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Original scientific paper

Effect of Fly Ash and Indus River Sand on Mechanical, Durability and Environmental Performance of Autoclaved Aerated Concrete (AAC)

Mohsin ALI, Abdul Salam BULLER*, Tariq ALI, Samreen SHABBIR, Aqeel AHMED, Jawad Ur REHMAN

Abstract: Nowadays construction industry is trying to develop energy-efficient and environmentally friendly materials. In this regard, various types of concrete are designed but still, there is a need for a material that is energy efficient and sustainable, one of which is Autoclaved Aerated Concrete (AAC). Therefore, this study utilizes various waste products locally available to produce lightweight (AAC). This research work focuses on reducing Carbon Dioxide release with the help of cement substitutive substances like Fly ash (FA) in Autoclaved aerated concrete (AAC). The main objective of the present study is to investigate the mechanical and durability performance of AAC by adding FA and Indus River Sand (IRS) as substitutes for cement and fine aggregate respectively. Various percentages of Fly ash (5, 10, 15, 20, 25, and 30%) and Indus River sand (25, 50, 75, and 100%) were used as replacements for Cement Type I and Fine aggregate in AAC. Afterward, this concrete was cured in an Autoclave machine for curing period of 9 hours. In the end, various tests i.e. compressive strength, split tensile strength test, dry density, embodied carbon, and embodied energy of AAC were conducted to check the influence of both materials as replacements on the performance of concrete. Test results show that the maximum compressive strength of 2.01 MPa was achieved at an optimum percentage of FA, which is 20%. Moreover, at 100% replacement of IRS compressive strength was further increased to 2.29 MPa. Similar trends were achieved in the case of split tensile strength increase. Furthermore, durability in terms of embodied carbon and embodied energy was also checked and it was found that embodied carbon and embodied energy were decreased by 21.6% and 27.5%. It was revealed from test results that using an optimum percentage of FA and Indus River sand enhances both the mechanical and durability performance of AAC due to the filling effect of FA and IRS.

Keywords: autoclaved aerated concrete; durability properties; fly ash; indus river sand; mechanical properties

1 INTRODUCTION

The largest menace facing mankind in this age is global warming. The impression of this threat can be observed in the current downpour in Pakistan. Carbon dioxide is one of the significant donors in this menace. Amusingly, 20 to 40% of the entire carbon ejection is contributed by the construction industry. Every year, 4.4 billion tons of concrete is produced which put up 5 - 8% of global Carbon ejections. A large amount of cement is required for concrete and it is manufactured by the clinker process. This clinker process uses a huge amount of energy and emits a significant amount of CO_2 emission as well as becomes the reason for global warming. Moreover, due to the overmuch utility of aggregates, the earth layer becomes thinner increasing the chances of natural disaster [1]. Furthermore, fly ash being an industrial outgrowth causes serious health and environmental hazards as it is shunned as a backfill. Along with that, if Indus River sand is used as a fine aggregate then it will decrease the deleterious effects on the environment. Therefore, by using these materials as cement and fine aggregate replacement in the Autoclaved aerated concrete, the environment can be saved.

Along with the world, Pakistan is also fronting such difficulties, and progress toward sustainable civil engineering is immediately needed as deposition of lignite coal is in trillion tons under the Tharparkar zone surface and its utilization has been started in its own mine mouth power plant [1]. Pakistan can be energized for almost 200 years by the rich coal resource of Tharparkar, with 175 trillion tons of coal fuel deposition. As time elapsed, there will be growth in the thermal power plants which will result in a rise in issues regarding solid remains disposal from combustion and off-gas cleaning (Bottom ash and Fly ash). So, the usage of green materials or environment-friendly materials like Aerated concrete can solve these problems to an appreciable extent. [2].

Autoclaved aerated concrete is the most suitable material, which matches very well with current and future heat transfer co-efficiency. It contains an enormous number of air-filled small pores, which cause low thermal conductivity. With the increase in the number of pores in Autoclaved aerated concrete, the density of Autoclaved Aerated Concrete (AAC) is decreased. Moreover, when fly ash-based AAC and sand-based AAC are compared, it is seen that the former has better thermal insulation than the latter with the same density [3]. The materials used in the manufacturing of AAC are gypsum, cement, burnt lime, and siliceous materials like fly ash or sand, and aluminum powder is used as the foaming agent. After several hours of reaction time, the cutting of smooth and workable mass produced is done and its curing is performed under hydrothermal conditions between 5 - 10 hours at 180-190 °C, with the use of saturated steam at 10-12 bar pressure [3].

