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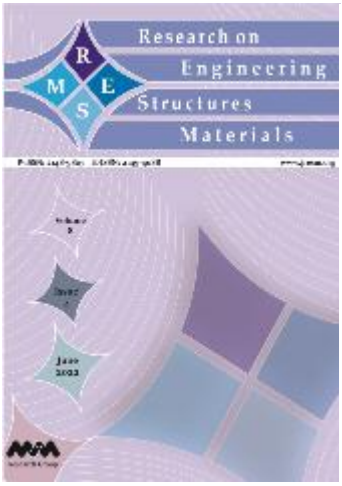

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Research Article

Investigation on the effect of ultra fine rice husk ash over slag based geopolymer concrete

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Abstract

In this study, The study investigates the production of sustainable geopolymer concrete using industrial wastes such as Ground Granulated Blast Furnace Slag and ultra fine Rice Husk Ash (URA). The effect of partial substitution of GGBS with URA in proportions such as 0, 5, 10, 15 and 20 percent is investigated for workability, drying shrinkage, compressive and tensile strength over different ages of concrete ranging from 7 to 90 days. A micro structural investigation through Scanning Electron Microscope and X-Ray Diffraction Analysis is carried out to analyze the micro structure of matrix. Further a sustainability analysis is conducted over the geopolymer specimens through the parameters such as cost efficiency, energy efficiency and CO2 efficiency. Results from the tests indicate a significant enhancement in workability, compressive and tensile strength and decrease in the drying shrinkage values with 15 percent utilization of URA in GPC. Micro structural study also exhibited a compact and dense microstructure of the specimen. Results clearly portray the coexistence of both calcium-based product and sodium-based product. Sustainability analysis indicates increased cost efficiency and Eco efficiency and reduction in the energy consumption with the utilization of 15 percent of URA. The study also reported the possibility of reduction of carbon footprint by increasing the dependency over Geopolymer concrete. The findings of the study unleash hefty potential towards utilizing grounded RHA in alkali activated concrete.

1. Introduction

The most versatile building material is concrete, and the principal constituent for producing concrete is cement. However, a substantial quantum of energy is consumed for the production of cement, that emits a hefty amount of CO_2 corresponding to the manufacturing process[1,2]. It is also to be noted that, making 1 t of cement liberates half a tonne of CO_2. Furthermore, if carbon fuel is utilised in this operation, an additional 0.45 t of CO_2 will be produced. As a result, producing 1 t of cement produces nearly 1 t of CO_2[2–4]. On the other hand, clinker is the primary raw material needed for cement manufacturing process, which is formed by processing limestone at temperatures more than 1000°C. The essential energy for this heating is obtained through the combustion of fossil fuels. As a result, the cement sector is thought to be responsible for about 8 percent of global CO_2 emissions[4,5]. A substitute for cement or a technology for concrete with no cement is the sustainable option. This demands the necessity of invention of cement less material for a sustainable progress in the construction sector.

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The concept under the creation of geopolymer concrete (GPC) is to give a long-term alternative to traditional cement concrete of lowering CO_2 emissions. Furthermore, because this method makes use of industrial by-products, economic benefits are provided owing to their inexpensive nature. Furthermore, this technology helps to solve the problem of industrial by-product disposal.

