Utilization of Industrial and Agricultural By-Products in Blended Cement Mortars – Creating an Effort of Circular Economy in Indian Cement Industry

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Outline of Presentation

- Introduction
- Research Objectives
- Materials and Methods
- Results and Discussion
- Conclusions

Introduction - Cement and CO_2

- The rapid increase in the concentration of CO_2 has fastened the process of global warming on this planet.

- Cement production has austere impacts as it accounts for 2.4% of the global CO_2 emissions and is therefore considered as a major source of global CO_2 (Marland et al. 1989)

- India is already the second-largest manufacturer of cement and it might produce 600 million tonnes of cement by 2025 and 1500 Million tonnes by 2050 ("Cement" 2011).

- Indian government has declared its target of dropping its greenhouse gas emission intensities by 20%-25% per ton of cement by 2030 compared to 2010 (CII 2010)

https://www.worldbank.org/en/news/feature/2016/10/03/ukraine-reaffirms-climate-commitments-to-tackle-ghg-emissions-from-industry

- Reaching deep de-carbonisation requires joint efforts by government agencies and privately owned cement sector.

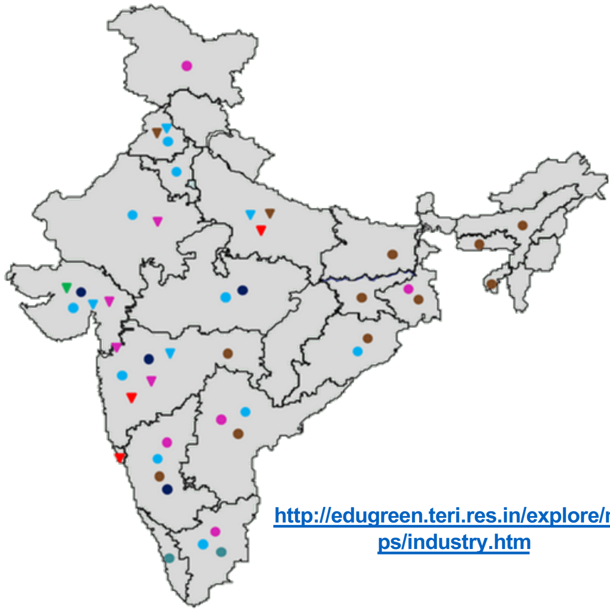
Introduction – Status of Cement Production in India

- Currently India has nearly 215 large cement production plants and is in list of top ten exporters by value and volume

- The Indian cement industry is targeting to condense its CO_2 emissions by around 0.35 Tons of CO_2 per ton of cement in 2050 (World Business Council for Sustainable Development 2018).

- Adoption of low-carbon technologies, in the Indian Cement industry like the implementation of Carbon Capture and Usage and Storage (CCUS) at the production of blended types of cement by end of 2050 could save up to 212 Million Tons CO_2 emissions (World Business Council for Sustainable Development 2018; WCA 2018).

- Since the last decade, the Indian cement industry has been incessantly promoting and increasing the share of blended cements.

