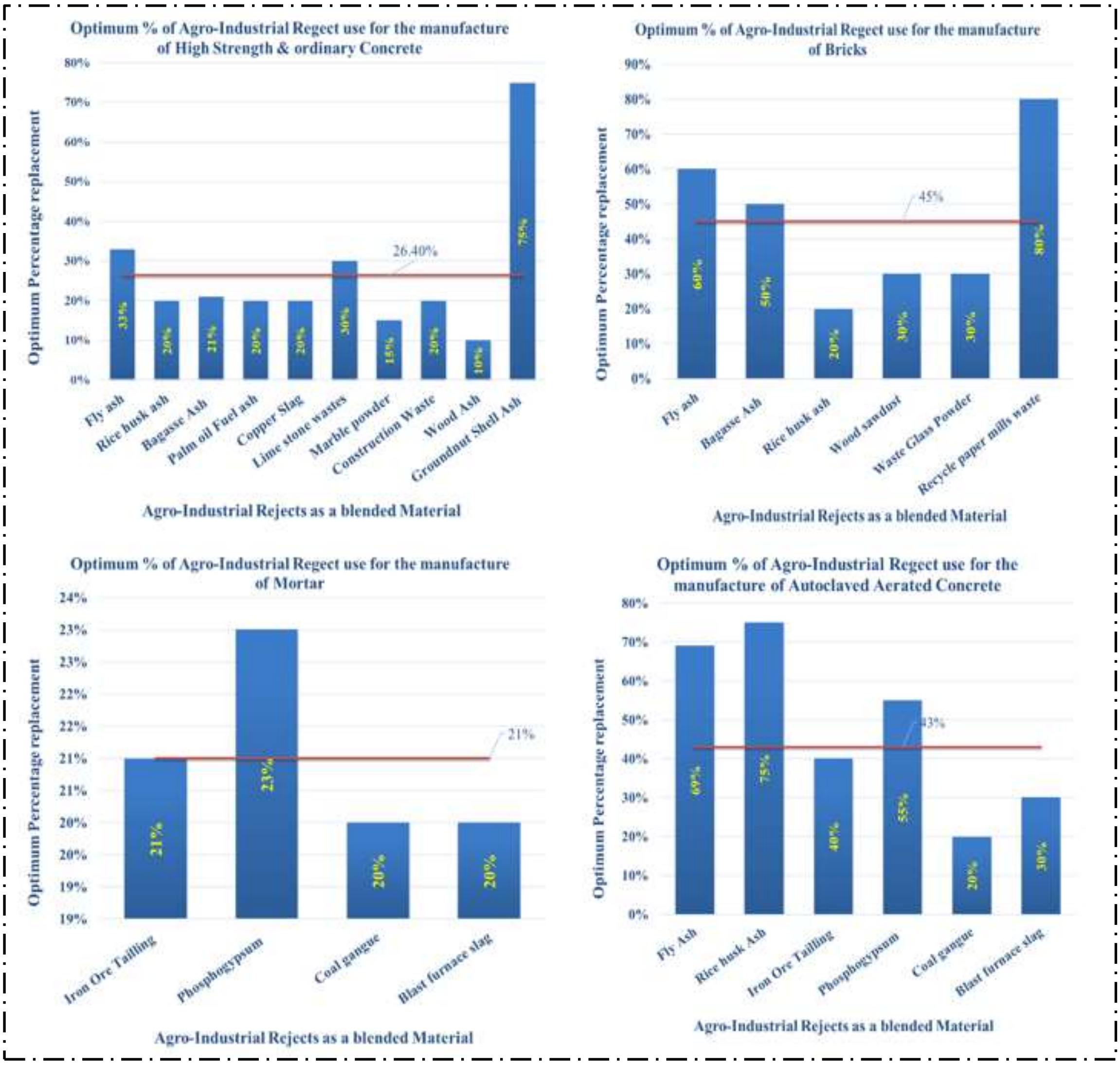

Figure 8 - CO_2 emission by cement industries by top 10 countries

Table 6 - Average % of agro-industrial rejects used as a blended material

Sr. No	Products	Average % of Waste used as a blended Material
01	High Strength and ordinary Concrete	26.4 %
02	Brick	45%
03	Mortar	21%
04	Autoclaved Aerated	36%
	Average	**32%**

The mathematical analysis of the data acquired from the referred papers indicates that a reasonable **32%** of cement could be successfully replaced with different agro- industrial rejects for the production of various construction products as shown in **table 6. Figure 9** shows the schematic diagram represented average % of Waste used as a blended material for the development of construction products.

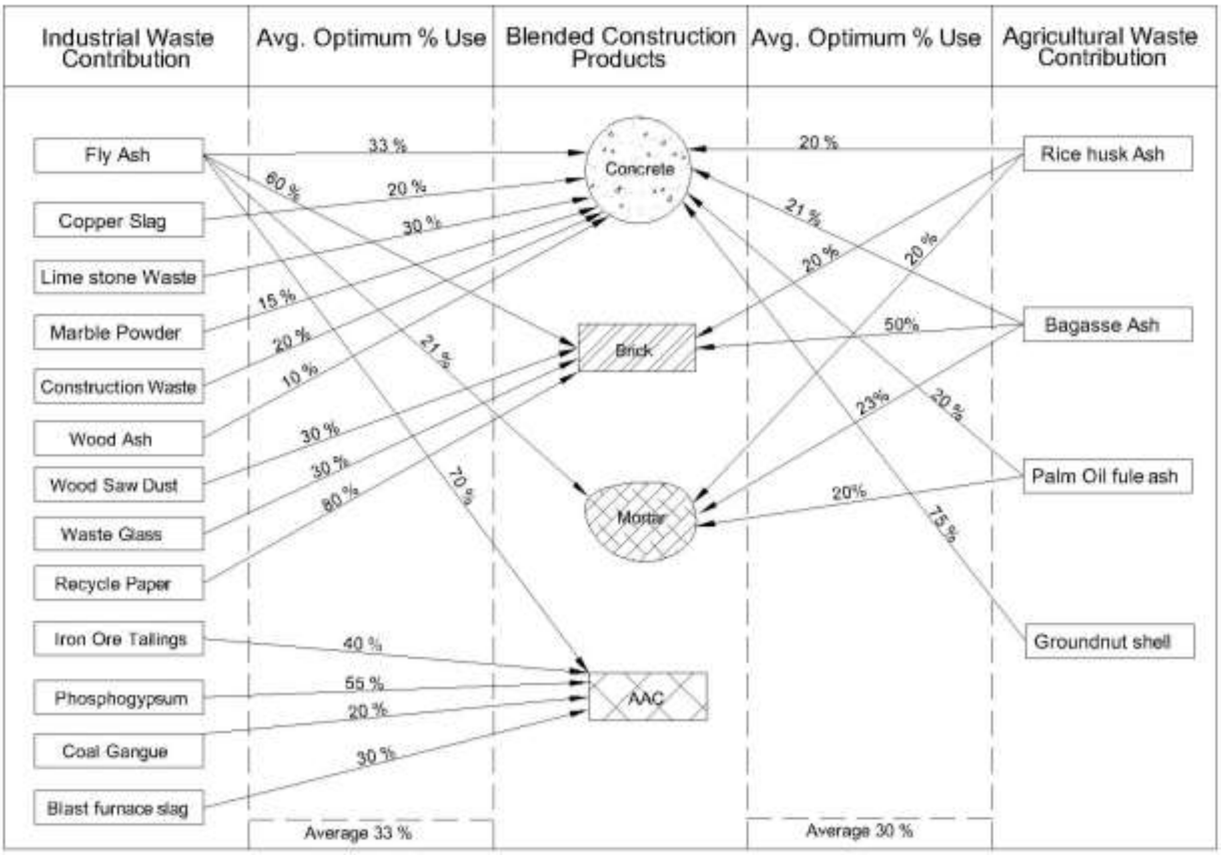

Figure 9 - Schematic Diagram shows the average of optimum percentage of industrial or agricultural waste use for development of blended construction products.