Plenty of research works focus on the utilization of flyash for the development of geopolymer concrete[6–8], bio medical waste ash[9,10], wood ash[11–15], GGBS[16–18]. Low calcium fly ash is widely preferred owing to its abundance availability and cheap cost. Geopolymer concrete synthesized from low calcium type yield fair engineering properties, elevated temperature properties, reduced drying shrinkage and creep[19–23]. The shortfall of utilization of class C type of fly ash is its requirement to be heat cured which focused its application to only precast products[24]. Another contemporary source material for the development of GC is Rice Husk Ash (RHA). The perceived benefits of RHA based geopolymer material in improving mechanical properties are mostly related to high silica concentration of RHA[25–27]. In comparison to other source materials, RHA has the highest silica concentration ranging around 95.0 percent and the lowest alumina level not higher than 2.0 percent. More RHA volume results in higher silica content enabling a higher Si/Al ratio. Komnitsas and Zaharaki claimed higher mechanical strength with the higher Si/Al ratio[28]. However on the other hand, Songpiriyakij, et al., claimed reduction in characteristic strength with a further increase in Si/Al ratio[29]. Fletcher et al., suggest 24 as the limiting value for Si/Al ratio to be efficient in achieving the engineering properties[30]. The pitfall of utilization of URA for developing a sustainable building material is its requirement for heat curing at elevated temperatures to exhibit fair engineering properties[31]. The advent of deployment of GGBS in geopolymer concrete enabled the production of geopolymer concrete without heat curing conditions with outstanding engineering properties[16,21,32,33]. Further with the utilization of GGBS, Davidoits reported minimum requirement of sodium silicate solution which forms the major part of alkaline activator solution for the polymerization reaction to happen[34]. Davidovits reported the ability of GGBS based GPC to set and harden in minimum time using less quantity of alkaline activator solution[34]. Blending of GGBS with RHA would prove beneficial in synthesizing the geopolymer concrete at ambient curing conditions[35].Hence in this work, effort has been made to develop geopolymer concrete using RHA and GGBS.

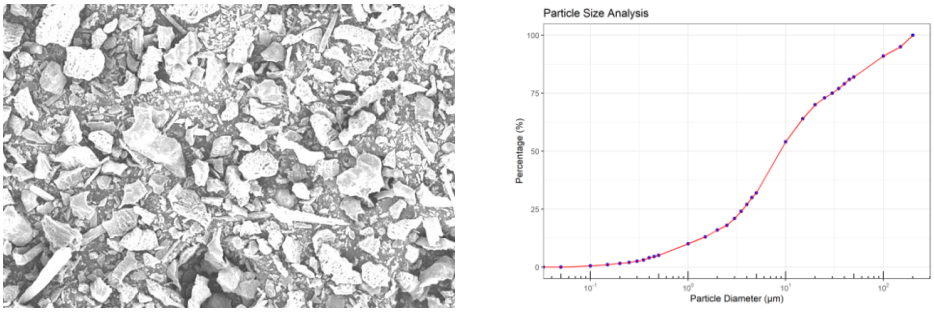
A considerable quantity of these by-products such as GGBS and RHA are produced, and disposing of them has become a big concern. Predominantly these wastes are land-filled which is against the sustainable development. Furthermore, as the iron and steel industries expand, so will the generation of slag, which poses a significant environmental risk. From the market survey, India stands first in the global RHA production with about 105 million tonnes of Rice. Kusbiantoro et al., reported 200 kilo gram of ash generation for each 1 Metric Tonne production of Rice[31,36]. Hence utilizing these wastes for the synthesise of building material would again lessen the disposal problems and strain over the environment when compared with the other alternative source material[37].

The focus of the research is to create GPC using ultra fine RHA as a fractional substitute to GGBS as a source material and examine its mechanical characteristics. While RHA has high silica oxide level, GGBS has high calcium content and lower silica oxide content. It is therefore reasonable to assume that adding RHA to the GGBS based geopolymer concrete could increase the amount of silica available for the polymerization reaction that could improve the characteristics of GPC. Further RHA is grinded in this work to ultra fine size with the objective of increasing the specific surface area and reactivity. The novelty of this research work lies in investigating the effect of ultra fine grinded RHA over GGBS based GPC over properties such as workability, drying shrinkage,

compressive and tensile strength. A micro structural investigation using Scanning Electron Microscopy (SEM) analysis and X-Ray Diffraction (XRD) was also carried out to detect the morphology, chemical composition and crystalline phases to characteristics of matrix. Further a sustainability analysis is conducted over the geopolymer specimens through the parameters such as cost efficiency, energy efficiency and CO2 efficiency.