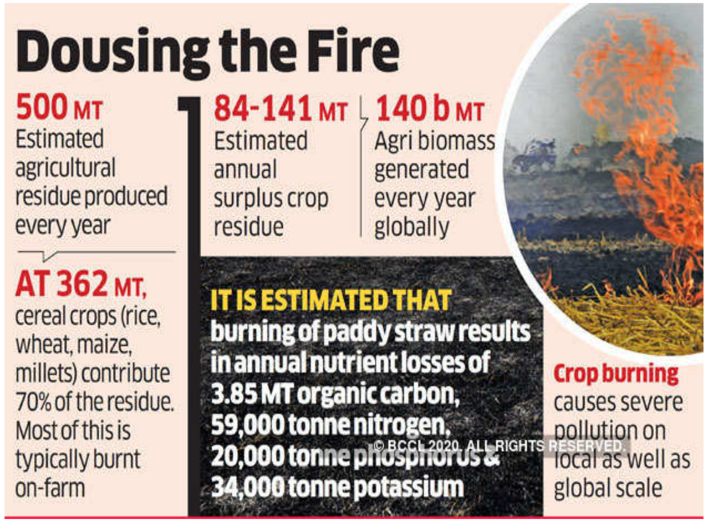


http://edugreen.teri.res.in/explore/maps/industry.htm

Scenario of Industrial by-products in India

- **In an estimation, 1340 MT of coal is required up to the year 2030 for fulfilling the electricity demands of India and this will lead to an annual generation of around 536 MT to 603MT of coal combustion products (CCP's) which are mainly fly ash and coal bottom ash.**
- **Out of this quantity, the fly ash consumption will be around 310 MT by 2030 while the remaining amount will be left as unused. Likewise, the generation of coal bottom ash will increase by three-four times to the current annual generation of 20 MT approximately (CEA New Delhi 2018).**
- **Currently, more than 64% out of a total generation of fly ash (in 2016-17) has been succefully utilized in various sectors while there are no reliable figures available for the effective use of coal bottom ash up to the end of the year 2018-19 (CEA New Delhi 2018).**

Scenario of Agricultural by-products in India



https://www.newsclick.in/why-do-farmers-burn-crop-residue-punjab Burning of Rice Residues in Punjab, India, Prior to the Wheat Season

- **<u>Burning the agricultural residues</u> generates 362 Million tonnes of ashes (rice husk ash, corncob ash, sugarcane bagasse ash) out of the total weight (500Mt) of residues (rice husk straw, corncob, and sugarcane bagasse).**

Research Objectives

- Fewer studies are available for industrial wastes and agricultural wastes based cements/mortars/concretes which highlights the reduction of CO_2 emissions from use of blending cements/mortars with industrial and agricultural wastes.

- To overcome the observed gap, this contribution focuses on the performance of the blended mortars based on industrial and agricultural. Herein, a generalized approach has been adopted for estimating CO_2 emissions reductions for blended mortars satisfying the parental need (i.e. compressive strength) regardless of any environmental constraints.

- The study evaluates the CO_2 intensities of different blended types of cement that use either industrial or agricultural wastes.

- This contribution sheds some light on the impact of industrial and agricultural wastes as clinker substitutes on the compressive strengths of blended mortars and estimates the resulting CO_2 reductions compared to conventional mortar mix made with Portland cement.

Materials and Properties

- Cement and Natural Fine Aggregates
- Portland cement of 43 grade
- Natural river-based sand with a maximum particle size of 4.75 mm (ASTM C136 / C136M - 19 2019; ASTM C128 - 15 2015).
- Industrial By-Products
  - Fly ash (FA)
  - Coal bottom ash (CBA)
  - Ground granulated blast furnace slag (GGBFS)

-Agricultural By-Products
-Sugarcane bagasse ash (SCBA)
-Rice husk ash (RHA)
-Corncob ash (CCA)

- Collectively, all types of ashes were sieved through 90-micron sieve

Chemical composition of Industrial and Agricultural Wastes in relative to PC

Compounds		Industrial Wastes*				Agricultural Wastes**		
	PC (%)	FA (%)	CBA (%)	CS (%)	GGBS (%)	RHA (%)	SCBA (%)	CCA (%)
SiO_2	20.1	56.50	57.76	39.41	34.06	93.15	61.59	66.38
Al_2O_3	6.80	17.70	21.58	2.84	18.8	0.21	5.92	7.48
Fe_2O_3	4.30	11	8.56	53.45	0.7	0.21	7.36	4.44
CaO	61.3	3.20	1.58	5.61	32.4	0.41	5.0	11.57
MgO	2.6	5.40	1.19	2.63	10.75	0.45	1.17	2.06

*Singh et al. 2020; Singh et al. 2019
** Verma et al. 2015; Mutua, Nyombi, and Mutuku 2016; Cheah and Ramli 2011; Michael 2016

Mix Details and Proportions

Details of blended mortar mixes containing different proportions of industrial and agricultural wastes

Designation	Mix proportions for industrial waste based mortars				Mix proportions for agricultural waste-based mortars									
	Kg/m^3 (cement to sand ratio of 1:2.75; W/C 0.40)				Kg/m^3 (cement to sand ratio of 1:2.75; w/c=0.45)									
	20% replacement				RHA at 5, 10, and 15% replacement				SCBA at 5, 10, and 15% replacement			CCA at 5, 10, and 15% replacement		
	C-0	CFA-20	CCBA-20	CGGBS-20	C-0	CRHA-5	CRHA-10	CRHA-15	CSCBA-5	CSCBA-10	CSCBA-15	CCCA-5	CCCA-10	CCCA-15
PC	575	460	460	460	563	535	507	479	535	507	479	535	507	479
Replacement content	0	87	96	104	0	18.5	37.5	56.5	18	36	54	19	38	57
Sand	1627	1627	1627	1627	1592	1592	1592	1592	1592	1592	1592	1592	1592	1592
Water	226	226	226	226	253	253	253	253	253	253	253	253	253	253
Superplasticizer	14.3	12.3	10.3	5.6	2.3	11	13.5	16	2.8	3.8	7.5	3.4	4.9	10.5