Recently many researchers have investigated the mechanical and durability performance of aerated concrete. Ali. T et. al [4] investigated the mechanical and durability performance of aerated concrete by incorporating rice husk ash (RHA) at 3, 7, 28 and 90 days of water curing. RHA was replaced with cement up to 15% and they found that an optimum level of 10% was suitable for enhancing both the mechanical and durability performance of aerated concrete. Another study was conducted by [5] and they examined the performance of autoclave aerated concrete by adding both fly ash of different class and GGBS. Mechanical performance in terms of compressive strength, density and modulus of elasticity were conducted. Furthermore, XRD, SEM and EDX were also carried to check the microstructural analysis of samples. Comparing Class F Fly Ash to Class C Fly Ash based AAC blocks, the results showed that the dosage of "15% GGBS + 85% cement" had the maximum compressive strength, modulus of elasticity, and modulus of rupture. Additionally, adding GGBS to the production process would raise AAC's compressive strength by up to 68%. Lashari. A. R et. al [6] checked the combined effect of fly and silica fume of strength and embodied carbon of autoclave aerated concrete. Fly ash was replaced with cement up to 20% and optimum percentage of up to 20 was used in mix. According to the experimental findings, the combination of replacing 15% of the cement with silica fume and 30% of the cement with fly ash produced the maximum compressive and split tensile strength of AAC. The lowest density was also observed at this ratio, demonstrating the lightweight nature of AAC without sacrificing its strong properties. Numerous investigations have been carried out which determine the hydration of autoclaved concrete [7-9], effect of pozzolanic on mechanical properties and water absorption [10, 11], development of microstructure using fly ash [12, 13], potential effect of fly ash and silica fume on aerated concrete [14, 15], effect of red mud on mechanical and fresh properties of autoclaved concrete [16] and effect healing with the addition of supplementary materials in normal concrete [17, 18]. Many other studies have also shown the effect of waste materials on normal, recycled aggregate, asphalt and self-healed concrete [9, 19].

In the production of concrete hill sand is normally used to fill internal gaps but because of rapid growth in the construction industry natural aggregates are depleting, thus it is important to use other materials, which replace hill sand with the same performance. The Indus river sand is an alternative that is nowadays utilized in concrete as a fine aggregate replacement [20]. The M25 grade concrete was examined by [21] at three distinct curing times (7, 14 and 28 days). Natural sand was substituted with 10%, 20%, 30%, 40%, and 50% by weight of fine aggregate in foundry sand. The findings showed a 30% improvement in compressive strength. Nevertheless, a drop in compressive strength was observed with an increase in substitute percentage. The mechanical properties of concrete were tested at various ratios of 0%, 15%, 25%, and 35% when foundry sand was substituted for natural sand [22]. The best percentage, according to the results, was 25%, which produced the strongest results. D. Chaurasiya [23] examined M25-grade concrete under various curing conditions (7, 14, and 28 days).

Thermal power stations are one of the great sources of air pollution as they generate the most important waste, fly ash that causes environmental pollution because of its soluble ions and fineness. With the development of these power plants, the quantity of fly ash is also increased which has a huge impact on the environment. Fly ash is merely utilized as an additive material in the cement and concrete production and construction industry. Moreover, pozzolanic materials such as pulverized fuel ash are also used in AAC production in some attempts. Studies have been conducted on checking the properties of aerated concrete, which are based on lime-based fly ash and parameters of cellular concrete production (Verma et al., 1983). Many of the studies are concluded on determining the effect of properties of fly ash on aerated concrete such as its variable nature and late hydration characteristics. Conversely, very few studies have also been conducted on cement-based fly ash Aerated Concrete for its phase stability and microstructural development when fly ash fully replaces Indus River sand.