2. Materials and Methodology

Geopolymer concrete in this investigation was made utilizing GGBS, ultra fine RHA (URA), fine and coarse aggregate and alkaline activator solution. GGBS is procured from salem steel plant in Tamil Nadu, India. URA was procured from a local Rice mill in Salem, Tamil Nadu, India. URA is then grounded using a ball mill for about 6 hours. SEM analysis and Particle Size Analysis (PSA) for URA was carried out to find out morphology and specific surface area and are depicted in Figure 1. From SEM analysis it is seen that URA are flaky in nature. Hence it can be apprehended that URA has large potential specific surface area which could enhance the dissolution of silica ions leading to the release of precursor ions necessary for the formation of monomers. PSA reports about 90 percent of the particles less than 100 micrometer thereby confirming the ultra fine nature of URA enhancing the possibility of polymerization reaction rate. Specific gravity of URA is found as 2.34. Specific gravity of GGBS was found to be 2.9. The chemical composition of URA and GGBS procured is listed in Table 1. From Table 1, it can be observed that the GGBS is having almost equal quantities of calcium oxides and silica oxides. URA contains almost 90 percent of silica oxide serving the purpose of its addition to the geopolymer matrix. Another significant factor that affects the properties of geopolymer concrete is the alkaline activator solution. A combination of NaOH and Na_2SiO_3 solution is utilized as the alkaline activator solution. Sodium hydroxide and sodium silicate solution are mixed in the ratio of 1:2.5. A 12M NaOH solution is made and combined with the sodium silicate solution 24 hours before concrete mixing. M-sand from the local quarry is used as the fine aggregate (FA) and coarse aggregate (CA) of 20 mm is used as coarse aggregate solution. Specific gravity of FA and CA was determined to be 2.54 and 2.61.



(a) (b)

Fig. 1 (a) SEM analysis of URA, (b) PSA of URA

The different materials are proportioned in accordance with modified guidelines for mix design[38]. The GGBS and URA are mixed dry first, then FA and CA are added. The alkaline solution is then added to the mixture and well stirred for about 5 minutes in the mixer. The concrete is then casted in to respective sizes and shapes depending on the test to be conducted. The total number of the specimens casted to determine the properties is listed in Table 2a. An average result value of three tested specimens is taken as the result of the particular tested mix id. The specimens are then ambient cured. Ambient curing in

this test was conducted by placing the casted specimen inside the laboratory under the shade in open condition. The ambient temperature during the entire time of casting and curing was in the range of 36 to 39 degree Celsius. URA is added as a partial substitute to GGBS in varying fractions such as 0, 5, 10, 15 and 20 percent. The mix proportions for the different mixes are listed in Table 2b. The effect of addition of URA over GGBS based geopolymer concrete is investigated in this study in three phases such as matrix performance, micro-structural characterization and sustainability analysis. Matrix characterization is carried out by determining properties such as workability, drying shrinkage, compressive and tensile strength for 3, 7, 28 and 90 days. Further micro structural characterization is carried out through SEM analysis and XRD analysis to examine morphology and flaws in the matrix. Sustainability impact is carried out by determining the cost efficiency, energy efficiency and CO_2 efficiency.

Table 1. Chemical composition of Base Materials

Chemical Composition	GGBS	URA
SiO_2	42.3	89.57
Fe_2O_3	1.14	0.51
Al_2O_3	13.6	0.81
CaO	41.1	0.69
MgO	1.1	0.39
Na_2O	0.3	0.23
K_2O	0.56	0.20
SO_3	-	0.13

Table 2 (a). Specimen details

Mix ID	Drying Shrinkage			Compressive Strength			Tensile Strength		
	7D	28D	96D	7D	28D	96D	7D	28D	96D
GR0	3	3	3	3	3	3	3	3	3
GR5	3	3	3	3	3	3	3	3	3
GR10	3	3	3	3	3	3	3	3	3
GR15	3	3	3	3	3	3	3	3	3
GR20	3	3	3	3	3	3	3	3	3
Total		45			45			45	

Table 2 (b). Mix Proportions

Mix ID	GGBS (kg/m^3)	URA (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)
GR0	550	0	95.86	239.64	531.32	929.62
GR5	522.5	27.5	95.86	239.64	529.19	925.89
GR10	495	55	95.86	239.64	527.06	922.16
GR15	467.5	82.5	95.86	239.64	524.93	918.43
GR20	440	110	95.86	239.64	522.79	914.69

3. Results and Discussions

3.1 Matrix Analysis

3.1.1 Workability

The effect of addition of URA as a partial substitute of GGBS in GPC over workability is investigated through the compaction factor test and slump test as per IS 1191-2018[39].

