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Life Cycle Analysis of Plain Cement Concrete and Green Concrete of Different Waste Pozzolanic Materials

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Abstract- With the expeditious growth in the construction industry, the concerns on the environmental emissions from concrete production are increasing. So, it the need of hour to choose an alternative and innovative approach to meet the necessity of sustainable constructions. This research explores the Life Cycle Assessment (LCA) of green concrete of M15 grade using fly ash (FA), sugarcane bagasse ash (SCBA), rice husk ash (RHA) and powdered glass waste (GW) separately at different binder replacement levels of 5%, 10%, 15% and 20%. LCA was carried out on OpenLCA software using Ecoinvent and Agribalyse databases on a “cradle to gate” approach. Environmental impacts of each green concrete on different replacement settings were assessed using ReCipe Midpoint (H), which in result shows that environmental impacts were least on 20% replacement. After that a comparative analysis was carried out between traditional and green concrete with 20 % binder replacements. Remarkably, up to 20% replacement of supplementary materials resulted in increased compressive strength on 28 days. Comparative LCA on CML-IA baseline and GWP100a showed that SCBA concrete on 20% replacement had least environmental impacts. RHA concrete was identified as a major contributor to ozone layer depletion. Human and marine toxicity were more notable in FA concrete.

Keywords- Life Cycle Assessment, Sugarcane Bagasse Ash, Fly ash, Rice Husk Ash, Glass waste, Compressive strength, Environmental impacts

I. INTRODUCTION AND LITERATURE REVIEW

The increasing rate of Global infrastructure and urbanization development has stoked up an unmatched demand for construction materials, which in result are contributing to major carbon dioxide (CO_2) emissions. According to a report concrete is responsible for 4 to 8 percent of total global CO_2 emissions [1]. According to Buchanan and Honey (1994) CO_2 emissions can be significantly reduced using waste supplementary pozzolanic materials. In this forefront Green concrete is a sustainable alternative to reduce the environmental carbon footprints [2].

LCA is a tool that helps to understand the environmental effects of processes and products throughout their entire life cycle, especially when it comes to greener construction LCA plays a vital role in improving sustainability. Many of the researches were initiated to develop methods for more comprehensive life cycle sustainability analysis [3]. Usually LCA is carried out using the standard ISO 14040-14044 [4]. However most of the researchers only focus on the LCA of concrete from the ‘’cradle to gate’ stages [5]. A LCA conducted on green concrete utilizing silica fume (SF) and fly ash as binder replacements. Analysis was carried out using SimaPro and Ecoinvent data base which results in that the mixture were quit effect for the reduction of CO_2 emissions but at the same time the human toxicity was increased due to addition of FA [6]. In case of self-healing geo-polymer, Green concrete using GW and sodium silicate a comparative LCA was done using the ISO standards on Gabi Sphera software. The results shows that the emission of CO_2 in concrete mixes with and without the additions of sodium silicate was 710 to 1181 kg CO_2 eq. which in fact were lesser than conventional concrete (CC) mix [7]. With the replacement of SCBA on different replacement levels from 20% to 80% in concrete the mechanical strengths was increased by 12 % on 60% replacement level. Also SCBA resulted in reduced environmental carbon foot prints wit lowering of production cost of concrete [8]. An alkali activated green concrete made with GW shows reduced global warming potentials and acidification potential by the percentage of 64% and 23 % respectively by using SimaPro as a LCA software. In comparison with the traditional Portland concrete the green concrete with alkali activator also shows enhanced mechanical strengths [9]. The existing studies on LCA of green concrete primarily focuses on comparing its environmental impact against plain cement concrete. However, there is a notable research gap concerning the comparative analysis of different types of green concretes and the evaluation of best alternative material for the production of green concrete. This study is aiming to identify the most sustainable options amongst different by products and provide valuable insights for enhancing the environmental performance of concrete production.

II. MATERIAL AND METHODS

2.1 Selection of Waste Material

Siddique, R (2011) provides comprehensive details on the usage of several waste materials and byproducts used in concrete [10]. 4 types of waste pozzolanic materials SCBA, FA, RHA and powdered GW were used in this study. The percentage of components which are responsible for binding properties of each waste material are given in Table I. Selection of materials were also based on easy availability in Pakistan.