Experimental Program

- The evaluation of mechanical strength is the leading deciding factor for depicting the performance of any of the mortar irrespective of environmental constraints

- A generalized approach has been adopted for estimating CO_2 emissions reductions for blended mortars satisfying the parental need (compressive strength) regardless of any environmental exposures.

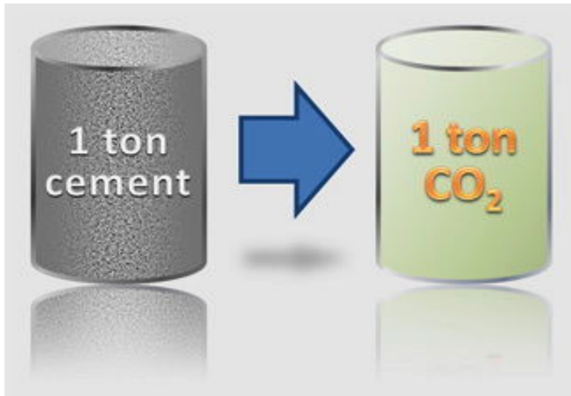
- Compressive strength tests

This test covers the determination of the compressive strength of cement mortars, using 50 mm x 50 mm x 50 mm cubical specimens following (ASTM C109/C109M 2016). Two curing periods of 7 days and 28 days were selected for performing the preceding tests.

- Calculations of CO_2 emissions

Considering all parameters (collection of raw material, processing, manufacturing and transportation) and for ease in calculations, the production of one ton of cement congruently produces one ton of CO_2 in environment.

- The current estimation has adopted a similar pattern for calculation of CO_2 emissions for the designed industrial and agricultural wastes-based mortar mixes.



https://www.us-concrete.com/low-co2-concrete

Results and Discussions

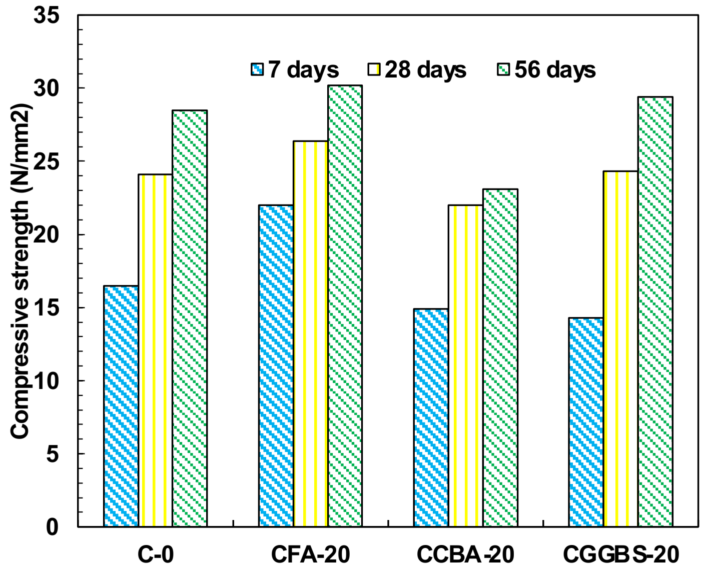
Compressive Strength Tests Results - Industrial wastes-based mortars

- The compressive strength of blended mortar mixes containing 20% of fly ash (CFA-20) has been observed to be higher (increase of an order of 5.5%, 2.4%, 2%) than that of the control masonry mix at all curing periods.

- The compressive strength has been decreased marginally up to 5% for the mortar mix CCBA-20 after a curing period of 56 days compared to that of control mortar mix C-0.

- The compressive strength values of the mortar mix CGGBS-20 are better than that of control mortar mix C-0 after a higher curing period (>28 days) despite initial reduction at 7 days of curing.