The variation in the results with the utilization of URA is listed in Table. 3. From Table 3, it is pragmatic that with the addition of URA, there is a continuous increase in the compaction factor values. As the quantity of URA increases the workability of GPC increases due to the ultra-fine nature and very small particle size of URA compared with GGBS. This is witnessed from the particle size analysis (PSA) of URA as well. This could be witnessed during the mixing of the concrete as well. As per British Road Note 4, with addition of 20 percent URA, workability is improved to medium from low category and compaction becomes optional for better stability whereas without URA, GGBS based GPC needs hand compaction for better stability.

3.1.2 Drying Shrinkage

Concrete drying shrinkage is an important metric for assessing the durability and serviceability aspect. The blended effect of URA and GGBS over drying shrinkage in GPC specimens of size 40 x 40 x 150 mm is investigated as per IS 516-2020 (Part-6)[40].

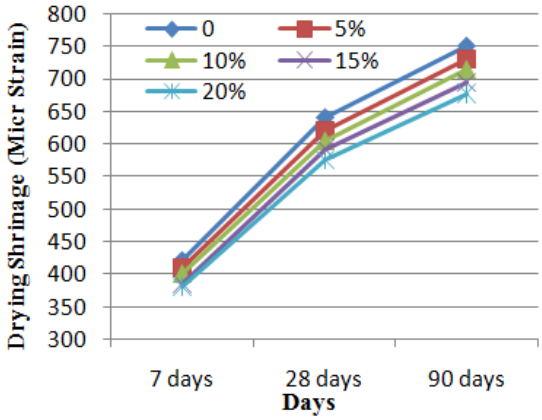


Fig. 2 Drying shrinkage results

Table 3. Mechanical characterization

Mix ID	Workability			Drying Shrinkage (Micro Strain)			Compressive Strength (MPa)			Tensile Strength (MPa)		
	CF	Slump	D.o.W	7D	28D	90D	7D	28D	90D	7D	28D	90D
GR0	0.85	30	Low	420	640	750	40.5	44.2	47.8	4.0	4.4	4.8
GR5	0.86	45	Low	410	620	730	42.3	45.8	49.4	4.3	4.7	5.1
GR10	0.88	60	Medium	400	605	715	44.6	47.5	52.7	4.4	4.9	5.3
GR15	0.89	70	Medium	385	590	695	47.4	51.8	56.5	4.8	5.3	5.8
GR20	0.9	75	Medium	380	575	675	42.4	45.2	48.5	4.3	4.6	4.8

Figure 2 depicts the variation of drying shrinkage values with addition of URA for different ages such as 7, 28 and 90 days. A gradual decrease in the drying shrinkage values throughout the addition of URA across all the ages. From Figure 2, it is observed that about 55 percent of 90 days shrinkage strain values are observed in 7 days itself and about 85 percent of the 90 days shrinkage strain values are observed in 28 days. The majority of drying shrinkage occurs in the initial few days as a result of the rapid internal loss of relative humidity from the surface of the specimens. Beyond 90 days, the increase

in drying shrinkage is insignificant. Drying shrinkage is essentially caused by the evaporation of water present in the pores due to the reduced humidity level in the environment. During drying, capillary stresses are induced in the capillary water present in the matrix are responsible for the shrinkage strain. The decrease in drying shrinkage caused by the addition of URA shows that the escape of internal moisture during drying was controlled owing to the refinement of the pore structure contributed by the ultra fine URA.

3.1.3 Compressive Strength

Compressive strength of GPC specimens for various additions of URA is investigated as per IS 516-2021 [41] for 7,28 and 90 days. GPC specimens of size 150 x 150 x 150 mm are tested. The strength values are listed in Table 3. Figure 3 depicts the variation of characteristic strength across the ages such as 7, 28 and 90 days for the utilization of URA in various proportions such as 0, 5, 10, 15 and 20 percent.