Based on the above discussion it was observed that there is clear gap in utilizing the fly ash along with Indus river sand as partial replacement of cement and hill sand respectively especially in Autoclaved Aerated Concrete (AAC). Therefore, this study aims to investigate the mechanical and durability performance of AAC by adding both fly ash and Indus river sand. The objectives of this study are dual fold. Firstly, chemical characterization of FA and Indus river sand was carried in terms of XRD and SEM analysis. In second step both of these materials were used with different percentages in AAC to examine various properties of concrete. Fly ash up to 30 % with interval of 5% and Indus River Sand up to 100% with interval of 25% were used as substitutes of cement and hill sand respectively.

2 EXPERIMENTAL PROGRAM

2.1 Materials and Mix Proportions

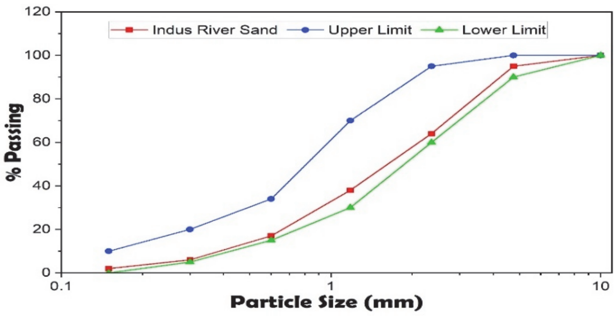
Type 1 Ordinary Portland cement Fly Ash of class F was used in this research. Fly ash was dried for 24 hours and sieved through a 75 um sieve for use as a binding material in AAC. The number of oxides in Fly ash and cement was determined by the X-ray fluorescence (XRF) method. These oxides are shown in Tab. 1. It fulfilled the chemical requirements of fly ash used in binding composition (ASTM C618-19) [24]. Moreover, Hill sand also used in this research, was collected from the local market Jamshoro, Sindh, Pakistan, and has water absorption of 1.8%. Indus River Sand used in this research was collected from the shore of Jamshoro River Indus at a depth of 6 ft. in order to prevent dust and has high-water absorption of 2.66%. The sieve analysis of fine aggregates and Indus River sand was carried out by using ASTM-C136 [25] as summarized in Fig. 1. Aluminum powder was used as an aerating agent. It has a light gray color. The aluminum powder used in this investigation was obtained from Karachi and had an average particle size of 0.2 mm. Particles of aluminum have a diameter of less than 100 microns. Lastly, tap water was also utilized for mixing and curing. Mix proportions of all the materials used in this study are given in Tab. 2.

Table 1 XRF of FA and PC

Binder	Oxides / %							Physical Property
	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	SO_3	LOI	Specific Gravity
FA	58.70	23.18	6.35	8.72	1.98	0.48	4.62	2.44
PC	20.78	5.11	3.17	60.22	0.18	2.86	2.45	3.15

Table 2 Mix proportions of ACC

Mix Proportions	Binder Contents / %		Fine aggregate / %		Aerating agent / %	Amount of Material Required to Produce 1 m^3 Autoclave Aerated Concrete / kg					
	PC	Fly Ash	Fine aggregate	Indus River Sand	Aluminum	PC	Fly ash	Fine aggregate	Indus river sand	Aluminum	Water (w/c = 0.7)
Controlled	100	0	100	0	0.4	300	0	600	0	1.2	210
FA5	95	5	100	0	0.4	285	15	600	0	1.2	210
FA10	90	10	100	0	0.4	270	30	600	0	1.2	210
FA15	85	15	100	0	0.4	255	45	600	0	1.2	210
FA20	80	20	100	0	0.4	240	60	600	0	1.2	210
FA25	75	25	100	0	0.4	225	75	600	0	1.2	210
FA30	70	30	100	0	0.4	210	90	600	0	1.2	210
OFA25IRS	80	20	75	25	0.4	240	60	450	150	1.2	210
OFA50IRS	80	20	50	50	0.4	240	60	300	300	1.2	210
OFA75IRS	80	20	25	75	0.4	240	60	150	450	1.2	210
OFA100IRS	80	20	0	100	0.4	240	60	0	600	1.2	210



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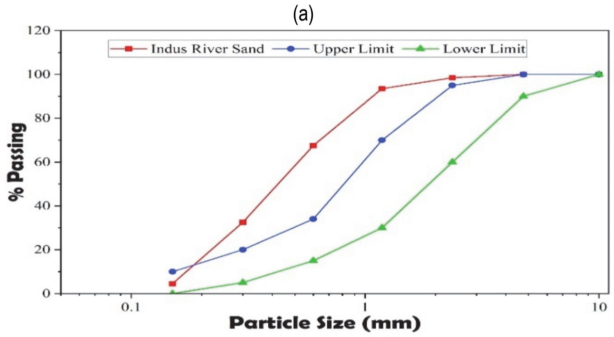