Assessment of reduction in environmental impact due to utilisation of solid waste

In India, 146 MT cement produced in the year 2006 which increase to 375 MT in the year 2023 which emits around 177 MT of CO_2 into the atmosphere and if we could not control this exponential demand of cement then the forecasted demand of cement may reach up to 712 MT by the year 2050 which may evolve around 375 MT of CO_2 which is almost 2.1 times of the year 2023.

The successful research for the utilisation of agro-industrial rejects as a blended material to replace cement as a binding and filler material for the production of construction products not only helps to break the chain of this exponential emission of greenhouse gases, but also helps to reduce the energy required for the production and transportation of cement and solves agricultural and industrial waste stacking problems indirectly.

The estimated reduction in emissions of anthropogenic CO_2 and other greenhouse gases and the reduction in energy use after utilisation of an average of 32% of agro-industrial rejects as a cementitious blend is illustrated in the **table 7** below. **Table 8** reveals the forecasted greenhouse gases evolved and energy consumed by cement Industry with and without utilization of agro-industrial rejects as a blended from year 2024 to 2050**. Figure 10** shows the expected cement consumption both with and without the use of agro-industrial waste.

Table 7 – Reduction in emission of GHG

	Year	Consumption of Cement In India in Million tons	Forecasted Consumption of Cement after utilization of 32 % Indo-Agriculture waste as a blended material in Million Tons	Reduction in Cement Production Per Year in Million Tons	Reduction in emission of Green House Gases into the Environment				Energy Save in GJ
					Reduction in CO_2 emission in Atmosphere per year in Million Tons	Reduction in NO_2 emission in Atmosphere per year in Million Tons	Reduction in SO_2 emission in Atmosphere per year in Million Tons	Reduction in emission of particulate matter in Atmosphere per year in Million Tons	
Forecasted	2025	393	267	126	107	0.38	0.19	0.03	502
	2026	405	276	130	110	0.39	0.19	0.03	519
	2027	418	284	134	114	0.40	0.20	0.03	535
	2028	431	293	138	117	0.41	0.21	0.03	552
	2029	444	302	142	121	0.43	0.21	0.03	568
	2030	456	310	146	124	0.44	0.22	0.03	584
	2031	469	319	150	128	0.45	0.23	0.03	601
	2032	482	328	154	131	0.46	0.23	0.04	617
	2033	495	336	158	135	0.47	0.24	0.04	633
	2034	507	345	162	138	0.49	0.24	0.04	650
	2035	520	354	166	141	0.50	0.25	0.04	666
	2036	533	362	171	145	0.51	0.26	0.04	682
	2037	546	371	175	148	0.52	0.26	0.04	699
	2038	559	380	179	152	0.54	0.27	0.04	715
	2039	571	388	183	155	0.55	0.27	0.04	731
	2040	584	397	187	159	0.56	0.28	0.04	748
	2041	597	406	191	162	0.57	0.29	0.04	764
	2042	610	415	195	166	0.59	0.29	0.04	780
	2043	622	423	199	169	0.60	0.30	0.05	797
	2044	635	432	203	173	0.61	0.30	0.05	813
	2045	648	441	207	176	0.62	0.31	0.05	829
	2046	661	449	211	180	0.63	0.32	0.05	846
	2047	673	458	215	183	0.65	0.32	0.05	862
	2048	686	467	220	187	0.66	0.33	0.05	878
	2049	699	475	224	190	0.67	0.34	0.05	895
	2050	712	484	228	194	0.68	0.34	0.05	911
				4715 Mt	**4008 Mt**	**14 Mt**	**7 Mt**	**1 Mt**	**18862**

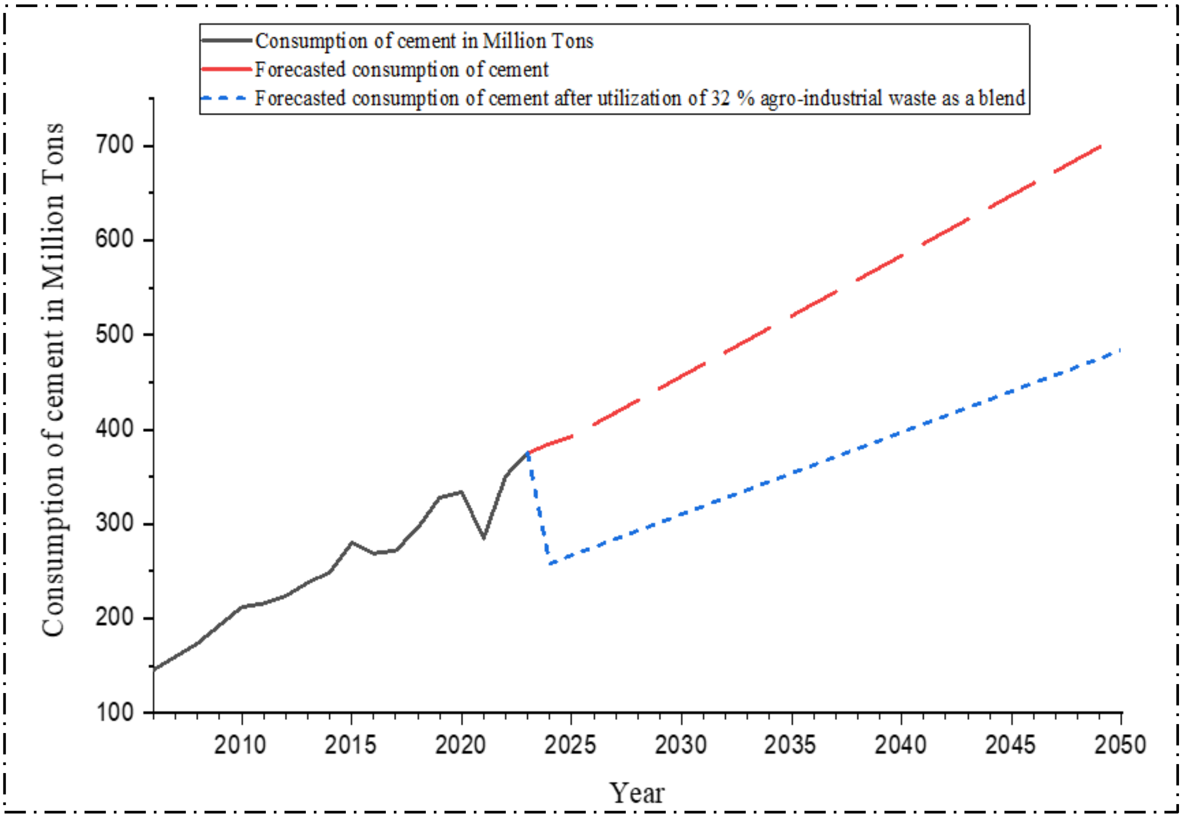

Figure 10 - Forecast consumption of cement with and without utilization of agro-industrial rejects