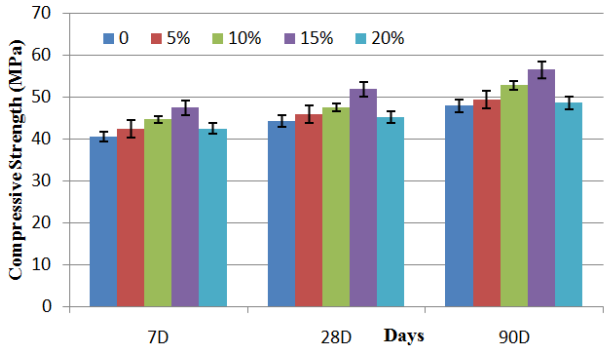


Fig. 3 Compressive strength results

About 85 percent of 90 days strength is observed in 7 days itself for the specimen with zero percent UURA and about 84 percent of the 90 days strength is observed in 7 days itself for the specimen with 15 percent URA. Hence the influence for the early attainment of strength by the URA is negligent. However, GR15, with 15 percent of URA exhibited the maximum compressive strength with 56.5 MPa at 90 days. The test reported increase in strength with the addition of URA till 15 percent and beyond that it decreases. The enhancement in compressive strength with the inclusion of URA up to 15 percent corresponds to the higher SiO_2 content of URA which increased the overall SiO_2/Al_2O_3 ratio thereby enhancing the polymerization reaction. This increase is further enhanced by the ultra-fine nature of URA than GGBS which could increase the specific surface area of the source material available for the reaction to occur [42]. The cohabitation of CSH, induced by the extra silica with the polymerization product NASH, could be related to the increase in strength with the introduction of URA. But URA when added in excess i.e.) more than 15 percent, a decrease in strength is reported. This is due to the fact that GGBS and URA has different solubility rates and at times when almost equal quantities are used, different solubility rates becomes an issue [31]. Moreover, excess URA leads to the presence of additional unreactive silica which hinders polymerization reaction. Similar research works report the reduction in compressive strength because of expansion and cracking that occurs due to the existence of excess silica in the matrix[43,44].

3.1.4 Tensile Strength

Tensile strength of GPC specimens for various additions of URA is investigated as per IS 516-2021 [41] for 7,28 and 90 days. GPC cylindrical specimens of diameter 150 mm and

height 300 mm are tested. The strength values are listed in Table 3. Figure 4 portrays the transformation of split tensile strength across the ages such as 7, 28 and 90 days for the utilization of URA in various proportions such as 0, 5, 10, 15 and 20 percent.

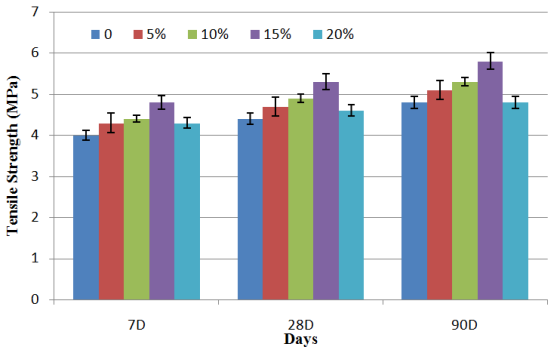


Fig. 4 Tensile strength results

About 84 percent of 90 days strength is observed in 7 days itself for the specimen with zero percent URA and about 83 % of the 90 days strength is observed in 7 days itself for the specimen with 15 percent URA. Hence the influence for the early attainment of strength by the URA is negligent. The reported values are in line with the results of compressive strength values. However, GR15, with 15 percent of URA exhibited the maximum tensile strength with 5.8 MPa at 90 days. The test reported enhancement in strength with the addition of URA till 15 percent and beyond that it decreases.

The reason for augmentation in tensile strength with the utilization of URA up to 15 percent is similar to that of observed in compressive strength and corresponds to the higher SiO2 content of URA which increased the overall SiO2/Al2O3 ratio and the ultra fine nature of URA than GGBS which could increase the specific surface area of the source material available for the reaction to occur [42]. Whereas at 20 percent of URA, about 90 percent of 90 days strength is observed in 7 days itself and about 96 percent of 90 days strength is observed in 28 days. Thereby making the presence of unreactive excess silica explicit. This excess silica hinders the polymerization reaction at higher URA dosage. Also at higher URA dosage, the Si/Al ratio increases beyond 24 which is the threshold value for the effective polymerization reaction[30].

