Journal of Materials and Engineering Structures

Research Paper

A Comparative Study of Life Cycle Assessment for Sustainable Concrete Mixes

Sunita Kumari [a,*], Rinku Walia [b]

[a] *Department of Civil Engineering, Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Haryana, 131039, India*

[b] *Department of Civil Engineering, I.K. Gujral Punjab Technical University Hoshiarpur Campus, Hoshiarpur 146001, India*

ARTICLE INFO

Article history :

Received : 15 September 2021

Revised : 26 June 2022

Accepted : 29 June 2022

Keywords:

Rice husk

Coal

Global Warming

Concrete

LCA

ABSTRACT

Developing countries need infrastructure for development thereby increasing the demand for concrete. The production of raw materials, manufacturing of concrete, and transportation process emit a large amount of greenhouse gases and particulate matters in the atmosphere which has increased energy consumption as well as global warming potential (GWP), acidification potential (AP), and eutrophication potential (EP) impact. In the present study, a comparative Life Cycle Assessment (LCA) is performed on five types of concrete mix and two fuels like coal and agricultural waste.

The controlled mixed concrete CM-O was prepared by 100% OPC and the other four types of agricultural waste concrete were prepared by partial replacement of cement with agricultural waste ash in one cubic meter concrete. Optimum replacement level of cement was obtained based on 28 days compressive strength of concrete. LCA was evaluated by using CML methodologies on Microsoft excel for Cradle - to - gate boundary system. Similarly, environmental load due to the burning of coal and agricultural waste was evaluated. The results indicated that agricultural waste concrete has the potential to decrease the environmental load of the manufacturing of concrete. The environmental load is 1701.985 kwh, 501.051kg, 4.327kg and 466.091g for energy consumption, GWP, AP, and EP respectively for one cubic meter of controlled mix concrete. The results indicated that Rice husk ash at a replacement level of 12.5% of cement has 4.3%, 10%, 7.1%, and 3.7% lesser environmental impact for energy, GWP, AP, and EP respectively when compared with controlled mixed concrete. Further, the use of agricultural waste as fuel emits very less amounts of greenhouse gases mainly CO2, SO2, and NOx, and has an overall less impact on environmental compared to coal. This study would encourage the industrialists to make decisions about the use of agricultural waste as supplementary cementitious materials (SCMs) and fuel.

* *Corresponding author. Tel.: +00000000000.*
E-mail address: waliarinks@gmail.com

e-ISSN: 2170-127X,

RESEARCH REVIEW of Sciences and Technologies

1 Introduction

According to Intergovernmental Panel 2007, Climate Change is variation in climate over a decade due to natural phenomena or anthropogenic activities. In 2005, the concentration of CO_2 was 379 PPM which raised the temperature to 0.74ºC and is estimated that the earth would warm by 3ºC by 2100. Natural disasters such as drought, floods, cyclones, etc. are influenced by small variations in temperature. In India, the rise in temperature resulted in the summer flow of Ganga and Brahmaputra, impact the agriculture production rate, the monsoon pattern, and the rise in sea levels. The presence of water vapours, methane, NOx, and CO_2, CFCs contribute to global warming. CO_2 is a major greenhouse gas, produced global warming. Cement production is one of the major sources of CO_2 that uses an enormous amount of limestone, clay, and iron ore as raw materials and petroleum coke natural gases as fuel. The calcination of raw materials emits annually 1.8Gt carbon dioxide and 2.37 Gt air pollutants i.e. sulphur dioxide, volatile organic compound, hydrogen fluoride, hydrogen chloride, carbon monoxide, and ammonia. Manufacturing and transportation of concrete by a vehicle also emits CO_2 in the atmosphere. These values may vary as per the manufacturing process and distance of mining as well as the types of vehicles [1, 2].

In 2019, global cement production was 4050 million metric tons while in India it was 86.6 million metric tons. Therefore, concrete is the most widely used material for construction and its environmental impact and problems are taking very seriously. Life Cycle Assessment (LCA) can be used as a tool to assess the environmental impact of concrete up to the construction and demolition process. Further, it provides the cement manufacturer and engineers to reduce the environmental impact by substituting the cementitious materials in concrete. According to ISO 14040, LCA has five elements: Selection of impact categories, Classification of element from inventory, Characterisation of impact category as per environmental model, Normalisation for relative magnitude, and weighing ranking according to their severity. Out of these five first three are the most important elements of LCA [3].