Table 8 - Forecasted greenhouse gases evolved and energy consumed by cement Industry **with and without** utilization of agro-industrial rejects as a blended from year **2024 to 2050**

Greenhouse gases	**Without** utilization of Agro-Industrial rejects as a blend	**With** utilization of Agro-Industrial rejects as a blend	Reduction in emission of greenhouse gases	% Saving
CO_2 in Mt	12525	8517	4008	32 %
NO_2 in Mt	44	30	14	
SO_2 in Mt	22	15	7	
Particulate matter in Mt	3.4	2.4	1	
Energy in GJ	58940	40078	18862	

6. CONCLUSIONS

The world is advancing to a circular, sustainable economy by replacing the linear, fossil fuel-based one. Sustainable construction is becoming a growing trend in the concrete industry in recent years because of its impact on the environment.

- From the studied literature, it is observed that utilizing waste-based, sustainable building materials promotes a waste-based economy and provides advantages such as waste management, employment, economic development, and environmental protection.
- These environmentally friendly products promote environmentally friendly construction methods while addressing limited resources and climate change.
- Energy usage and greenhouse gas emissions can be reduced by partially replacing agro-industrial waste for cement. This might meet demand for the next 15 years by reducing cement production by 5000 Mt, lowering CO_2 emissions by 3400 Mt, and saving 16,000 GJ of energy by 2050.

FUTURE SCOPE

1. The utilization of agro-industrial waste may significantly strengthen frameworks towards the circular economy. The development of closed-loop systems that minimize the production of waste requires integrated models which link waste producers, processors, and ultimately users.
2. The development of efficient real-time energy recovery, leachate, and emissions monitoring systems would provide enhanced validation of environmental impact reductions. AI, IoT, and remote sensing may increase possibilities for collecting and analysing data.
3. Developing mix formulations that effectively absorb CO_2 (carbonation curing, CO_2 mineralization) along with employing carbon capture technology during cement manufacture are intriguing possibilities for further research. Materials for construction that are carbon-negative or net-zero can be made possible through this.
4. Several recent developments are building with modular components and additive manufacturing. The development of customized cementitious blends for 3D printing and prefabricated structures could lead the way for advancements in expedient and environmentally friendly building.

Author Contributions: For research articles with multiple authors, include a brief paragraph outlining each author's contributions using the following format: "Conceptualization, formal analysis, investigation, methodology, validation, and writing–original draft, **Anshul Nikhade**.; conceptualization, formal analysis, investigation, methodology, validation, and writing–original draft, **Devendra Padole**.; investigation, validation, and writing–original draft, **Sameer Algburi**.; conceptualization, formal analysis, investigation, methodology, validation, and writing–original draft, **Monali Wagh**.; Formal analysis, validation, and writing–original draft, **Harshal Nikhade**.; resources, validation, writing–original draft, and writing–review and editing, **Ahmed M. Abdulhadi**.; validation, writing–original draft, **Hasan Sh. Majdi**.; validation, writing–original draft, **Adel Hadi Al-Baghdadi**.; validation, writing–original draft, **Prajakta Waghe.**

All authors have read and agreed to the published version of the manuscript." Authorship should be restricted to individuals who have made significant contributions to the research.

Funding: "This research received no external funding"

Conflicts of Interest: Authors must declare any conflicts of interest or state, “The authors declare no conflicts of interest.” It is essential to identify and disclose any personal circumstances or interests that may be perceived as influencing the representation or interpretation of the reported research results. Additionally, any involvement of funders in the design of the study, data collection, analysis, interpretation, manuscript writing, or decision to publish must be clearly stated. If there was no role for the funders, please include the statement: “The funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.”

REFERENCES

1. Agrawal, A., K. K. Sahu, B. D. Pandey. 2004. ‘Solid Waste Management in Non-Ferrous Industries in India’. *Resources, Conservation and Recycling* 42(2):99–120. doi: 10.1016/j.resconrec.2003.10.004.
2. Agrawal, Dhiraj, Khalid Ansari, Uday Waghe, Manmohan Goel, S. P. Raut, Harshal Warade, Essam Althaqafi, Saiful Islam, and Osamah J. Al-sareji. 2025. ‘Exploring the Impact of Pretreatment and Particle Size Variation on Properties of Rubberized Concrete’. *Scientific Reports* 15(1):11394. doi: 10.1038/s41598-025-96402-y.
3. Algin, Halil Murat, and Paki Turgut. 2008. ‘Cotton and Limestone Powder Wastes as Brick Material’. *Construction and Building Materials* 22(6):1074–80. doi: 10.1016/j.conbuildmat.2007.03.006.
4. Aliabdo, Ali A., Abd Elmoaty M. Abd Elmoaty, Esraa M. Auda. 2014. ‘Re-Use of Waste Marble Dust in the Production of Cement and Concrete’. *Construction and Building Materials* 50:28–41. doi: 10.1016/j.conbuildmat.2013.09.005.
5. Amin, N., and K. Ali. 2011. ‘Chemical Activation of Bagasse Ash in Cement Mortar’. 23(2):89–96. doi: 10.1680/adcr.8.00031.
6. Andrew, Robbie M. 2018. ‘Global CO_2 Emissions from Cement Production’. *Earth System Science Data* 10(1):195–217. doi: 10.5194/essd-10-195-2018.
7. Aprianti, Evi, Payam Shafigh, Syamsul Bahri, and Javad Nodeh Farahani. 2015. ‘Supplementary Cementitious Materials Origin from Agricultural Wastes – A Review’. *Construction and Building Materials* 74:176–87. doi: 10.1016/j.conbuildmat.2014.10.010.
8. Armstrong, Thomas. 2012. ‘An Overview of Global Cement Sector Trends’. *International Cement Review*.
9. Armstrong, Thomas .. 2018. ‘A Review of Global Cement Industry Trends’. *International Cement Review*.
10. Arun Kumar, M., K. Prasanna, C. Chinna Raj, V. Parthiban, P. Kulanthaivel, S. Narasimman, and V. Naveen. 2022. ‘Bond Strength of Autoclaved Aerated Concrete Manufactured Using Partial Replacement of Flyash with Fibers – A Review’. *Materials Today: Proceedings* 65:581–89. doi: 10.1016/j.matpr.2022.03.191.
11. Bahurudeen, A., Deepak Kanraj, V. Gokul Dev, and Manu Santhanam. 2015. ‘Performance Evaluation of Sugarcane Bagasse Ash Blended Cement in Concrete’. *Cement and Concrete Composites* 59:77–88. doi: 10.1016/j.cemconcomp.2015.03.004.
12. Bahurudeen, A., K.S Vaisakh, Manu Santhanam. 2017. ‘Availability of Sugarcane Bagasse Ash and Potentialf Use as a Supplementary Cementitious Material in Concrete ’.