3.2 Micro-structural Characterization

Micro-structural investigation was carried out using SEM and XRD analysis. SEM and XRD examination were performed on cracked sections of 90-day compressive strength test specimens for GPC mixes containing 15% URA. Figure 5 shows the micro structure of GPC.

From Figure 5, it is clear that there are no voids or cracks and a dense, compact microstructure is reported. This could be due to the presence of ultra fine URA which contributed to the higher surface area of the source materials favoring the formation of precursor ions. This is also due to the presence of 15 percent silica which contributed to the higher silica content thereby enhancing the polymerization reaction.

XRD analysis is carried out over the optimum specimen GR15 with 15 percent URA addition in order to identify the crystalline phases and the chemical composition. Figure 5 depicts the intensity versus position of GR15. Results clear portray the coexistence of both calcium based product and sodium based product. Calcium based products (CSH) are the result of interaction between the GGBS precursor ions and silica supplied by the

URA. Sodium based products (NaSH) are the usual polymerization products. Quartz (SiO2) with the highest peak are the silica based products. Existences of these products are responsible for the observed characteristics of GC.

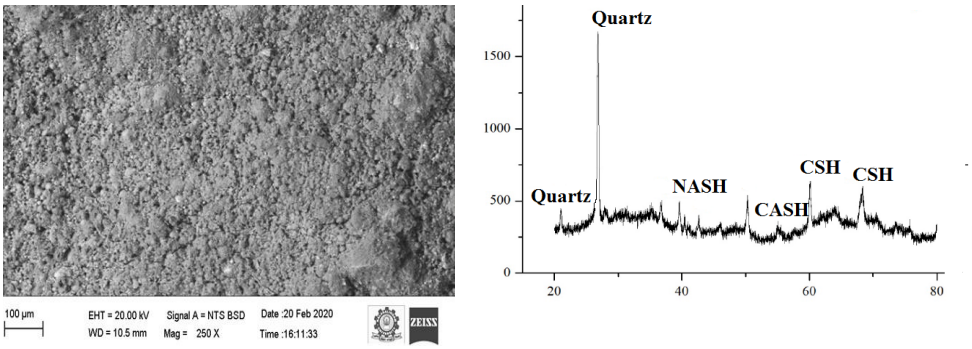


Fig. 5 SEM and XRD analysis of GR15 sample

3.3 Sustainability Analysis

3.3.1 Cost Efficiency

Cost efficiency is one of the essential parameter to be considered for sustainability. Cost efficiency of the specimens is evaluated based on the ratio of strength delivered to the incurred cost of production of different ingredients such as GGBS, URA, NaOH, Na2SiO3, FA and CA present in the matrix. Equation (1) gives the formulae to calculate the cost of efficiency. Market price of the materials is considered as the cost of materials.

$$Cost\ efficiency = \frac{Strength\ in\ MPa}{Cost\ of\ materials\ per\ cubic\ meter} \quad (1)$$

Table 4. Cost Analysis of GPC

Material	Rate / Tonne	GR0		GR5	
		Quantity (kg)	Cost (Rs)	Quantity (kg)	Cost (Rs)
GGBS	2000	550	1100	522.5	1045
URA	1500	0	0	27.5	41.25
NaOH	12250	95.86	1174.285	95.86	1174.285
Na2SiO3	10000	239.64	2396.4	239.64	2396.4
FA	900	531.32	478.188	529.19	476.271
CA	775	929.62	720.4555	925.89	717.5648
Total Cost (Rs)			5869.3285		5850.771

Material	Rate / Tonne	GR10		GR15		GR20	
		Quantity (kg)	Cost (Rs)	Quantity (kg)	Cost (Rs)	Quantity (kg)	Cost (Rs)
GGBS	2000	495	990	467.5	935	440	880
URA	1500	55	82.5	82.5	123.75	110	165
NaOH	12250	95.86	1174.285	95.86	1174.285	95.86	1174.285
Na2SiO3	10000	239.64	2396.4	239.64	2396.4	239.64	2396.4
FA	900	527.06	474.354	524.93	472.437	522.79	470.511
CA	775	922.16	714.674	918.43	711.7833	914.69	708.8848
Total Cost (Rs)			5832.213		5813.655		5795.081

The investigation is carried out in India; hence rupees was used as the currency. The various cost of the materials is listed in Table 4 and the subsequent rate of different mixes are also calculated and listed in Table 4.