1.1 Life Cycle Assessment

Life Cycle assessment provides support to decide the best option of the manufacturing process and raw materials by comparing the two products or processes with their environmental impact. It is an instrument that quantifies the environmental impact [4] This method is adopted by many researchers to evaluate and compare the environmental impact of the production of cement and concrete. Morsali 2016 has studied using Simapro and LCA that the production of Portland cement affects the human health, deplete resources, degrade air and water due to emission of CO2, NOx, SOx, CH4, Cu, Ch and Zn in the atmosphere [5]. Huntizinger, 2009 indicated that cement blended with cement kiln dust can save a 5% environmental impact over the conventional method of manufacturing [6]. Cankaya et al., 2019 compared the production of cement with traditional raw material and fuel with alternate raw materials and fuel using SimaPro 8.0.4 software and concluded that overall environmental impact can reduce upto12% and 3% by the use of alternative clinkers and fuel [2]. Colangelo et al., 2018 performed LCA and found that the recycled aggregate of blast furnace slag in concrete has a minimum negative impact on the environment [7]. Asadollahfardi et al. 2019, suggested that OPC is the most economical and environmentally friendly material in concrete at the production stage as compared to micro silica, nano-silica, and micro-nano bubble concrete [8]. OPC has 56%, 17%, and 38% low burden to the environment, and is assessed on SimaPro 8.1 software. Mohammadi et al has investigated, using cradle – to – gate system with CML 2001 methodology that Global Warming Potential ranged from 209 kg – 521 kg CO2eq., acidification from 0.670 kg – 1.609kg SO2-eq. and eutrophication from 0.108kg – 0.259kg PO4 – eq. per cubic meter for M20 MPa benchmark concrete in Australia [9]. Similarly, Soleimani et al. 2017 concluded that sludge-based bio concrete used as binder and aggregates are more eco-friendly than conventional concrete [10]. Pesta et al. 2019, concluded that the Climate Change category (GWP) of recycled aggregates concrete and brick aggregates concrete has an environmental impact of 1,51Kg CO2 eq. and 1,18Kg CO2eq. respectively for the production of 1m3 concrete [11]. Statistical methods can be used to minimize the error and improvement reliability on the available data [12]. According to Onn et al. (2019) investigated by LCA, the use of GGBFS in concrete shows good performance for compressive strength and carbon footprint with increased replacement levels but it would be better up to 50% for cost consideration [13].

According to Intergovernmental Panel on Climate Change (IIPCC), SCM can be used to reduce carbon dioxide emissions like the substitution of by-product or waste materials such as fly ash and rice husk ash, etc. [14]. Agricultural ashes such as rice husk ash (RHA), Corncob Ash (CCA), Sunflower seed husk ash (SSA) and groundnut husk ash (GHA) have been used as supplementary cementitious materials (SCMs) in concrete. Rice husk ash is used as SCM in concrete due to its pozzolanic properties when in amorphous condition. It acts as mineral and pozzolanic admixture of cement in partially crystalline or fully crystalline condition [15, 16]. Cement replaced by up to 20% with RHA can reduce 65% of environmental impact and global warming potential more than 30% was computed with LCA [17]. 284kg CO_2eq/m^3 GWP produced by fly ash and Rice husk ash blended concrete as compared to 544kg CO_2eq/m^3 of conventional concrete was calculated by LCA [18] Various researcher has worked over the replacement of cement with sunflower seed husk, corn cob ash , Groundnut husk ash found that they enhance the compressive strength of concrete [19-21].

Sometimes these agricultural wastes can be used as fuel in industries instead of coal. Corncob and de-oiled sunflower seed husk as solid biomass used as fuel for boilers in small industries [22, 23]. Rice husk and groundnut husk are used as fuel in the pulping processing paper industry [24].

In the present study, life cycle assessment is used to compare the environmental impact of conventional concrete and fuel with alternated concrete and fuel. Where conventional concrete is controlled mixed concrete compared with agricultural concrete and coal with agricultural waste. The aim of this study is to the determination of the LCA of one cubic meter concrete mix production, for 'Cradle – to – Gate' boundary system in terms of energy, global warming, acidification and eutrophication potential. On the basis of this a comparative LCA study of ashes can be done to find out their environment impact.

2 Methodology

As per International Organisation for Standards ISO 14040 following stages are included in LCA for the research work: Establishment of scope and boundaries, Inventories of raw materials, Analysis of Environmental Impact using inventory, Interpretation of results, and suggestion.