- However, the compressive strength of all mortar mixes has increased with the curing period due to pozzolanic behavior, refinement of pore structure, the formation of additional strength imparting hydration products such as C-S-H, etc.



Compressive strength tests result for blended mortars containing Industrial wastes

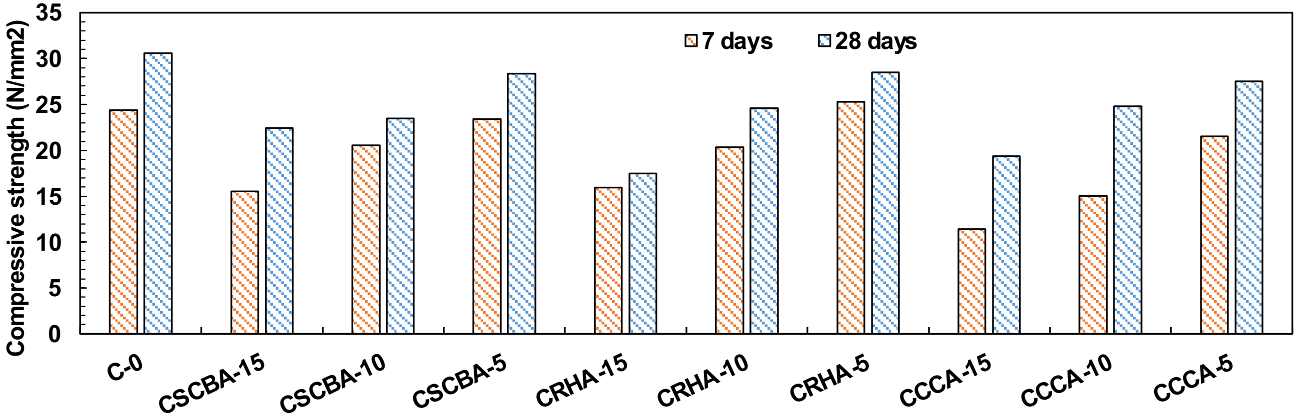
Results and Discussions

Compressive Strength Tests Results - Agricultural wastes-based mortars

- **The test results revealed that with an increase in percentage replacement of agricultural wastes (rice husk ash/sugarcane bagasse ash/corncob ash) the compressive strength of masonry mortars has been decreased compared to control mortar mix (up to 40% decrease).**

- **Hence, the sequence has been suggested for the blended mortars based on the compressive strength test results: C0>CRHA>CSCBA>CCCA.**

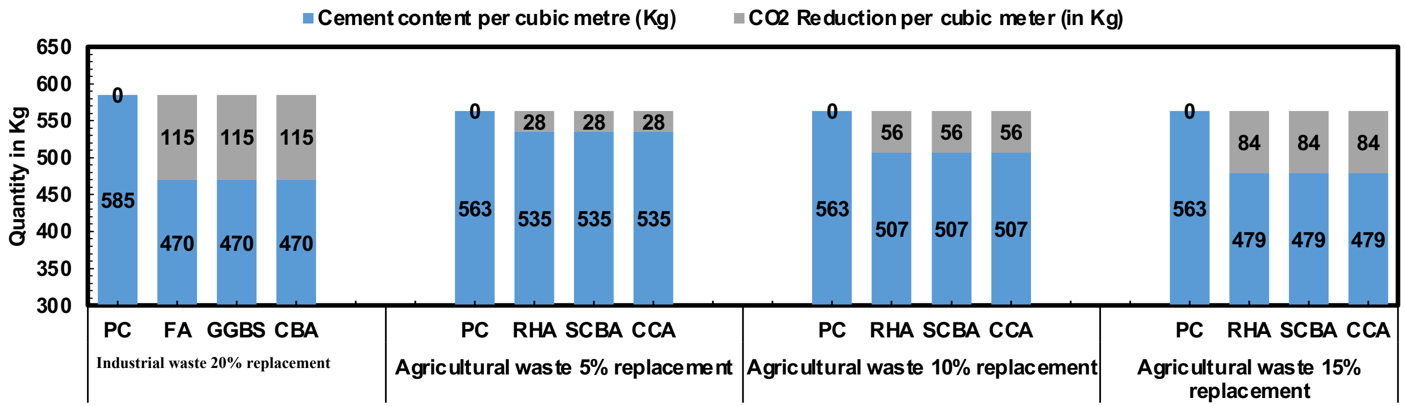
- **Rice husk ash-based mixes results in the best performance in terms of compressive strength tests results as compared to other agricultural wastes.**