(b)

Figure 1 Grading curve (a) Hill sand (b) Indus river sand

2.2 Specimen Preparation

For the initial work, a controlled mix was prepared by keeping constant aeration of a minimum of 30 mm. Trial experiments were carried out on control samples in this work to better understand the behavior of volume change brought on by aluminum powder aeration. By weight of cement, the ranges of 0.3%, 0.4%, 0.5%, and 0.6% were chosen. Less aeration was seen at 0.3% of aluminum powder, and samples were unable to expand to fill one-third of the mold. Samples were able to fill the necessary mold at 0.4% aluminum, bulge to a diameter of 20 to 40 mm, and then be cut to level the mold's surface, as seen in Fig. 2. However, the majority of samples were destroyed during demolding at 0.5% and 0.6% of aluminum powder due to significant aeration. Trial and error led to the conclusion that the bulging should be between 25 and 40 mm, which allowed for correct sample casting. As a result, 0.4% of the cement's weight should be made up of aluminum powder. Cubes (100 × 100 × 100) mm and cylinders (100 × 200) mm were cast for compressive strength and split tensile strength as depicted in Fig. 2. Fig. 2 also shows the aeration process and AAC curing during this study.

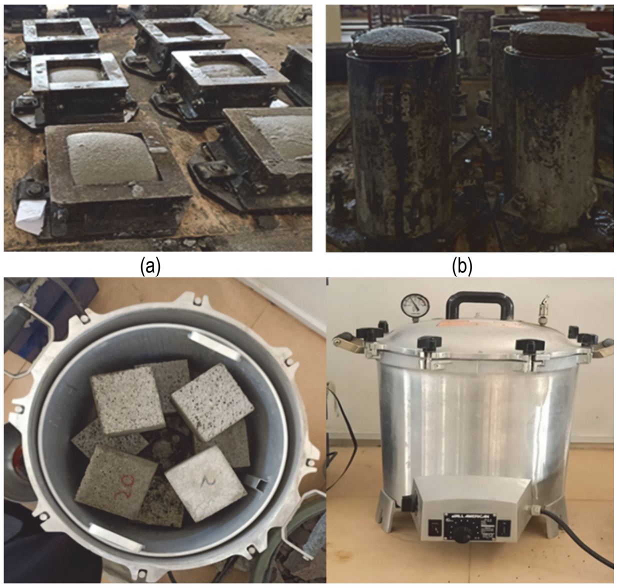

(a) (b)
(c)

Figure 2 Specimen preparation of AAC (a) Aeration of cubes (b) Aeration of cylinders (c) Autoclave curing

2.3 Test Methods
2.3.1 Compressive Strength

11 mix types of AAC were prepared in this research. For each design mix of AAC, 6 cubes (100 mm ×100 mm × 100 mm) were used for analyzing compressive strength. 66 cubes were tested in this research. The compressive strength of Autoclave aerated concrete was recorded according to the code ASTM C1693-11 [26]. Fig. 3a shows the assembly of the compressive strength test of Autoclaved Aerated concrete (AAC).


(a) (b)

Figure 3 Testing of cubes and cylinders during this study (a) Compressive strength test (b) Split tensile strength test

2.3.2 Split Tensile Strength

Similarly, for each design mix of AAC, 6 concrete cylinders were used checking splitting tensile strength. A Total of 66 concrete cylinders of size (200 mm length and 100 mm diameter) was done for examining the splitting tensile strength of AAC. Fig. 3b shows the assembly of split tensile strength test of AAC samples.