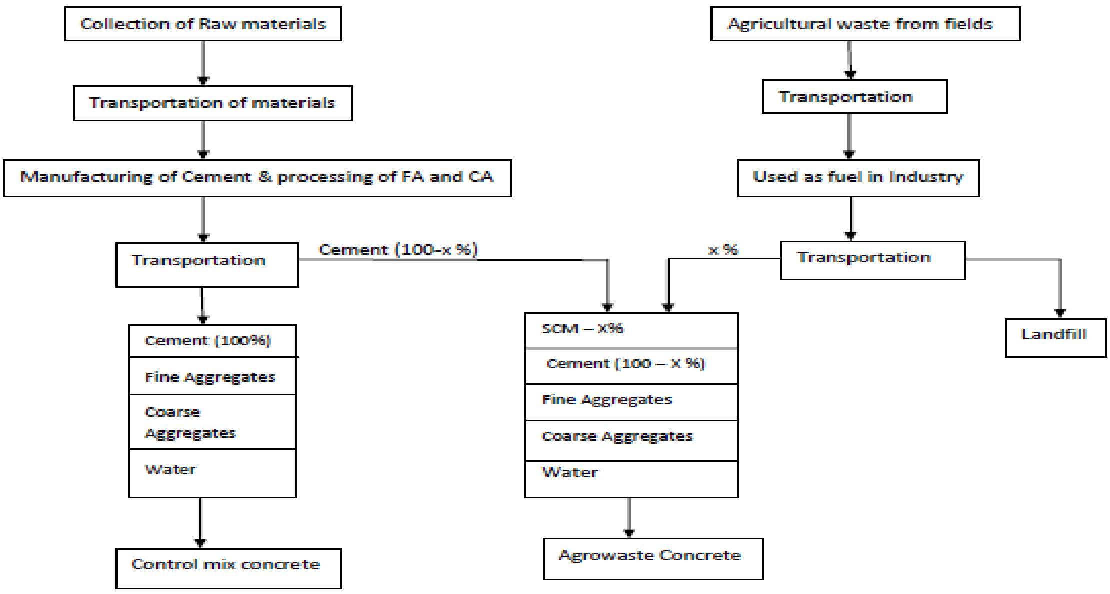
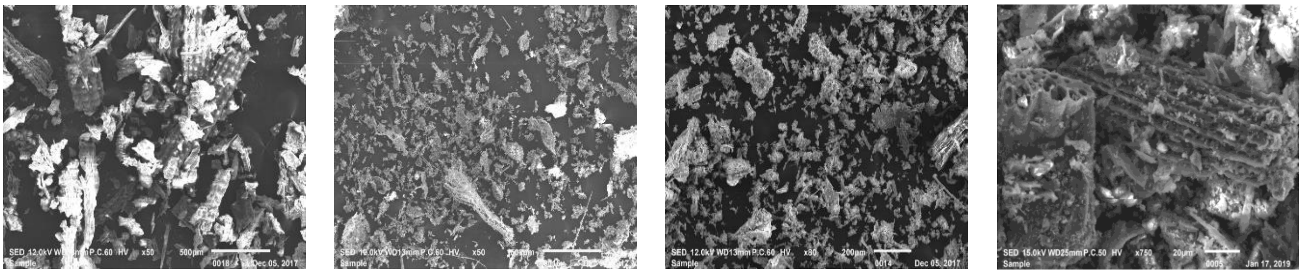


Fig. 1 – Boundary System 'Cradle – to – Gate'

The scope is the LCA of production of 1m^3 of M20 grade controlled mixed concrete and agricultural waste concrete, prepared by ordinary Portland cement of 43 grade. Agricultural waste concrete is prepared by partial replacement of cement with agricultural waste such as RHA (Rice husk ash), CCA (Corncob ash), GHA (Groundnut husk ash), and SSA (Sunflower seed husk ash). The optimum replacement is obtained based on 28 days compressive strength of cubes of concrete. 'Cradle – to – gate' boundary system is considered, which includes extraction of raw materials, production, and transportation of raw materials to the construction site and manufacturing of concrete as shown in figure 1. For comparing LCA of concrete the necessary condition is that all types of concrete should have the same characteristics. "This means all types of concrete should have the same strength, mechanical properties workability, and durability." The mix proportion of all the concrete is determined so that all have the same compressive strength and workability. End – of –life scenario was not considered. Only air emission during the manufacturing of cement, fine aggregates, coarse aggregates, and concrete were considered for controlled mixed concrete.

2.1 Raw materials

Table 1 shows the properties of raw material used to design controlled mixed and agricultural waste concrete with various supplementary cementitious materials combinations such as rice husk ash (CM-R), groundnut husk ash (CM-G), corncob ash (CM-C) and sunflower seed husk ash (CM-S). The SEM images of all the agricultural waste used are shown in figure2. All concrete designed are optimized based on 28 days compressive strength with various agricultural ashes having cementitious properties. The optimum level of replacement RHA, CCA, GHA, and SSA for are found to be 12.5%, 7.5%, 10%, and 10% respectively. It improves the sustainability and environmental impacts that are related to concrete manufacturing industries. Raw materials of the five concrete: CM-0 (100% OPC), CM-R (87.5% OPC &12.5% RHA), CM-G (90% OPC & 10% GHA), CM-C (92.5% OPC & 7.5% CCA) and CM-S (90% OPC & 10% SSA) and 28 days compressive strength are shown in table 2. A comparative studied of the cradle – to gate Life Cycle Assessment is performed to help the industrialist can choose the best option from concrete mix designs with SCMs. CML methodology is selected and its evaluation is performed on Microsoft excel using all the life cycle inventories.