13. Bahurudeen, A., and Manu Santhanam. 2015. 'Influence of Different Processing Methods on the Pozzolanic Performance of Sugarcane Bagasse Ash'. *Cement and Concrete Composites* 56:32–45. doi: 10.1016/j.cemconcomp.2014.11.002.
14. Balogun, Biola., Raj G C, Aglina Moses Kwame, and . 2016. 'Air Pollution Control in Cement Industries in India'. *Biola Balogun Lappeenranta – Lahti University of Technology LUT*.
15. Bayer Ozturk, Zahide, and Elif Eren Gultekin. 2015. 'Preparation of Ceramic Wall Tiling Derived from Blast Furnace Slag'. *Ceramics International* 41(9):12020–26. doi: 10.1016/j.ceramint.2015.06.014.
16. Bheel, Naraindas, Gohar Nadeem, Abdulrazak H. Almaliki, Yaser Khaled Al-Sakkaf, Yakubu Aminu Dodo, and Omrane Benjeddou. 2024. 'Effect of Low Carbon Marble Dust Powder, Silica Fume, and Rice Husk Ash as Tertiary Cementitious Material on the Mechanical Properties and Embodied Carbon of Concrete'. *Sustainable Chemistry and Pharmacy* 41:101734. doi: 10.1016/j.scp.2024.101734.
17. Biricik, Hasan, Fevziye Aköz, I. lhan Berktay, and Ali N. Tulgar. 1999. 'Study of Pozzolanic Properties of Wheat Straw Ash'. *Cement and Concrete Research* 29(5):637–43. doi: 10.1016/S0008-8846(98)00249-X.
18. Bisht, Laxman Singh., and Mokaddes Ali. Ahmed. 2018. 'Paratransit System Characteristics in Mid-Size City of Silchar, India'. *Urbanization Challenges in Emerging Economies*.
19. Chen, C., G. Habert, Y. Bouzidi, and A. Jullien. 2010. 'Environmental Impact of Cement Production: Detail of the Different Processes and Cement Plant Variability Evaluation'. *Journal of Cleaner Production* 18(5):478–85. doi: 10.1016/j.jclepro.2009.12.014.
20. Chindaprasirt, P., and S. Rukzon. 2008. 'Strength, Porosity and Corrosion Resistance of Ternary Blend Portland Cement, Rice Husk Ash and Fly Ash Mortar'. *Construction and Building Materials* 22(8):1601–6. doi: 10.1016/j.conbuildmat.2007.06.010.
21. Chindaprasirt, P., S. Rukzon, and V. Sirivivatnanon. 2008. 'Resistance to Chloride Penetration of Blended Portland Cement Mortar Containing Palm Oil Fuel Ash, Rice Husk Ash and Fly Ash'. *Construction and Building Materials* 22(5):932–38. doi: 10.1016/j.conbuildmat.2006.12.001.
22. Cho, Young Keun, Sang Hwa Jung, and Young Cheol Choi. 2019. 'Effects of Chemical Composition of Fly Ash on Compressive Strength of Fly Ash Cement Mortar'. *Construction and Building Materials* 204:255–64. doi: 10.1016/j.conbuildmat.2019.01.208.
23. Chopra, Divya., Rafat. Siddique, Kunal. 2015. 'Strength, Permeability and Microstructure of Self-Compacting Concrete Containing Rice Husk Ash'. *Biosystems Engineering* 130:72–80. doi: 10.1016/j.biosystemseng.2014.12.005.
24. Chowdhury, S., A. Maniar, O. Suganya, and . 2015. 'Strength Development in Concrete with Wood Ash Blended Cement and Use of Soft Computing Models to Predict Strength Parameters'. *Journal of Advanced Research* 6(6):907–13. doi: 10.1016/j.jare.2014.08.006.

25. Chusilp, Nuntachai, Chai Jaturapitakkul, and Kraiwood Kiattikomol. 2009. 'Utilization of Bagasse Ash as a Pozzolanic Material in Concrete'. *Construction and Building Materials* 23(11):3352–58. doi: 10.1016/j.conbuildmat.2009.06.030.
26. Chusilp, Nuntachai., Chai. Jaturapitakkul, Kraiwood. Kiattikomol. 2009. 'Utilization of Bagasse Ash as a Pozzolanic Material in Concrete'. *Construction and Building Materials* 23(11):3352–58. doi: 10.1016/j.conbuildmat.2009.06.030.
27. CPHEEO. 2000. '"Industrial Solid Waste,"'. *Municipal Solid Waste Management* 71–114.
28. Dana, Kausik., Jayanta. Dey, Swapan Kumar. Das. 2005. 'Synergistic Effect of Fly Ash and Blast Furnace Slag on the Mechanical Strength of Traditional Porcelain Tiles'. *Ceramics International* 31(1):147–52. doi: 10.1016/j.ceramint.2004.04.008.
29. Das, Kasturima, Bikramjit Goswami, and Girija T. R. 2025. 'Waste to Wealth: An Approach Towards Sustainable Construction from Pollutants'. *Nature Environment and Pollution Technology* 24(1):B4210. doi: 10.46488/NEPT.2025.v24i01.B4210.
30. Das, S. K., Sanjay. Kumar, P. Ramachandrarao. 2000. 'Exploitation of Iron Ore Tailing for the Development of Ceramic Tiles'. *Waste Management* 20(8):725–29. doi: 10.1016/S0956-053X(00)00034-9.
31. Değirmenci, Nurhayat. 2008. 'Utilization of Phosphogypsum as Raw and Calcined Material in Manufacturing of Building Products'. *Construction and Building Materials* 22(8):1857–62. doi: 10.1016/j.conbuildmat.2007.04.024.
32. Demis, S, J. G. Tapali, and V. G. Papadakis. 2014. 'An Investigation of the Effectiveness of the Utilization of Biomass Ashes as Pozzolanic Materials'. *CONSTRUCTION & BUILDING MATERIALS* 68:291–300. doi: 10.1016/j.conbuildmat.2014.06.071.
33. Demis, S., J. G. Tapali, V. G. Papadakis. 2014. 'An Investigation of the Effectiveness of the Utilization of Biomass Ashes as Pozzolanic Materials'. *Construction and Building Materials* 68:291–300. doi: 10.1016/j.conbuildmat.2014.06.071.
34. Duc, Pham Anh, P. Dharanipriya, Bharath Kumar Velmurugan, and M. Shanmugavadivu. 2019. 'Groundnut Shell -a Beneficial Bio-Waste'. *Biocatalysis and Agricultural Biotechnology* 20:101206. doi: 10.1016/j.bcab.2019.101206.
35. Garg, Mridul, and Neeraj Jain. 2010. 'Waste Gypsum from Intermediate Dye Industries for Production of Building Materials'. *Construction and Building Materials* 24(9):1632–37. doi: 10.1016/j.conbuildmat.2010.02.029.
36. H. Mahmoud, Z. A. Belel, C. Nwakaire. 2012. 'Groundnut Shell Ash as a Partial Replacement of Cement in Sandcrete Blocks Production'. *International Journal of Development and Sustainability* 1(3):1026–32.
37. Hargreaves, David. 2013. '"The Global Cement Report 10th Edition"'. *International Cement Review*.