Table 1: Chemical Composition of waste products responsible for binding

Components	FA [11]	SCBA [12]	RHA [13]	GW [14]
Silicon dioxide (SiO_2)	49.45 %	73 %	87.40 %	71.35 %
Aluminum oxide (Al_2O_3)	29.61 %	6.7 %	3.00 %	1.01 %
Ferric oxide (Fe_2O_3)	10.72 %	6.3 %	1.49 %	0.67 %
Calcium oxide (CaO)	3.47 %	2.8 %	1.40 %	8.74 %

2.2. Concrete Design Mix and Pozzolan Replacement

Replacement is done on 0%, 5%, 10%, 15% and 20% by weight of the cement for each of the waste by product separately in M15 grade concrete having w/c ratio of 0.52. A book by Steven H. Kosmatka covers various aspects of concrete mixes and replacement of pozzolanic materials [15].

2.3 LCA of Concretes

International Organization for Standardization (ISO), ISO 14040, and ISO 14044 provide general framework and principles for conducting LCA. The functional unit used for this research was 1m^3 of M15 grade with the pozzolan replacement of 0%, 5%, 10%, 15% and 20% of each by product. Total of 17 mixes were designed shown in Table 2.

OpenLCA software was used for this study. It also includes a component level "frameworks" which demonstrates life cycles which can be dissected and determine by OpenLCA [16]. For this research Ecoinvent (APOS lci) and Agribalyse were used with the full inventory as per "cradle to gate approach" of life cycles of different products from extraction of their raw material, transportations, processing and final products. This approach was selected because it focuses on emissions from extraction to concrete production, as it constitutes the primary comparison basis, while disregarding emissions during transportation, mixing, and disposal. Input parameters were added including the concrete ingredients with the replacement of waste materials on 5%, 10%, 15% and 20%.

Table 2: Design mix for 1m3 of M15 (1:2:4) concrete

Composition for 1 m3 of M15 Concrete									
		Cement (Kg)	Crush (Kg)	Sand (Kg)	RHA (Kg)	SCBA (Kg)	FA (Kg)	GW (Kg)	Water (Kg)
	Traditional (0%)	316.8	1408	704.88	-	-	-	-	164.73
RHA replacement	M1:RHA5%	300.96	1408	704.88	15.84	-	-	-	164.73
	M2:RHA10%	285.12	1408	704.88	31.68	-	-	-	164.73
	M3:RHA15%	269.28	1408	704.88	47.52	-	-	-	164.73
	M4:RHA20%	253.44	1408	704.88	63.36	-	-	-	164.73
SCBA replacement	M1:SCBA5%	300.96	1408	704.88	-	15.84	-	-	164.73
	M2:SCBA10%	285.12	1408	704.88	-	31.68	-	-	164.73
	M3:SCBA15%	269.28	1408	704.88	-	47.52	-	-	164.73
	M4:SCBA20%	253.44	1408	704.88	-	63.36	-	-	164.73
FA replacement	M1:FA5%	300.96	1408	704.88	-	-	15.84	-	164.73
	M2:FA10%	285.12	1408	704.88	-	-	31.68	-	164.73
	M3:FA15%	269.28	1408	704.88	-	-	47.52	-	164.73
	M4:FA20%	253.44	1408	704.88	-	-	63.36	-	164.73
Glass Waste replacement	M1:GW5%	300.96	1408	704.88	-	-	-	15.84	164.73
	M2:GW10%	285.12	1408	704.88	-	-	-	31.68	164.73
	M3:GW15%	269.28	1408	704.88	-	-	-	47.52	164.73
	M4:GW20%	253.44	1408	704.88	-	-	-	63.36	164.73

2.4 Assumptions

Following assumptions were made during the LCA.

- As replacement of different waste products by weight of cement did not affect the emissions during the mixing of concrete mix in mechanical mixture or batching plant so the input for energy used in mixing was neglected in LCA.
- Distance for each concrete ingredient is considered within a 100 km radius that is why emissions during transportation of each ingredient to the batching plant are neglected.

2.5 LCA Methods

Processes were created for the production of 1m^3 of concrete of all the mixtures shown in Table II then a product system for each step was calculated to find out environmental footprints and GHS emissions with the LCA method i.e. ReCipe Midpoint (H) [17]. First LCA was carried out on the 16 green concrete mixes using Global Warming Potential (GWP) 100a method after that compression strengths were calculated on the replacement percentage having least environmental impacts. Concrete mixes are than compared with traditional concrete with no waste replacements. The comparative analysis was carried out using the LCA methods GWP100a and CML-IA baseline and different environmental indicators were studied.