RHA **GHA** **CCA** **SSA**

Fig. 2 – SEM image of Raw material used as a substitute for cement in concrete

Table 1 – Raw materials used

Material	Type	Specific Gravity	Finesse Modulus
Cement	OPC 43 grade	3.16	227 (m^2/kg)
Fine Aggregates	River Sand	2.703	2.64
Coarse Aggregates	Crushed Stone	2.690	6.87
GHA	Laboratory Prepared	1.54	-
CCA	Laboratory Prepared	1.937	-
SSA	Industry	1.17	-
RHA	Industry	1.78	-

Table 2 – Quantity of raw materials of 1m^3 concrete mix proportion

Material	Cement (kg)	% ash	Ash (kg)	Fine Aggregates (kg)	Coarse Aggregates (kg)	Total (kg)	28 days compressive strength (N/mm^2)
CM-0	348.33	--	--	695.71	1190.32	2234.36	30.52
CM-R	304.789	12.5	43.541	681.81	1166.99	2197.12	27.01
CM-C	322.205	7.5	26.125	682.18	1167.16	2197.66	26.73
CM-G	313.497	10	34.833	683.77	1169.88	2201.98	26.8
CM-S	313.497	10	34.833	685.76	1173.29	2207.38	26.72

2.2 Life cycle Inventories for Energy consumption and Air emission

Energy consumption and air emission by the cement, fine aggregates, coarse aggregates, agricultural waste ashes, and one cubic meter of concrete are shown in table 3 and table 4.

Cement and Concrete: During the extraction of raw material, grinding and heating process energy is required in the form of thermal, electricity, and coal firms. For the mixing of raw materials diesel is used for mixer to manufacture concrete. All the data used for energy and air emission is collected from the EIA manual guidelines for the cement industry 2019 in India.

Table 3 – Energy consumption (kwh/kg) during the production of raw material

Raw Material	Cement	C A	F A	T (50km)	1m^3 Concrete
Thermal	0.84	-	-	-	-
Coal	0.03	-	-	-	-
Natural gas	-	-	-	10	-
Diesel	-	0.00410	0.00410	-	5.575
Electricity	0.82	-	-	-	-

Table 4 – Air emission (g/kg) during the production of raw material [25, 26]

Air Emission	Cement	C A	F A	T (50km)	1m^3 Concrete	RHA	GHA	SSA	CCA
NOx	6.2	0.015579	0.015579	13.84	13.2244	0.45	1.75	1.7	1.7
SO_2	4.9	0.005447	0.005447	--	98.7536	2.4	2.62	0.5	0.5
CH_4	--	0.001296	0.001296	--	0.43329	-	-	-	-
CO_2	1150	1.377926	1.377926	837.5	5698.21	1.46	1.75	0	0
N_2O	--	0.000055	0.000055	--	0.0291	-	-	-	-

Table 5 – Environment Impact of Control Mix Concrete

Impact Category	Energy (Kwh/Kg)	GWP (g eq. CO_2)	AP (g eq. SO_2)	EP (g eq. PO_4)
Cement	588.677	400579.500	3121.036	262.640
C A	4.880	1660.467	19.464	2.410
F A	2.852	970.498	11.376	1.409
Concrete	5.575	5716.330	110.369	1.719
Transport	1100	92125.0	1065.680	197.912
Total	1701.985	501051.796	4327.926	466.091

Coarse and Fine Aggregates: For the extraction, cleaning and processing of aggregates diesel is required. During these activities air emission take place. The data is reciprocated here as all the activities are the same and the quality of aggregates does not change with geographical conditions (Marinkovic et al. 2013) [25].

Agricultural waste: Rice Husk, groundnut husk, corncob, and sunflower seed husk do not require energy. This waste produced energy when used as fuel in industries. Ashes used in concrete are neutral for energy consumption. Air emission of agricultural waste is collected from India.

Transportation: Transportation emission of raw materials depends upon the distance, type of vehicle, and fuel consumption. For this purpose, a diesel vehicle of 3 ton carrying capacity was used. The total distance travelled by the vehicle was assumed to be 50 km.

The equivalence factors of 1kg CH_4 and N_2O are 21kg eq.CO_2 and 310kg eq. CO_2 respectively for GWP, 1kg NO_2 is 0.70kg eq. SO_2 for AP and 1kg NOx is 0.13kh eq. PO_4 (Marinkovic et al. 2013) [25].

3 Results and Discussion

3.1 Life cycle impact assessment

LCIA is calculated by CML methodology to assess the environmental impact of manufacturing concrete and various agricultural concrete in the present study. It is based on midpoint and damaged -oriented approaches of LCA. It includes energy, GWP, AP, and EP. Evaluated cumulative energy consumption, air emission and impact characteristics for the manufacturing and transportation of raw material of one cubic meter of concrete are shown in Figures 3 and 4.

3.2 Controlled mixed concrete (CM-0)

The result in figure 3 and Table 5 indicated that the controlled mixed concrete has the highest environmental load of energy (1701.985 kwh), GWP (501.051 kg), AP (4327.926 g), and EP (466.091g) for $1m^3$ of concrete. The maximum energy consumed by transportation was found to be 65% due to transportation of raw materials to the processing unit, after that at a construction site 34% of total energy is used in cement production for extraction, grinding and heating purpose.