38. Hegazy, Badr El-Din Ezzat., Hanan Ahmed. Fouad, Ahmed Mohammed. Hassanain, and . 2012. 'Incorporation of Water Sludge, Silica Fume, and Rice Husk Ash in Brick Making'. *Advances in Environmental Research* 1(1):83–96. doi: 10.12989/aer.2012.1.1.083.
39. Hosseinian, Hamed, Euth Ortiz Ortega, Ingrid Berenice Aguilar Meza, Andrea Rodríguez Vera, María José Rosales López, and Samira Hosseini. 2022. 'Characterization Techniques for Thermal Analysis'. Pp. 153–80 in.
40. H.R., Nikhade, and B. Ram Rathan Lal. 2021. 'Experimental Studies on Sugar Cane Bagasse Ash Based Geomaterials'. *International Journal of Engineering and Management Research* 11(5). doi: 10.31033/ijemr.11.5.1.
41. Hsu, Shihwen, Maochieh Chi, and Ran Huang. 2018. 'Effect of Fineness and Replacement Ratio of Ground Fly Ash on Properties of Blended Cement Mortar'. *Construction and Building Materials* 176:250–58. doi: 10.1016/j.conbuildmat.2018.05.060.
42. IBEF. 2019. '"Indian Brand Equity Foundation" 2019.'
43. IBEF. 2020. '"India Brand Equity Foundation. Real Estate"'.
44. Jackson, R. B., C. Le Quéré, R. M. Andrew, J. G. Canadell, J. I. Korsbakken, Z. Liu, G. P. Peters, and B. Zheng. 2018. 'Global Energy Growth Is Outpacing Decarbonization'. *Environmental Research Letters* 13(12):120401. doi: 10.1088/1748-9326/aaf303.
45. Jahandari, Soheil, Zhong Tao, Zhonghua Chen, Dave Osborne, and Maroun Rahme. 2023. 'Coal Wastes: Handling, Pollution, Impacts, and Utilization'. Pp. 97–163 in *The Coal Handbook*. Elsevier.
46. James, Jijo, and P. Kasinatha Pandian. 2017. 'A Short Review on the Valorisation of Sugarcane Bagasse Ash in the Manufacture of Stabilized / Sintered Earth Blocks and Tiles'. 2017.
47. Jankovsky, Ondrej. 2017. 'Study on Pozzolana Activity of Wheat Straw Ash as Potential Admixture for Blended Cements'. *Ceramics - Silikaty* 327–39. doi: 10.13168/cs.2017.0032.
48. Jha, Manas Kumar, and Manuj Dev. 2024. 'Impacts of Climate Change'. Pp. 139–59 in.
49. Katare, Vasudha D., and Mangesh V. Madurwar. 2017. 'Experimental Characterization of Sugarcane Biomass Ash – A Review'. *Construction and Building Materials* 152:1–15. doi: 10.1016/j.conbuildmat.2017.06.142.
50. Khurge, Deepti, Prachi Palsodkar, Prasanna Palsodkar, Abdullah Faiz Al Asmari, Tinku Biswas, Khalid Ansari, Dhiraj Agrawal, Ahmed M. Abdulhadi, and Saiful Islam. 2025. 'IoT-Powered Flexible Road Dividers for Accident Impact Reduction'. *Rocznik Ochrona Środowiska* 27:135–51. doi: 10.54740/ros.2025.012.
51. Kibriya, Tahir, and Leena Tahir. 2017. 'Sustainable Construction — High Performance Concrete Containing Limestone Dust as Filler'. 404–11. doi: 10.4236/wjet.2017.53034.
52. Kubissa, Wojciech, Tamás Simon, Roman Jaskulski, Pavel Reiterman, and Marcin Supera. 2017. 'Ecological High Performance Concrete'. *Procedia Engineering* 172:595–603. doi: 10.1016/j.proeng.2017.02.186.
53. Kulkarni, V. R. 2012. '"Evolution of RMC in India"'. *16th International ERMCO Congress on RMC, Verona, Italy* 1–31.

54. Kumar, Sanjeet, Md Asfaque Ansari, Lakshmi Kant, and Nitya Nand Jha. 2025. 'An Experimental Investigation on Sustainable Concrete Made with Refractory Brick as a Substitute of Natural Fine Aggregate'. *Nature Environment and Pollution Technology* 24(1):B4202. doi: 10.46488/NEPT.2025.v24i01.B4202.
55. Kumar, Sunil. 2003. 'Fly Ash–Lime–Phosphogypsum Hollow Blocks for Walls and Partitions'. *Building and Environment* 38(2):291–95. doi: 10.1016/S0360-1323(02)00068-9.
56. Kuranchie, Francis Atta, Sanjay Kumar Shukla, Daryoush Habibi, and Alireza Mohyeddin. 2015. 'Utilisation of Iron Ore Tailings as Aggregates in Concrete'. *Cogent Engineering* 2(1):1083137. doi: 10.1080/23311916.2015.1083137.
57. Kurzekar, Atul S., Uday Waghe, Khalid Ansari, Anant N. Dabhade, Tinku Biswas, Sameer Algburi, Mohammad Amir Khan, Essam Althaqafi, Saiful Islam, and Jagadesh Palanisamy. 2024. 'Development and Optimization of Geopolymer-Based Artificial Angular Coarse Aggregate Using Cut-Blade Mechanism'. *Case Studies in Construction Materials* 21:e03826. doi: 10.1016/j.cscm.2024.e03826.
58. Łaźniewska-Piekarczyk, Beata., Monika. Czop, Jan Antoni. Rubin. 2024. 'The Multifaceted Comparison of Effects of Immobilisation of Waste Imperial Smelting Furnace (ISF) Slag in Calcium Sulfoaluminates (CSA) and a Geopolymer Binder'. *Materials* 17(13):3163. doi: 10.3390/ma17133163.
59. Madurwar., S. Mandavgane, Rahul. Ralegaonkar. 2014. 'Use of Sugarcane Bagasse Ash as Brick Material'. *Current Science Association* 1044–51.
60. Madurwar, Mangesh., Sachin. Mandavgane, Rahul. Ralegaonkar. 'Development and Feasibility Analysis of Bagasse Ash Bricks'. *Journal of Energy Engineering* 141(3). doi: 10.1061/(ASCE)EY.1943-7897.0000200.
61. Madurwar., Rahul V. Ralegaonkar, Sachin A. Mandavgane. 2013. 'Application of Agro-Waste for Sustainable Construction Materials: A Review'. *Construction and Building Materials* 38:872–78. doi: 10.1016/j.conbuildmat.2012.09.011.
62. Manna, Dinabandhu, Ranjana Chowdhury, Rajnish K. Calay, and Mohamad Y. Mustafa. 2024. 'Experimental Insights into the Fermentation of Pyro-Syngas to Ethanol in a Semi-Batch and Continuous Stirred Bioreactor with Mathematical Modelling and Optimization'. *Energies* 17(3):562. doi: 10.3390/en17030562.
63. Marghussian, V. K., and A. Maghsoodipoor. 1999. 'Fabrication of Unglazed Floor Tiles Containing Iranian Copper Slags'. *Ceramics International* 25(7):617–22. doi: 10.1016/S0272-8842(98)00075-3.
64. Martin, Ancy G., Atul Jayapal, Krishna Vikram, and Bavigadda Kavya. 2024. 'Crop Residue Management through Utilization : A Review'. *Environment and Ecology* 42(2B):745–53. doi: 10.60151/envec/CEAM9171.
65. Mehta, P. 2001. 'Reducing the Environmental Impact of Concrete'. *Concrete International* 61–66.
66. N. Saleh, Alaa, Alyaa A. Attar, Sameer Algburi, and Omer K. Ahmed. 2023. 'Comparative Study of the Effect of Silica Nanoparticles and Polystyrene on the Properties of Concrete'. *Results in Materials* 18:100405. doi: 10.1016/j.rinma.2023.100405.
67. Nath, P., and P. Sarker. 2011. 'Effect of Fly Ash on the Durability Properties of High Strength Concrete'. *Procedia Engineering* 14:1149–56. doi: 10.1016/j.proeng.2011.07.144.