2.6 Compressive Strength Test

As per ASTM C39/C39M-21 and ACI 318-19 [18] compressive strengths were calculated on the 7th, 14th and 28th day after the casting of concrete samples. Concrete cylinder molds of 6'' diameter and 12'' height were used for the sampling of all concrete mixes according to ASTM C39/C39M-21.

III. Results and Discussions

3.1 LCA Results for All Green Concrete Mixtures

Results indicate that environmental impacts and total GHG emissions in $KgCO_2$.eq are gradually decreasing by increasing the replacement percentage of each waste pozzolanic material and least at the replacement level of 20%. Graphical representation for the LCA results are shown in Figure 1.

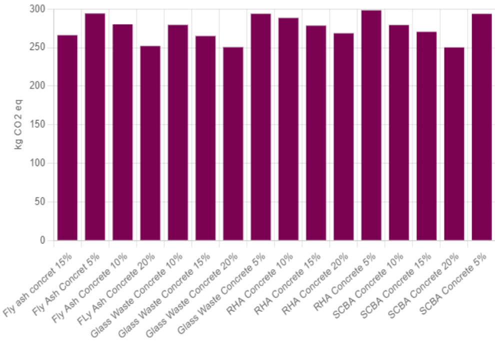

Figure 1: Results for CO2 emissions of all green concrete

3.2 Compressive Strength:

Green concrete mix having least environmental impacts for all four types of waste products which in this case are of 20% replacement were then compared with traditional concrete. The compression tests were carried out on the green concrete having least environmental emissions. Figure 2 shows the results of M15 green concrete on 7th, 14th and 28th day.

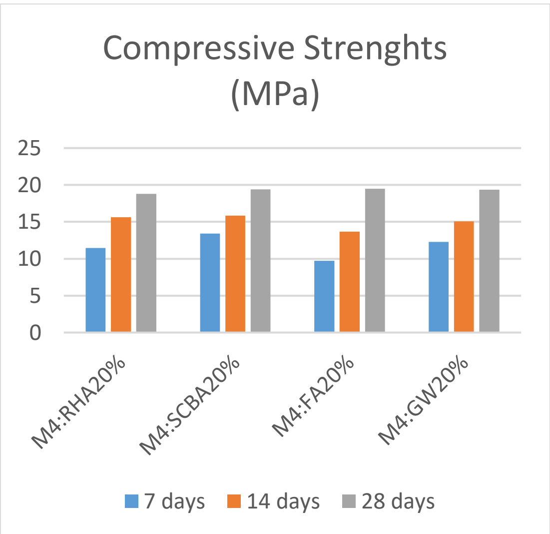

Figure 2: Compressive Strengths of Green concrete on 20% replacement

3.3 Comparative LCA

Green concrete mix with replacement level of 20% for all four types of waste products are than compared with Traditional concrete with no waste replacements Table 3 shows the results of LCA using method of CML-IA baseline and GWP100a.

Table 3: Comparative Results of Green and Conventional Concrete

Impact category	CC	M4:FA20%	M4:RHA20%	M4:SCBA20%	M4:GW20%	Units
Abiotic depletion	7.94E-04	6.52E-04	6.93E-04	6.50E-04	6.50E-04	kgSb eq
fossil fuels depletion	1.42E+03	1.18E+03	1.23E+03	1.17E+03	1.18E+03	MJ
Acidification	6.89E-01	5.82E-01	6.18E-01	5.69E-01	5.71E-01	$kgSO_2$ eq
Eutrophication	1.98E-01	1.71E-01	2.34E-01	1.64E-01	1.64E-01	$kgPO_4$--- eq
Fresh water ecotox.	4.27E+01	4.85E+01	4.01E+01	3.60E+01	3.60E+01	kg1,4-DB eq
Global warming	3.07E+02	2.52E+02	2.68E+02	2.49E+02	2.50E+02	$kgCO_2$ eq
Human toxicity	5.15E+01	5.73E+01	4.75E+01	4.30E+01	4.30E+01	kg1,4-DB eq
Marine ecotoxicity	1.23E+05	1.50E+05	1.11E+05	1.04E+05	1.04E+05	kg1,4-DB eq
Ozone layer depl.	8.92E-07	9.17E-07	1.05E-06	7.49E-07	8.57E-07	kgCFC-11 eq
Photochem oxidation	2.94E-02	2.51E-02	2.83E-02	2.46E-02	2.47E-02	kgC_2H_4 eq
Terrestrial ecotox.	4.30E-01	3.72E-01	3.61E-01	3.49E-01	3.49E-01	kg1,4-DB eq