GWP (92%) is largest for cement production due to the emission of 1.15kg/kg of CO_2 during calcination of limestone and fossil used as fuel for the manufacturing of cement. Transportation emits a higher amount of CO_2during the combustion of fuel. AP and EP are 28% of total acidification potential and 40% of total eutrophication potential for cement was due to air emission of a large amount of greenhouse gases.

3.3 Agricultural waste concrete (CM-R, CM-C, CM-G and CM-S)

From results shown in Figures 3 & 4, it is found RHA added concrete (CM-R) has the least environment load in all phases of concrete. It has 4.3%, 10%, 7.1%, and 3.7% lesser environmental impact for energy, GWP, AP, and EP respectively when compared with controlled mixed concrete due to the highest replacement level (12.5%) of cement in concrete.

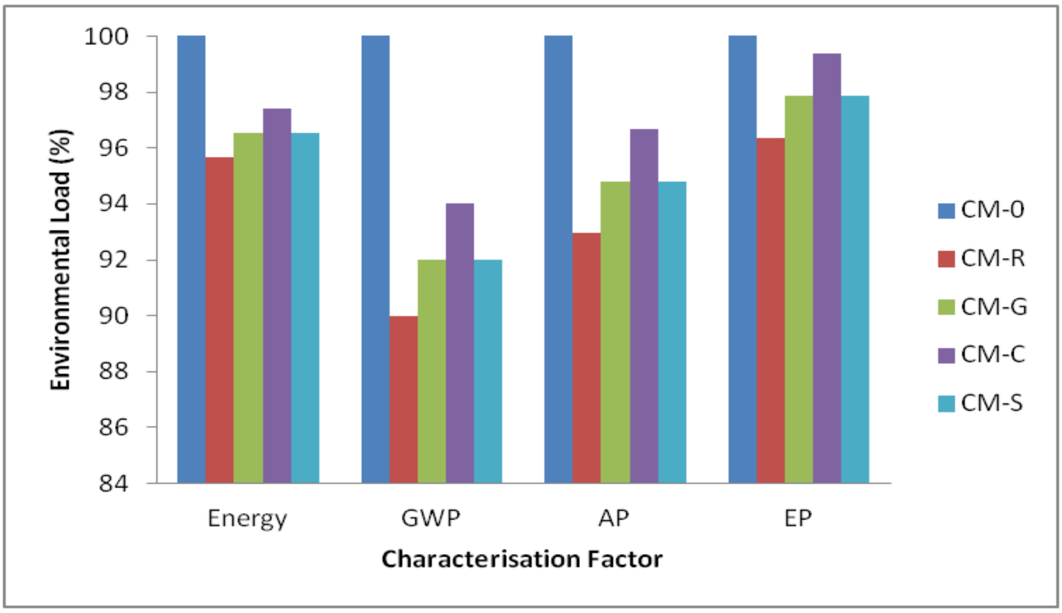


Fig. 3 – An environmental load of various concrete

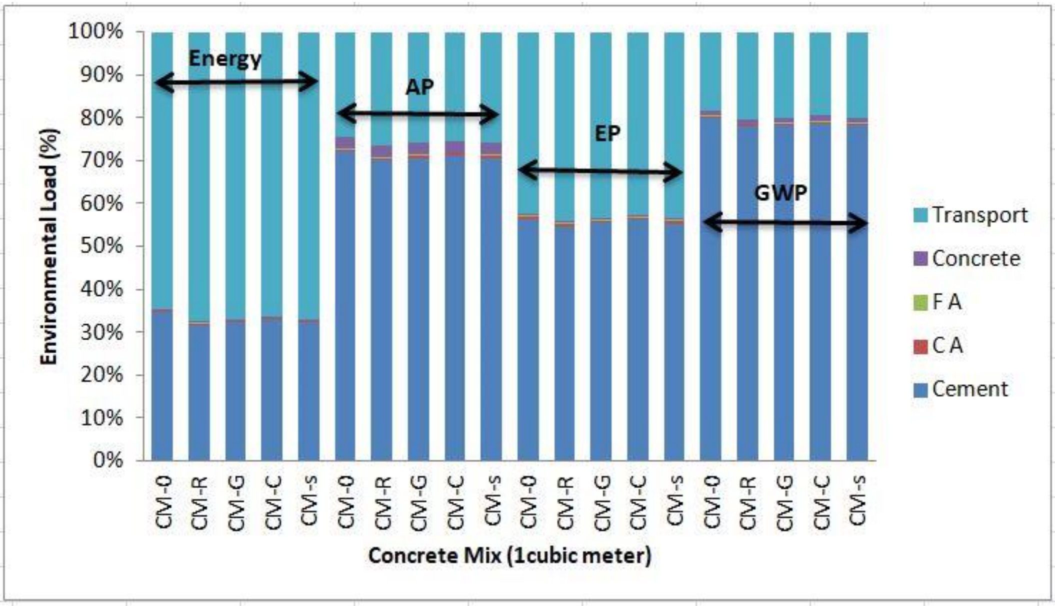
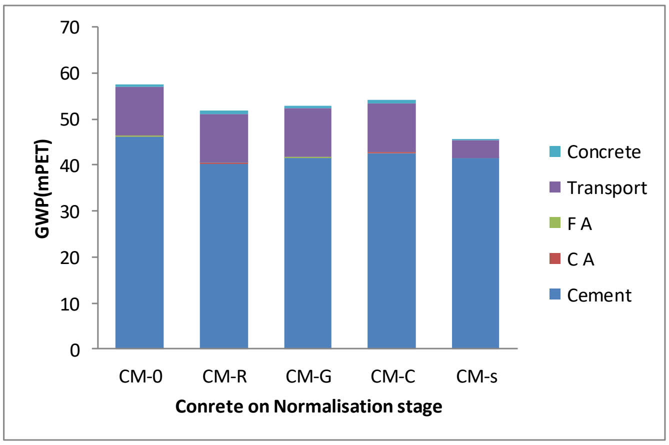
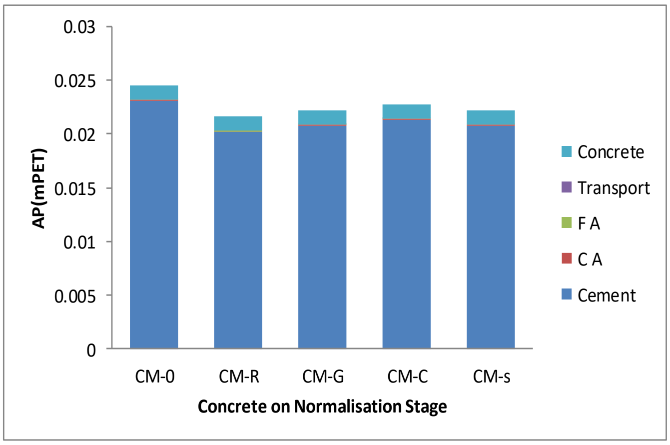


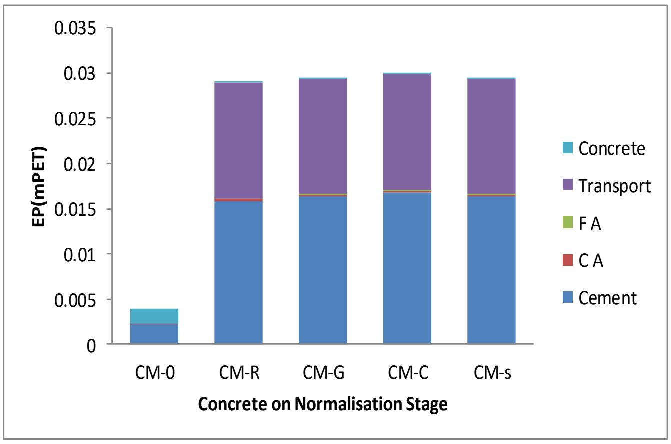
Fig. 4 – Environmental Impacts of various concrete at various phases



(a)



(b)



(c)

Fig. 5 – (a), (b) & (c): Normalisation of concrete at various characterisation phases

GHA and SSA (CM-G & CM-S) share an equal amount of environmental load at each phase. It has 3.5%, 8%, 5.2%, and 2.1 % lesser environmental impact for energy, GWP, AP and EP, when compared with controlled mixed concrete. It may be the same replacement level (10%)of cement in concrete. CCA (CM-C) has 2.6%, 6%, 3.3%, and 0.6 % lesser environmental impact for energy, GWP, AP, and EP when compared with controlled mixed concrete due to a 7.5% replacement level of cement.

It is interpreted that controlled mixed concrete has the maximum percentage of environmental load in all categories. Production of cement has the highest impact in GWP, AP and EP categories except energy, where transportation of raw materials has consumed maximum energy. The contribution of fine and coarse aggregates has the least environmental impact.

Normalisation stages are shown in figure5 (a), (b), and (C). The purpose of this interpretation is to find out the major phase with the greatest impact from a sequence of processes of cement utilisation and production. Because the process between one unit and another is different, there will be differences in the value of the impact produced in each cement production process. The impact value is influenced by input data at the LCI stage. Input data are in the form of the type of raw material used, type of fuel, type of energy, and emissions produced along with the quantity. The objective of normalisation is unit equalisation of impact assessment of various characterization factors, which can be compared with each other at any stage. Normalisation impact can be calculated by dividing the value of characterization impact and normalization factor. Normalisation factors are 8.7t/capita/yr., 1.22kg/capita/yr. and 1.27kg/capita/yr. for GWP, EP, and AP.