68. Nikhade, Anshul, and Anita Nag. 2022. ‘Effective Utilization of Sugarcane Bagasse Ash, Rice Husk Ash& Metakaolin in Concrete’. *Materials Today: Proceedings* 62. doi: 10.1016/j.matpr.2022.04.422.
69. Nikhade, Anshul, and Leeladhar Pammar. 2022. ‘Parametric Study of Concrete by Using SCBA, Metakaolin, Rice Husk Ash in Concrete – A Review’. *Materials Today: Proceedings* 60:1793–99. doi: 10.1016/j.matpr.2021.12.460.
70. Nikhade, Anshul, Sanket Sanghai, Mohammad Arsalan Khan, Meshel Q. Alkahtani, Mohammad Mursaleen, Harshal Nikhade, Devendra Padole, Avinash Badar, and Saiful Islam. 2025. ‘Experimental Study of Concrete by Effective Utilization of Agro-Waste and Metakaolin as a Partial Replacement for Cement’. *Materials Science and Technology*. doi: 10.1177/02670836251336289.
71. Nikhade, Harshal, Ram Rathan Lal Birali, Khalid Ansari, Mohammad Arsalan Khan, Hadee Mohammed Najm, S. M. Anas, Mohammad Mursaleen, Mohd Abul Hasan, and Saiful Islam. 2023. ‘Behavior of Geomaterial Composite Using Sugar Cane Bagasse Ash under Compressive and Flexural Loading’. *Frontiers in Materials* 10. doi: 10.3389/fmats.2023.1108717.
72. Nikhade, Harshal R., and B. Ram Rathan Lal. 2022. ‘Effect of Addition of Glass Fibre on Sugar Cane Bagasse Ash under Compressive Loading’. *Materials Today: Proceedings* 61:1109–14. doi: 10.1016/j.matpr.2021.11.063.
73. Nikhade, Harshal Ramesh, Anshul Ramesh Nikhade, Shital Telrandhe, Nitin K. Mandavgade, and Bhushan Yograj Hatwar. 2024. ‘Experimental Studies on Bagasse Ash Reinforced with GF and BF-Slag in Direction towards Sustainable Development’. *International Journal of Advances in Applied Sciences* 13(3):579. doi: 10.11591/ijaas.v13.i3.pp579-590.
74. Nwofor, T. C., and S. Sule. 2012. ‘Stability of Groundnut Shell Ash (GSA)/Ordinary Portland Cement (OPC) Concrete in Nigeria ’. *Advances in Applied Science Research* 3(4):2283–87.
75. Omar, Omar M., Ghada D. Abd Elhameed, Mohamed A. Sherif, and Hassan A. Mohamadien. 2012. ‘Influence of Limestone Waste as Partial Replacement Material for Sand and Marble Powder in Concrete Properties’. *HBRC Journal* 8(3):193–203. doi: 10.1016/j.hbrcj.2012.10.005.
76. Onyelowe, Ken C. 2012. ‘Cement Stabilized Akwuete Lateritic Soil and the Use of Bagasse Ash as Admixture’. *International Journal of Science and Engineering Investigations* .
77. Oriola, Folagbade, Moses, George. 2010. ‘Groundnut Shell Ash Stabilization of Black Cotton Soil ’.
78. Owaid, Haider Mohammed., Hamid. Roszilah, Sheikh Abdullah. Siti Rozaimah, and Tan Kofli. Noorhisham. 2018. ‘“Effects of Alum Sludge as Cement Partial Replacement on the Mechanical Properties of High-Performance Concrete,”’. *Green Technology and Entrepreneurship towards Sustainable Development,Proceedings of 3rd International Technical Conference 2012* 65–73.
79. Pandey, Shashank., Sinha. Debadityo, Sharma. Shikha. *A Report on Parliamentary Proceedings on Environmental Matters*.

80. Pappu, Asokan., Mohini. Saxena, Shyam R. Asolekar. 2007. 'Solid Wastes Generation in India and Their Recycling Potential in Building Materials'. *Building and Environment* 42(6):2311–20. doi: 10.1016/j.buildenv.2006.04.015.

81. Patel, S., and B. K. Pal. 2015. '"Current Status of an Industrial Waste: Red Mud an Overview,"'. *Int. J. Latest Technol. Eng. Manag. Appl. Sci.* 4:16.

82. Prasanth, P., Vidhya. B, Barathkumar. G, Sakthivel. R, Sivaraja. M, and Cet. N. S. N. 2019. '"Eco-Friendly Bricks (E-Bricks)," Vol. 6, No. 1, Pp. 30–34, 2019.' 6:30–34.

83. Prusty, Jnyanendra Kumar, Sanjaya Kumar Patro, and S. S. Basarkar. 2016. 'Concrete Using Agro-Waste as Fine Aggregate for Sustainable Built Environment – A Review'. *International Journal of Sustainable Built Environment* 5(2):312–33. doi: 10.1016/j.ijsbe.2016.06.003.

84. Radost Stanimirova, Nancy Harris, Katie Reytar, Ke Wang, and Melissa Barbanell. 2024. *Mining Is Increasingly Pushing into Critical Rainforests and Protected Areas* .