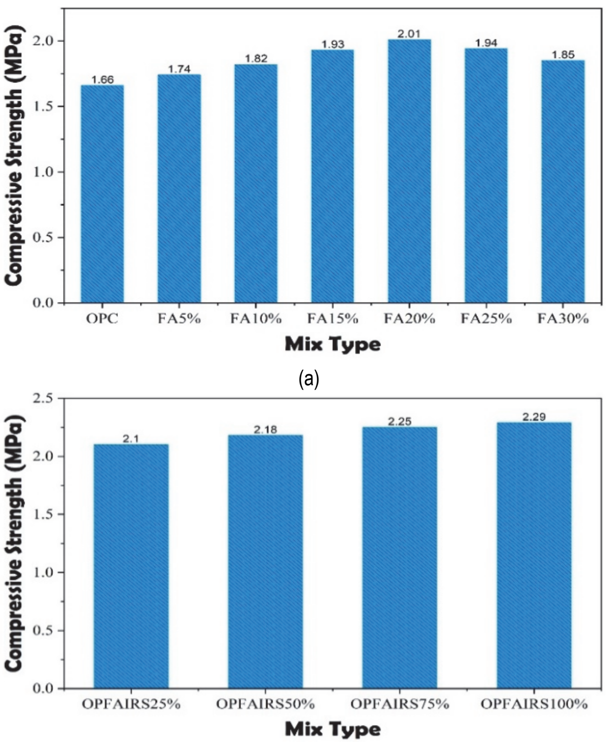
2.3.3 Dry Density

The dry density of all mix ids were checked according to the code ASTM C1693-11 [26]. After the experimental samples' masses stabilized at 105 °C in a drying oven, their weight was measured with a precision scale. In a similar manner, calipers were used to measure and record their sizes.

3 RESULTS AND DISCUSSIONS

3.1 Compressive Strength

Fig. 4a indicates the compressive strength of AAC blended with different content of fly ash as a cement replacement. Based on Fig. 4a it is clear that when fly ash was substituted for 20% of the cement, the ACC recorded its maximum compressive strength. The magnitude of this maximum compressive strength is 2.01 MPa. At 2.01 MPa, the compressive strength is 18% more than that of the controlled mix (1.66 MPa). At the controlled mixture, the lowest compressive strength was measured. The pore filling effect and the potential pozzolanic reaction of the FA are responsible for the improvement in compressive strength up to 20% cement substitution with Fly ash.



(b)

Figure 4 Compressive strength of AAC (a) with fly ash replacement (b) with IRS replacement

The strength of the autoclave-aerated concrete decreased as more FA was added because of the diluting effect of the FA, which lowers the amount of calcium hydroxide that is available for product formation. A similar trend was reported by [27, 28].

Fig. 4b indicates the compressive strength of AAC is further increased with the addition of Indus River sand as a fine aggregate replacement. The maximum strength was achieved at 100% replacement of IRS with sand, which is 2.29 MPa that is 82% higher than the strength achieved at 25% IRS replacement with sand.

This increase in compressive strength attributes to the higher water absorption and fineness of IRS than that of quartz sand, which fills the microporous left by other components of Autoclave aerated concrete that results in increase of the interfacial transition zone of Autoclave aerated concrete. Moreover, water absorption decreases the water cement ratio of the mix and increases the density of the mix, which can be seen in Fig. 5. This phenomenon increases the compressive strength of the mix.

3.2 Split Tensile Strength

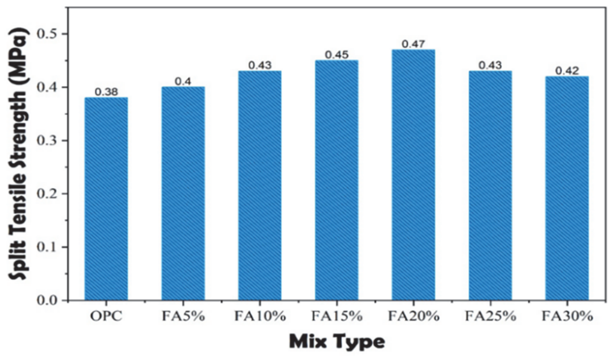
Fig. 5 indicates the split tensile strength of AAC blended with different % of cement replacement with fly ash. When 20% of the cement was substituted with FA, the maximum split tensile strength of ACC was measured at 0.47 MPa, nearly 19% higher than the controlled mix; the minimum strength was 0.38 MPa at the controlled mix. It came to light that adding 20% more FA to an ACC mixture increased the split tensile strength. This is because the smaller particles in the FA fill up all the spaces in the autoclaved concrete and make it denser than the control mix Autoclaved Aerated Concrete. The strength of the autoclave-aerated concrete decreased as more FA was added because of the dilution effect of FA. A similar kind of work was reported by [29]. Fig. 5b indicates the split tensile strength of AAC is further increased after the addition of Indus River sand. The higher water absorption and better grading of IRS- more fineness than the hill sand (quartz sand) increases the density of the mix and fills the pore; ultimately, increases the split tensile strength of the mix.