Figure 5(a) & (b) shows the normalization factor of GWP and AP for 1 m^3 various types of concrete which are similar to figure 3. GWP impact is higher due to concrete production and transportation. While for AP transportation emission has the least value because diesel used as fuel in vehicle emits less amount of SO_2. 5(C) shows the EP of concretes that controlled mixed concrete has the least eutrophication potential because all the other concretes have agricultural waste ash causing emission of nitrogen in the atmosphere.

4 Life Cycle Assessment of fuel

According to Coal India Limited, wet process, semi-dry process and dry process are the clinker manufacturing process of cement. G-4 to G-9 grade coal is available to use as fuel in the cement industry. In this study, the LCA of fuel is evaluated. For this purpose, two types of fuel are used (i) Coal (ii) use of biomass such as rice husk, groundnut husk, corncob, and sunflower seed husk.

During the combustion of coal as fuel emits CO, NOx, SO_2, and CO_2 range from 0.35g/kg, 5.24g/kg, 15.77g/kg and 1769g/kg respectively. It is estimated that 200kg of coal is required as fuel for the production of 350kg of cement; it is approximately equivalent to cement used in the present study for manufacturing of 1m^3 of concrete. The air emission during the burning of 200 kg fuel is given in table 6. The major concentration of emission NOx, SO_2, and CO_2 are considered.

Table 6 – Environmental impact of Coal and agricultural waste as fuel

Fuel	AP (g)	EP(g)	GWP(g)
Coal	6041.196	47.684	10232667
Rice Husk	543	11.7	292
Corncob	338	44.2	0
Groundnut husk	769	45.5	350
Sunflower S Husk	338	44.2	0

The result shows that the air emission is highest in terms of GWP for coal. Further, GWP is zero for corncob and sunflower seed husk compared to rice husk and groundnut husk. This is due to the zero-emission of carbon dioxide during the burning of waste [22, 26]. The results revealed that agricultural waste as fuel can be a better option in the industry.

5 Conclusions

This study indicated that substantial “environment friendly’ concrete can be manufactured. The results indicated that the use of agricultural waste ashes as SCMs in concrete mix design and as fuel in industries can reduce the overall greenhouse gases like CO_2, NOx, and SO_2 and therefore significantly enhance sustainability. Life Cycle Assessment of concrete and fuel helps the designers and industrialists to make decisions about the use of agricultural waste as SCMs and fuel in cement industries. The following conclusions can be drawn from studies:

The study indicated that the use of agricultural waste ashes such as RHA, GHA, CCA, and SSA are the alternatives of cement, improve the sustainability of concrete without losing the compressive strength. The optimum level of replacement RHA, CCA, GHA, and SSA were found to be 12.5%, 7.5%, 10%, and 10% respectively. The optimum replacement levels of agricultural waste ash in the mix design of concrete can enhance the properties and sustainability of concrete. The result indicated that the controlled mixed concrete has the highest environmental load of energy (1701.985 kwh), GWP (501.051 kg), AP (4327.926 g), and EP (466.091g) for $1m^3$ of concrete. The cement production accounts for 92 % GWP due to the emission of 1.15kg/kg of CO_2 during calcination of limestone and fossil used as fuel for the manufacturing of cement. Rice husk ash concrete at replacement level of 12.5% is found to be environmentally friendly. The use of these ashes in concrete can decreases the carbon dioxide emission and subsequently reduced the environmental impact. It would be advantageous in terms of waste disposal. Otherwise, it would be disposed of as waste in the landfill area and pollute the surrounding environment.

Conflicts of Interest: The authors declare they have no conflicts of interest.

REFERENCES

[1]- M.M. Mukherjee, Global Warming and Climate Change in India: A Social Work Perspective. Whanake : Pac. J. Community Devel., 3(1) (2017) 28-36.

[2]- S. Çankaya, B. Pekey, A comparative life cycle assessment for sustainable cement production in Turkey. J. Environ. Manage., 249 (2019) 109362. doi:10.1016/j.jenvman.2019.109362.

[3]- M.Z. Hauschild, Introduction to LCA Methodology, in Life Cycle Assessment: Theory and Practice, M.Z. Hauschild, R.K. Rosenbaum,S.I. Olsen, Editors. Springer International Publishing: Cham. (2018), 59-66. doi:10.1007/978-3-319-56475-3_6.

[4]- E.M. Nigri, S.D.F. Rocha, E. Romeiro Filho, Portland cement: an application of life cycle assessment. Product: Management and Development, 8(2) (2010) 167-172.

[5]- S. Morsali, Emissions from portland cement production using life cycle assessment inventory and method. Environ Energy Econ, 1(1) (2016) 1-8. doi:10.11648/j.eee.20160101.11.

[6]- D.N. Huntzinger, T.D. Eatmon, A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies. J. Cleaner Prod., 17(7) (2009) 668-675. doi:10.1016/j.jclepro.2008.04.007.

[7]- F. Colangelo, A. Forcina, I. Farina, A. Petrillo, Life Cycle Assessment (LCA) of Different Kinds of Concrete Containing Waste for Sustainable Construction. Buildings, 8(5) (2018) 70. doi:10.3390/buildings8050070.