85. Rajasekar, A., K. Arunachalam, M. Kottaisamy, and V. Saraswathy. 2018. 'Durability Characteristics of Ultra High Strength Concrete with Treated Sugarcane Bagasse Ash'. *Construction and Building Materials* 171:350–56. doi: 10.1016/j.conbuildmat.2018.03.140.

86. Rajya Sabha. 2011. '"PARLIAMENT OF INDIA," Vol. 1932, 2011.'

87. Rattanashotinunt, Chaiyanunt, Pongsiri Thairit, Weerachart Tangchirapat, and Chai Jaturapitakkul. 2013. 'Use of Calcium Carbide Residue and Bagasse Ash Mixtures as a New Cementitious Material in Concrete'. *Materials & Design (1980-2015)* 46:106–11. doi: 10.1016/j.matdes.2012.10.028.

88. Raut, S. P., Rohant Sedmake, Sunil Dhunde, R. V. Ralegaonkar, and Sachin A. Mandavgane. 2012. 'Reuse of Recycle Paper Mill Waste in Energy Absorbing Light Weight Bricks'. *Construction and Building Materials* 27(1):247–51. doi: 10.1016/j.conbuildmat.2011.07.053.

89. Raut, S., R. Ralegaonkar, S. Mandavgane. 2013. 'Utilization of Recycle Paper Mill Residue and Rice Husk Ash in Production of Light Weight Bricks'. *Archives of Civil and Mechanical Engineering* 13(2):269–75. doi: 10.1016/j.acme.2012.12.006.

90. Razak, Abdul., and H. Wong. 2005. 'Strength Estimation Model for High-Strength Concrete Incorporating Metakaolin and Silica Fume'. *Cement and Concrete Research* 35(4):688–95. doi: 10.1016/j.cemconres.2004.05.040.

91. Rukzon, Sumrerng, and Prinya Chindaprasirt. 2009. 'An Experimental Investigation of the Carbonation of Blended Portland Cement Palm Oil Fuel Ash Mortar in an Indoor Environment'. *Indoor and Built Environment* 18(4):313–18. doi: 10.1177/1420326X09336554.

92. Rukzon, Sumrerng, and Prinya Chindaprasirt. 2012. 'Utilization of Bagasse Ash in High-Strength Concrete'. *Materials and Design* 34:45–50. doi: 10.1016/j.matdes.2011.07.045.

93. Rukzon, Sumrerng, and Prinya Chindaprasirt. 2013. 'Strength, Porosity, and Chloride Resistance of Mortar Using the Combination of Two Kinds of Pozzolanic Materials'. *International Journal of Minerals, Metallurgy, and Materials* 20(8):808–14. doi: 10.1007/s12613-013-0800-x.
94. Rukzon, Sumrerng, and Prinya Chindaprasirt. 2014. 'Use of Ternary Blend of Portland Cement and Two Pozzolans to Improve Durability of High-Strength Concrete'. *KSCE Journal of Civil Engineering* 18(6):1745–52. doi: 10.1007/s12205-014-0461-y.
95. Sada, BH., YD. Amartey, S. Bakoc. 2013. 'An Investigation Into the Use of Groundnut as Fine Aggregate Replacement'. *Nigerian Journal of Technology*.
96. Sahu, Vaishali., and V. Gayathri. 2014. 'The Use of Fly Ash and Lime Sludge as Partial Replacement of Cement in Mortar'. *International Journal of Engineering and Technology Innovation,* 4(1).
97. Salas, Daniel Andrés, Angel Diego Ramirez, Carlos Raúl Rodríguez, Daniel Marx Petroche, Andrea Jael Boero, and Jorge Duque-Rivera. 2016. 'Environmental Impacts, Life Cycle Assessment and Potential Improvement Measures for Cement Production: A Literature Review'. *Journal of Cleaner Production* 113:114–22. doi: 10.1016/j.jclepro.2015.11.078.
98. Saleh, Alaa N., Alyaa A. Attar, Omer K. Ahmed, and Sameer S. Mustafa. 2021. 'Improving the Thermal Insulation and Mechanical Properties of Concrete Using Nano-SiO2'. *Results in Engineering* 12:100303. doi: 10.1016/j.rineng.2021.100303.
99. Sarkar, Jayashree Dey., Amrita Kumar. Sarkar, Prithusayak. Mondal. 2023. 'Sustainable Manipulation of Agricultural Residues in Bioenergy Production'. Pp. 713–37 in *Handbook of Energy Management in Agriculture*. Singapore: Springer Nature Singapore.
100. Sata, Vanchai., Chai. Jaturapitakkul, Kraiwood. Kiattikomol. 2004. 'Utilization of Palm Oil Fuel Ash in High-Strength Concrete'. *Journal of Materials in Civil Engineering* 16(6):623–28. doi: 10.1061/(ASCE)0899-1561(2004)16:6(623).
101. Sathurshan, Mathavanayakam, Ishanka Yapa, Julian Thamboo, Thuraisingam Jeyakaran, Satheeskumar Navaratnam, Rafat Siddique, and Jingxuan Zhang. 2021. 'Untreated Rice Husk Ash Incorporated High Strength Self-Compacting Concrete: Properties and Environmental Impact Assessments'. *Environmental Challenges* 2:100015. doi: 10.1016/j.envc.2020.100015.
102. Sen, Mrinal, Arkaprava Roy, Khushboo Rani, Arpita Nalia, Tanmay Das, Priti Tigga, Debopam Rakshit, Kousik Atta, Saptarshi Mondal, Vishwanath, and Abinash Das. 2024. 'Crop Residue'. Pp. 167–201 in *Waste Management for Sustainable and Restored Agricultural Soil*. Elsevier.
103. Shakir, Alaa., Sivakumar. Naganathan, Kamal Nasharuddin. Mustapha. 2013. 'Properties of Bricks Made Using Fly Ash, Quarry Dust and Billet Scale'. *Construction and Building Materials* 41:131–38. doi: 10.1016/j.conbuildmat.2012.11.077.