Compressive strength tests result for blended mortars containing Agricultural waste

Results and Discussions
CO_2 Emissions Reductions

- Presuming that for the manufacturing of every one cubic meter of non-conventional mortar/concrete, it saves the same amount of CO_2 emissions.
- For example, considering the case of industrial wastes-based mortar mixes wherein 20% of reduction in weight of Portland cement (as alteration with fly ash, bottom ash, and blast furnace slag) cuts the amount of cement by 115 kg per cubic meter.
- In other words, production of Portland cement along with the utilization of fly ash, coal bottom ash, and blast furnace slag (say 80% of Portland cement and 20% of fly ash/bottom ash/blast furnace slag) reduces the production of CO_2 by at least 20%.
- Likewise, the use of agricultural wastes like rice husk ash, bagasse ash, and corn cob ash would probably reduce the production of CO_2 in the environment up to the maximum by 15% during the manufacturing process of agricultural bi-products based mortars.



Results and Discussions
CO_2 Emissions Reductions

- As per projection 1500MT* of cement will be produced in India by end of year 2050.

- Utilization of alternatives with either of industrial/agricultural by-products (minimum 15% and maximum 40% by weight) would assuredly reduce the production of cement and subsequently save 225 MT – 600 MT of CO_2 assuming the reduction potential of 1 t of CO_2 per ton of Portland cement production.

- The analysis results in saving of overall cost of mortars made with alternative material compared to conventional mortars.

- From the calculations and comparison with conventional mortar mix, it was observed that merely 10% of replacement of Portland cement results in satisfactory economic saving i.e, 4% less to that of conventional mortars while the variation moves up from 4% to 6% for 20% replacement levels.

- *Assuming 1 t CO_2 per 1 t of Portland Cements, the substitution of 15-40% of the expected 1500 Mt Portland Cement by 2050 would lead to CO_2 reductions of 225-600 Mt CO_2 (15%*1500 = 225; 40%*1500 = 600)

Results and Discussions

- The performance of any mortar mix towards external forces can be judged using compressive strength values.
- The compressive strength values cannot predict the long-term performance of blended mortars. Thus, durability play a vital role in deciding the overall satisfactory performance.
- The current study promotes the idea of investigating the durability aspects of blended mortars with industrial and agricultural wastes for the real application in the construction industry.
- One of the key challenges of the current applicability of blended mortars is the non-availability of the standard guidelines which depict the specific replacement(s) of clinkers with aforesaid substitutes.
- Another challenge is the availability of these industrial and agricultural wastes in the vicinity of the required construction sites (long-distance transportation).
- Despite neglecting the CO_2 emissions during transportation, the current study offers encouraging results for practice of the aforesaid methodology.

Conclusions

- Supplementing the cement with pozzolans enhances the binding properties and is generally considered a decent option for achieving the desired quality and toughness.
- The use of industrial and agricultural wastes in cement is not only crucial for CO_2 reduction in cement production but also it is important to limit the environmental impacts of industrial production and agriculture.
- Based on the compressive strength results, the current study suggests the use of such blended mortars for minor engineering works where the mechanical strength is not the deciding criteria for the satisfactory performance of the structure.

https://www.pixtastock.com/illustration/518312

- The Indian cement and mortar industry has moved from conventional practice towards blending options for the manufacturing of non-conventional cements and mortars.

Conclusions

- **Blended cement made with industrial/agricultural by-products can successfully replace limestone clinkers.**
- **Based on the experimental results, the adoption of blended cement and mortars could probably contribute to a drop the CO_2 emissions in cement production by 15%-20%.**
- **Being the world's second-largest cement manufacturer, the Indian Government has been continuously hovering and endorsing the sustainable options for the existing and upcoming cement and mortar industry through various initiatives.**
- **Several goals have been set for increasing the utilization of industrial and agricultural by-products in blended cement mortars and curtailing the CO_2 emissions generated particularly from the Indian cement industry.**
- **The projected approach, however, is not sufficient to reach future CO_2 emissions reductions targets up to 2050.**

Thank You for your Kind Attention