Figure 6 shows the cost efficiency of different specimens for the incorporation of URA as a substitute to GGBS. In Figure 6, y axis represents the strength to cost ratio per cubic meter. From Figure 6, it is clear that there is an increase in the cost efficiency with respect to the utility of URA. An increase in cost efficiency of about 18 percent is witnessed with the utilization of URA for 15 percent. This is due to the reduced cost of URA and increased strength exhibited by the GPC specimens with addition to URA up to 15 percent. Hence the strength to cost ratio calculated for 1 cubic meter increases till 15 percent and then it decreases at 20 percent utilization of URA. The important factor that contributes for the increase in cost of the geopolymer specimens is the cost of sodium silicate solution. This could be reduced if the sodium silicate solution is prepared from rise husk solution by sol-gel method[45].

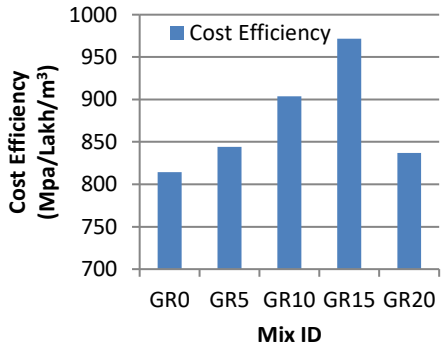


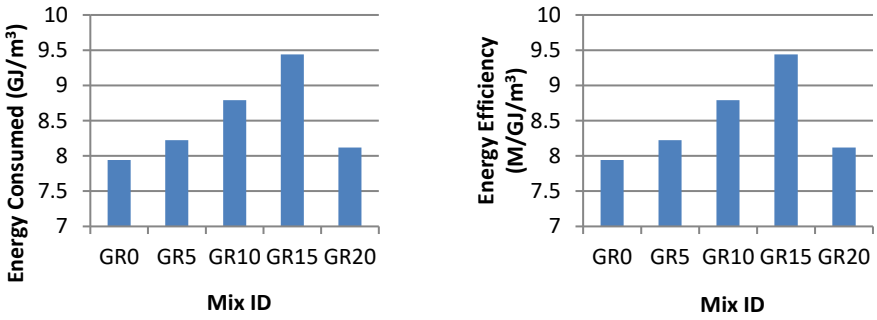
Fig. 6 Cost efficiency

3.3.2 Energy Efficiency

The primary parameter that affects sustainability is the energy efficiency. Energy efficiency is calculated as the ratio of strength exhibited to the sum of the energy consumed for the production of different ingredients such as GGBS, URA, NaOH, Na_2SiO_3, FA and CA present in the matrix. Equation (2) gives the formulae to calculate the Energy Efficiency. Energy efficiency of different specimens is indicated in Figure 7.

The quantum of energy needed for the generation of one tonne of GGBS and URA is 0.857GJ and 0.455GJ[46]. Energy consumed for the production of one tonne of FA and CA are 0.081GJ and 0.083GJ. Energy required to produce one tonne of sodium hydroxide and sodium silicate solution is 20.5GJ and 5.371GJ[47–49]. From Figure 7, it is explicit that there is a considerable decrease in the energy consumed with respect to the addition of URA.

$$Energy\ Efficiency = \frac{Strength\ in\ MPa}{Energy\ consumed\ for\ the\ Prouctiion\ of\ 1\ cubic\ meter} \quad (2)$$



(a) (b)

Fig. 7 (a) Energy consumption, (b) Energy efficiency

3.3.3 CO_2 Efficiency

CO2 efficiency is the second most important parameter that influences the sustainability. Carbon dioxide is liberated by burning of fuels that is responsible for energy required for the production of various materials. Compared to other materials, production of fine aggregate and coarse aggregate liberate least CO2 with 0.0048 tonne of CO2 for every one tonne of production. CO2 for the GGBS and URA is 0.052 and 0.025 tonne of CO2 for every one tonne of production. CO2 emission for NaOH is 1.915 and that of Na2SiO3 is 1.915 and 1.222 tonne of CO2 for every one tonne of production[50]. CO2 emission is calculated for every one cubic meter of different mix ids and is depicted in the Figure 8.