104. Sharma, Rahul, and Rizwan A. Khan. 2017. 'Durability Assessment of Self Compacting Concrete Incorporating Copper Slag as Fine Aggregates'. *Construction and Building Materials* 155:617–29. doi: 10.1016/j.conbuildmat.2017.08.074.
105. Sharma, Reeta. 2017. 'Cement Industry; Trends Report by The Energy and Resources Institute',. *The Energy and Resources Institute* 17.
106. Sivakrishna, A., A. Adesina, P. O. Awoyera, and K. Rajesh Kumar. 2020. 'Green Concrete: A Review of Recent Developments'. *Materials Today: Proceedings* 27:54–58. doi: 10.1016/j.matpr.2019.08.202.
107. SSEF. 2013. 'Technology Compendium On Energy Saving Opportunities Cement Sector'.
108. Sua-iam, Gritsada, and Natt Makul. 2013. 'Use of Increasing Amounts of Bagasse Ash Waste to Produce Self-Compacting Concrete by Adding Limestone Powder Waste'. *Journal of Cleaner Production* 57:308–19. doi: 10.1016/j.jclepro.2013.06.009.
109. Surabhi, S. 2017. 'Fly Ash in India: Generation Vis-à-Vis Utilization and Global Perspective'. *Int J Appl Chem* .
110. Turgut, Paki. 2008. 'Limestone Dust and Glass Powder Wastes as New Brick Material'. *Materials and Structures/Materiaux et Constructions* 41(5):805–13. doi: 10.1617/s11527-007-9284-3.
111. Turgut, Paki, and Halil Murat Algin. 2007. 'Limestone Dust and Wood Sawdust as Brick Material'. *Building and Environment* 42(9):3399–3403. doi: 10.1016/j.buildenv.2006.08.012.
112. Urade, Shreyash, Monali Wagh, Jatin Lakhe, Tanay Tembhurne, and Parimal Dharne. 2024. 'Performance Analysis of Self Compacting Concrete – A Review'. P. 020016 in.
113. Varjani, Sunita, Anil V. Shah, Shaili Vyas, and Vijay Kumar Srivastava. 2021. 'Processes and Prospects on Valorizing Solid Waste for the Production of Valuable Products Employing Bio-Routes: A Systematic Review'. *Chemosphere* 282:130954. doi: 10.1016/j.chemosphere.2021.130954.
114. Vejmelková, Eva, Milena Pavlíková, Martin Keppert, Zbyněk Keršner, Pavla Rovnaníková, Michal Ondráček, Martin Sedlmajer, and Robert Černý. 2010. 'High Performance Concrete with Czech Metakaolin: Experimental Analysis of Strength, Toughness and Durability Characteristics'. *Construction and Building Materials* 24(8):1404–11. doi: 10.1016/j.conbuildmat.2010.01.017.
115. Venkata, Mohan., Chiranjeevi., Shikha. Dahiya, and K. Naresh. 2018. 'Waste Derived Bioeconomy in India: A Perspective'. *New Biotechnology* 40:60–69. doi: 10.1016/j.nbt.2017.06.006.
116. Vinai, R., A. Lawane, J. R. Minane, and A. Amadou. 2013. 'Coal Combustion Residues Valorisation: Research and Development on Compressed Brick Production'. *Construction and Building Materials* 40:1088–96. doi: 10.1016/j.conbuildmat.2012.11.096.
117. Wagh, Monali, and U. P. Waghe. 2022. 'Development of Self-Compacting Concrete Blended with Sugarcane Bagasse Ash'. *Materials Today: Proceedings* 60:1787–92. doi: 10.1016/j.matpr.2021.12.459.
118. Wagh, Monali, and U. P. Waghe. 2024. 'Effect of Bagasse Ash on Performance of Self Compacting Concrete'. P. 070015 in *AIP Conf. Proc. 3188*.

119. Wagh, Monali, Uday Waghe, Alireza Bahrami, Khalid Ansari, Yasin Onuralp Özkılıç, and Anshul Nikhade. 2024. ‘Experimental Investigation of Mechanical and Durability Performances of Self-Compacting Concrete Blended with Bagasse Ash, Metakaolin, and Glass Fiber’. *Frontiers in Materials* 11. doi: 10.3389/fmats.2024.1351554.
120. Wagh, Monali, Charuta Waghmare, Amit Gudadhe, Nisha Thakur, Salah J. Mohammed, Sameer Algburi, Hasan Sh. Majdi, and Khalid Ansari. 2025. ‘Predicting Compressive Strength of Sustainable Concrete Using Advanced AI Models: DLNN, RF, and MARS’. *Asian Journal of Civil Engineering*. doi: 10.1007/s42107-025-01278-y.
121. Waghe, Uday, Dhiraj Agrawal, Khalid Ansari, Monali Wagh, Mugahed Amran, Badr T. Alsulami, Hassan M. Maqbool, and Yaser Gamil. 2023. ‘Enhancing Eco-Concrete Performance through Synergistic Integration of Sugarcane, Metakaolin, and Crumb Rubber: Experimental Investigation and Response Surface Optimization’. *Journal of Engineering Research*. doi: 10.1016/j.jer.2023.09.009.
122. Waghmare, Charuta, Mohammad Gulfam Pathan, Syed Aamir Hussain, Tripti Gupta, Anshul Nikhade, Monali Wagh, and Khalid Ansari. 2025. ‘Machine Learning Based Prediction of Compressive Strength in Roller Compacted Concrete: A Comparative Study with PDP Analysis’. *Asian Journal of Civil Engineering*. doi: 10.1007/s42107-025-01310-1.
123. Wang, Chang-long, Wen Ni, Si-qi Zhang, Shuang Wang, Guo-sheng Gai, and Wei-kang Wang. 2016. ‘Preparation and Properties of Autoclaved Aerated Concrete Using Coal Gangue and Iron Ore Tailings’. *Construction and Building Materials* 104:109–15. doi: 10.1016/j.conbuildmat.2015.12.041.
124. Worrell, Ernst, Lynn Price, Nathan Martin, Chris Hendriks, and Leticia Ozawa Meida. 2001. ‘Annual Review of Environment and Resources’. *Annual Review of Energy and the Environment* 26(1):303–29. doi: 10.1146/annurev.energy.26.1.303.
125. Yang, Lin, Yun Yan, and Zhihua Hu. 2013. ‘Utilization of Phosphogypsum for the Preparation of Non-Autoclaved Aerated Concrete’. *Construction and Building Materials* 44:600–606. doi: 10.1016/j.conbuildmat.2013.03.070.
126. Yang, Lin., Yun. Yan, Zhihua. Hu, and . 2013. ‘Utilization of Phosphogypsum for the Preparation of Non-Autoclaved Aerated Concrete’. *Construction and Building Materials* 44:600–606. doi: 10.1016/j.conbuildmat.2013.03.070.
127. Zareei, Seyed Alireza., Farshad. Ameri, Nasrollah. Bahrami. 2018. ‘Microstructure, Strength, and Durability of Eco-Friendly Concretes Containing Sugarcane Bagasse Ash’. *Construction and Building Materials* 184:258–68. doi: 10.1016/j.conbuildmat.2018.06.153.
128. Zareei, Seyed Alireza, Farshad Ameri, Farzan Dorostkar, and Mojtaba Ahmadi. 2017. ‘Rice Husk Ash as a Partial Replacement of Cement in High Strength Concrete Containing Micro Silica: Evaluating Durability and Mechanical Properties’. *Case Studies in Construction Materials* 7:73–81. doi: 10.1016/j.cscm.2017.05.001.
129. Zhang, Duo. 2024. ‘CO2 Utilization for Concrete Production: Commercial Deployment and Pathways to Net-Zero Emissions’. *Science of The Total Environment* 931:172753. doi: 10.1016/j.scitotenv.2024.172753.

130. Zhao, Sujing., Junjiang. Fan, Wei. Sun. 2014. ‘Utilization of Iron Ore Tailings as Fine Aggregate in Ultra-High Performance Concrete’. *Construction and Building Materials* 50:540–48. doi: 10.1016/j.conbuildmat.2013.10.019.