3.3 Dry Density

Fig. 6a shows the dry density of AAC blended with different contents of fly ash and cement. The data obtained indicate that an increase in fly ash content was associated with a decrease in dry density.

The maximum dry density was achieved at 15% replacement of FA which is almost equal to FA replacement in case of strength enhancement. Mixing was done by volume, only 2/3rd of the molds was filled with AAC. The fact that fly ash has a lower specific gravity than cement is the factor causing the density to decrease.

Fig. 6b indicates the Dry density of AAC is further increased after the addition of Indus river sand. That is because of the higher water absorption and better grading of IRS - more pore filling capability of the hill sand than the quartz sand.



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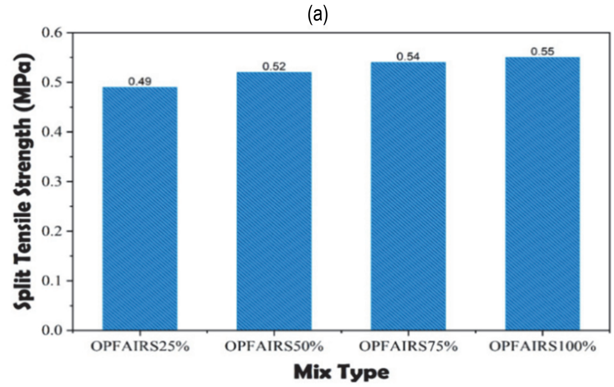
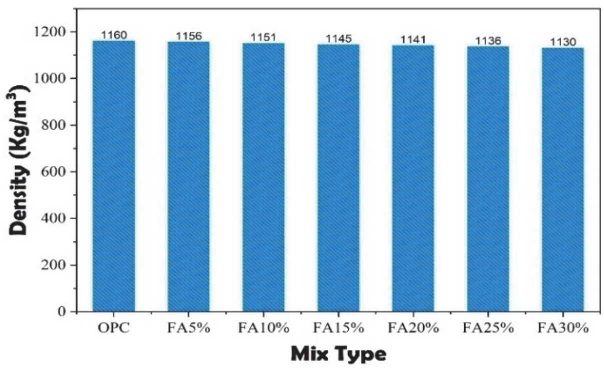


(b)

Figure 5 Tensile strength of AAC (a) with fly ash replacement (b) with IRS replacement



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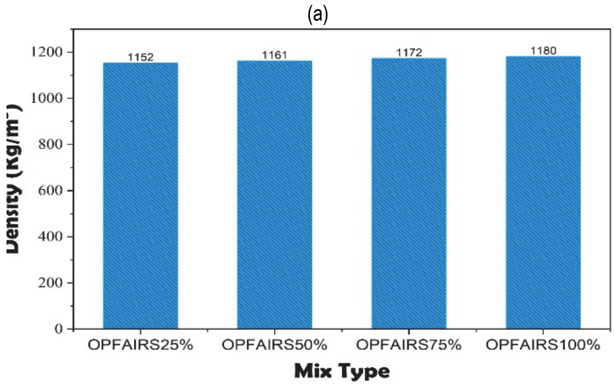

(b)

Figure 6 Density of AAC (a) with fly ash replacement (b) with IRS replacement

3.4 Environmental Impact Assessment

The Intergovernmental Panel on Climate Change (IPCC) Report has affirmed that, in comparison to 2010, GHG emissions must be reduced by 45% by 2030 and by 100% by 2050. To achieve these objectives, international cooperation needs to be strengthened even more [30, 31]. Since the construction industry is responsible for 39% of energy-related emissions worldwide, it is crucial for the response to the climate emergency when compared to other sectors [3, 30]. 30 billion tons of concrete are used annually worldwide as the backbone of the building industry, and its consumption is growing even faster than that of steel or wood [32]. Furthermore, of all the building materials, concrete has the largest carbon footprint, accounting for the fact that at least 8% of global carbon emission solely come from the cement for concrete production [33]. That is the reason why researchers have concentrated on identifying substitute materials that may be used to reduce the environmental impact of cement.