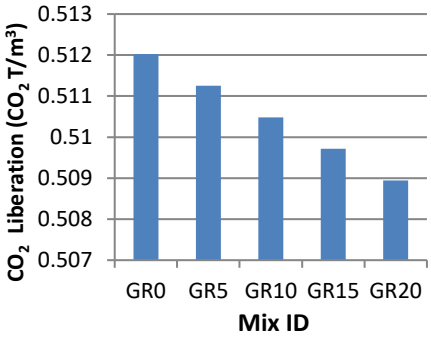


Fig. 8 CO_2 Efficiency

From Figure 8, its pragmatic that with the utilization of URA, there is a decrease in the liberation of CO_2. Eco efficiency is calculated similar to cost efficiency by the ratio of strength to the CO_2 emission and is depicted in Figure 9. Equation 3 gives the formulae to calculate the Eco Efficiency. Eco efficiency is calculated as the ratio of strength exhibited to the sum of the CO_2 liberated for the production of different ingredients such as GGBS, URA, NaOH, Na_2SiO_3, FA and CA present in the matrix.

$$Eco\ Efficiency = \frac{Strength\ in\ MPa}{CO2\ liberated\ for\ the\ Prouctiion\ of\ 1\ cubic\ meter} \quad (3)$$

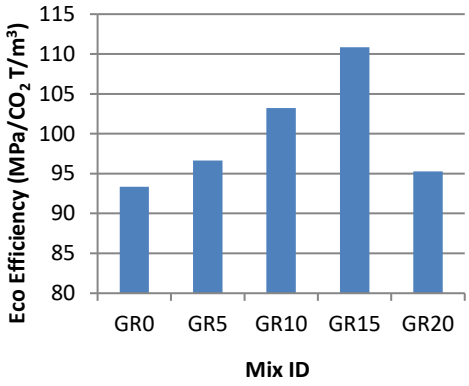


Fig. 9 Eco efficiency

From Figure 6,7 and 9, it is observed that GPC specimens with 15 percent URA addition as a substitute to GGBS exhibited better efficiency when compared to the other specimens. Also, it is observed that the strain over the environment could be reduced through the dependency on GPC.

4. Conclusion

The effect of URA addition as a partial substitution for GGBS in GPC over properties such as workability, drying shrinkage, compressive strength and tensile strength for different ages from 7 to 90 days was evaluated. With the utilization of URA, significant enhancements in engineering properties were reported. Micro-structural investigations reveal the dense microstructure and the chemical composition responsible for the enhancement in properties. Further sustainability analysis was performed to evaluate the impact of GC made to environment. Significant outcomes of this research work could be summarized as follows,

- Workability of the slag based GC increase with the increase in the utilization of URA owing to the ultra fine size and higher specific surface area of URA.
- With the incorporation of URA, there is decrease in the value of drying shrinkage strain values across all ages such as 7, 28 and 90 days. Significant reduction of about 7 percent is visible with the addition of URA at 15 % replacement level.
- There is a significant increase of about 18 percent in compressive strength and about 20 percent in tension strength with the addition of URA at 15 % replacement level.
- XRD study reveals the existence of CSH, NaSH and SiO_2 in the matrix that are responsible for the better performance of GC.
- Cost efficiency increases about 19 percent with the inclusion of URA in slag based GC.
- A gradual decrease in the energy consumption for production is reported with the utilization of URA.
- Eco efficiency increases by about 18.75 percent with the utilization of URA as a partial substitute of slag in GC.

The findings of the study open the path for the creation of URA-based sustainable construction materials. From the detailed sustainability analysis, in general it can be observed that in GC, the major decline in efficiency is due to the presence of sodium silicate solution followed by the sodium hydroxide solution. Further this efficiency can be

increased by reducing the dependency over NaOH and finding a sustainable way of producing sodium silicate solution which would prove beneficial to the scientific society. This research work could be extended by utilizing the sodium silicate solution that are synthesized using Rice Husk Ash and sodium hydroxide solution of less molarity.

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