[8]- G. Asadollahfardi, A. Katebi, P. Taherian, A. Panahandeh, Environmental life cycle assessment of concrete with different mixed designs. Int. J. Constr. Manag., 21(7) (2021) 665-676. doi:10.1080/15623599.2019.1579015.

[9]- J. Mohammadi, W. South, Life cycle assessment (LCA) of benchmark concrete products in Australia. nt. J. Life. Cycle. Assess., 22(10) (2017) 1588-1608. doi:10.1007/s11367-017-1266-2.

[10]- M. Soleimani, M. Shahandashti, Comparative process-based life-cycle assessment of bioconcrete and conventional concrete. J. Eng. Des. Tech., 15(5) (2017) 667-688. doi:10.1108/JEDT-04-2017-0033.

[11]- J. Pešta, T. Pavlů, V. Kočí, Life Cycle Assessment of Recycling Processes for Demolition Waste. IOP Conference Series: Earth and Environmental Science, 290(1) (2019) 012026. doi:10.1088/1755-1315/290/1/012026.

[12]- J. García Rey, V. Yepes Piqueras, Environmental assessment of concrete structures. Int. J. Constr. Eng. Manag., 1(3) (2012) 33-41. doi:10.5923/j.ijcem.20120103.04.

[13]- C.C. Onn, K.H. Mo, M.K.H. Radwan, W.H. Liew, C.G. Ng, S. Yusoff, Strength, Carbon Footprint and Cost Considerations of Mortar Blends with High Volume Ground Granulated Blast Furnace Slag. Sustainability, 11(24) (2019) 7194. doi:10.3390/su11247194.

[14]- M.W. Tait, W.M. Cheung, A comparative cradle-to-gate life cycle assessment of three concrete mix designs. nt. J. Life. Cycle. Assess., 21(6) (2016) 847-860. doi:10.1007/s11367-016-1045-5.

[15]- C. Elakkiah. Rice Husk Ash (RHA)—The Future of Concrete. Singapore: Springer Singapore. (2019), 439-447. doi:10.1007/978-981-13-3317-0_39.

[16]- L.A.-t. Bui, C.-t. Chen, C.-l. Hwang, W.-s. Wu, Effect of silica forms in rice husk ash on the properties of concrete. Int. J. Miner. Metall. Mater., 19(3) (2012) 252-258. doi:10.1007/s12613-012-0547-9.

[17]- A. Siddika, M.A.A. Mamun, M.H. Ali, Study on concrete with rice husk ash. Innov. Infrast. Sol., 3(1) (2018) 18. doi:10.1007/s41062-018-0127-6.

[18]- A.P. Gursel, H. Maryman, C. Ostertag, A life-cycle approach to environmental, mechanical, and durability properties of “green” concrete mixes with rice husk ash. J. Cleaner Prod., 112 (2016) 823-836. doi:10.1016/j.jclepro.2015.06.029.

[19]- S. Shahbazpanahi, R.H. Faraj, Feasibility study on the use of shell sunflower ash and shell pumpkin ash as supplementary cementitious materials in concrete. J. Build. Eng., 30 (2020) 101271. doi:10.1016/j.jobe.2020.101271.

[20]- I.N. Grubeša, M. Radeka, M. Malešev, V. Radonjanin, A. Gojević, R. Siddique, Strength and microstructural analysis of concrete incorporating ash from sunflower seed shells combustion. Struct. Concr., 20(1) (2019) 396-404. doi:10.1002/suco.201800036.

[21]- O.R. Bagal, M.A. Baccay, Effect of maize cob ash as supplementary cementitious material on the mechanical properties of concrete. Int. J. Mater. Eng. Innov., 10(2) (2019) 83-97. doi:10.1504/ijmatei.2019.099788.

[22]- M.-A. Perea-Moreno, F. Manzano-Agugliaro, A.-J. Perea-Moreno, Sustainable Energy Based on Sunflower Seed Husk Boiler for Residential Buildings. Sustainability, 10(10) (2018) 3407. doi:10.3390/su10103407.

[23]- A. Asonja, E. Desnica, L. Radovanovic, Energy efficiency analysis of corn cob used as a fuel. Energy Sources Part B, 12(1) (2017) 1-7. doi:10.1080/15567249.2014.881931.

[24]- V. Eswari Thai, E. Natarajan, Carbon footprinting for pulping process in paper industry. Int. J.Res. Emerging Sci. Technol., 1(4) (2015) 13-17.

[25]- S.B. Marinković, Life cycle assessment (LCA) aspects of concrete, in Eco-Efficient Concrete, F. Pacheco-Torgal, S. Jalali, J. Labrincha, V.M. John, Editors. Woodhead Publishing. (2013), 45-80. doi:10.1533/9780857098993.1.45.

[26]- S. Sharma, A. Kumar, Air pollutant emissions scenario for India. The Energy and Resources Institute. New Delhi, 2016.