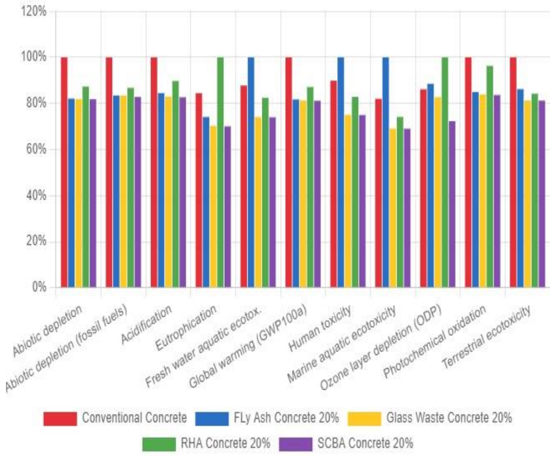

Figure 3: Bar chart for comparative analysis of Conventional and Green concrete

Figure 3 shows that in the case of global warming the highest results are of conventional concrete followed by RHA concrete, FA concrete, GW concrete and at the end the lowest results are for SCBA concrete. On the other hand, in the case of human and marine toxicity results for FA concrete are highest and lowest for SCBA concrete Being an organic agricultural waste by-product SCBA have the lowest concentration of harmful minerals and elements [19] on the other hand FA composite traces of heavy metal like arsenic and mercury which can result in human and marine toxicity scores [20]. RHA concrete is most responsible For Ozone depletion (OZP), a study conducted which shows that fertilizers used in Rice production contain the GHGs that results ozone depletions [21].

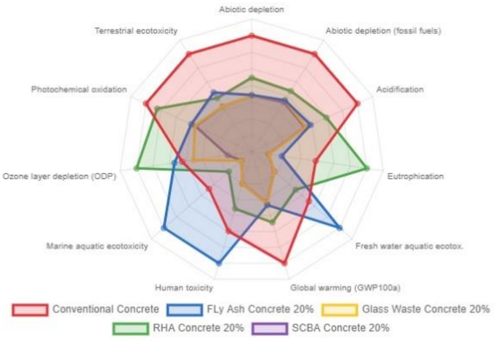

Figure 4: Radar chart for the Comparative LCA of Green concrete and Conventional concrete

The radar chart Fig. 4 clearly shows that green concrete using SCBA has the least area covered and points are nearest to the center of the chart showing that the environmental impacts by SCBA concrete are least then comes the Glass waste concrete with slightly higher results. Amongst all the 5 types of concretes including traditional and green concretes. Traditional concrete shows the highest environmental impact followed by Fly ash concrete and rice husk concrete

IV. CONCLUSIONS

The LCA results reflect the environmental benefits connected with green concrete production. By using different waste pozzolanic material construction industry of Pakistan can be made more sustainable and ecofriendly toward environment. There is great significance and potential to use waste pozzolanic materials to enhance the mechanical properties and reduce the environmental impacts. Amongst of all the supplementary materials SCBA shows the best results in reducing the environmental footprints by 18.9%. GW concrete showed slightly high emissions than SCBA concrete making it the second-best waste material to be used in green concrete. RHA concrete is responsible for major ozone depletion amongst the other green concretes. FA concrete is more responsible for human and marine toxicity by increasing toxicity by 8.4% than traditional Concrete. On average traditional concrete is majorly responsible for overall environmental impacts. Also, there is no decrease in required strength with the replacement of waste materials up to 20% by weight of cement. Due to its minimal environmental impacts, use of SCBA concrete should be promoted and prioritized in construction projects where sustainability is a key concern. While rice husk ash and fly ash can be valuable supplementary materials in concrete production, measures should be taken to address their environmental drawbacks. Research efforts should be continued to explore alternative materials or methods that can mitigate the environmental impacts.

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