Furthermore, waste products have emerged as preferred substitutes for aggregates and cement in this procedure. Every waste material that is used as a substitute in the production of concrete has an embodied carbon due to the shipping, processing, and screening involved. Compared to cement and aggregates, these materials will have a significantly lower embodied carbon value. However, it is crucial to determine the concrete's embodied carbon, including fly ash and Indus River Sand, in order for the building sector to accept the created concrete as an eco-friendly and eco-efficient concrete. All of the materials' equivalent CO_2 values were obtained from the literature (see Tab. 3). These numbers represent "cradle to gate," which covers mixing, transportation, and production. Each raw material's CO_2 per 1 m^3 of concrete was calculated, and all of the CO_2 from the various materials used to produce RCC was then added up using Eq. (1) as suggested by [34] to obtain the overall CO_2 emissions of each concrete mix ([8]).

$$CO_{2ACC} = \frac{1}{4}\sum_{i=1}^{n}\left(\mathrm{Wi} - \mathrm{CO2i} - \mathrm{e}\right) \quad (1)$$

where, CO_{2ACC} is the total embodied CO_2 of 1 m^3 ACC concrete, in kg CO_2/m^3 n is the total raw material in the AAC mix, Wi is the total amount in kg of material i to produce 1 m^3 concrete

Fig. 7 shows the influence of ingredients in autoclaved aerated concrete on embodied CO_2 emission of AAC consisting of FA as a cement replacement individually and Optimum FA % (20%) and Indus river sand as a fine aggregate replacement combined. The calculations of the total CO_2 emissions from each material used in the production of AAC are shown in Tab. 4. Tab. 5 shows that the total CO_2 emission of the FA5 mix is decreased to 390.322 kg CO_2/m^3 when 5% of the cement is replaced with fly ash. This is a reduction of 4.73% when compared to the control mix, which produced 409.71 kg CO_2/m^3. Additionally, an increase in fly ash content eliminated an equivalent quantity of cement CO_2 emissions. When 10% FA, 15% FA, 20% FA, 25% FA, and 30% FA were substituted for cement in the AAC mix, the total CO_2 emissions were 373.59 kg CO_2/m^3, 355.53 kg CO_2/m^3, 337.47 kg CO_2/m^3, 319.41 kg CO_2/m^3, and 301.35 kg CO_2/m^3, respectively.

These emissions were 8.82%, 13.22%, 17.63%, 22.45%, and 26.45% less than those of the control AAC mix. Similarly, Tab. 5 showed that the mix that substituted 25% of Indus River Sand and 20% of FA for cement produced a total CO_2 emission of 337.21 kg CO_2/m^3, which was 17.68% less than the control mix's 409.71 kg CO_2/m^3

emissions. Furthermore, it was found that adding 20% and 100% of FA to the AAC mix substituted cement, resulting in a further reduction of CO_2 emissions to 336.67 Kg CO2/m^3, a decrease of 17.82% from 409.7 kg CO_2/m^3 at the control mix of AAC. Additionally, Fig. 8 illustrates how the components of autoclaved aerated concrete, which include FA as a substitute for cement separately and Optimum FA% (20%) and Indus river sand as a substitute for fine aggregate jointly, affect the embodied energy of AAC. Tab. 6 shows the calculations of total embodied energy from individual materials used in the preparation of AAC. The lowest embodied energy of ACC is recorded at 30% Portland cement (PC) replacement.

Fly ash (FA). The magnitude of lowest embodied energy is 1648. 16 MJ/m^3, which is 28.16% lower than the control mix of ACC 2296.16 MJ/m^3. Fig. 8 shows that a significant portion of the embodied energy in autoclave-aerated concrete is produced by the PC. The contribution of other components in ACC is significantly less than that of PC. The addition of FA and Indus River Sand (IRS) to autoclave aerated concrete improved its sustainability, demonstrating the potential for improved autoclave concrete performance and sustainability through the use of these kinds of waste materials. To sum up, FA and IRS not only improved the strength qualities of concrete at nearly the same density as autoclave aerated concrete, but they also lessened the environmental impact of the material.

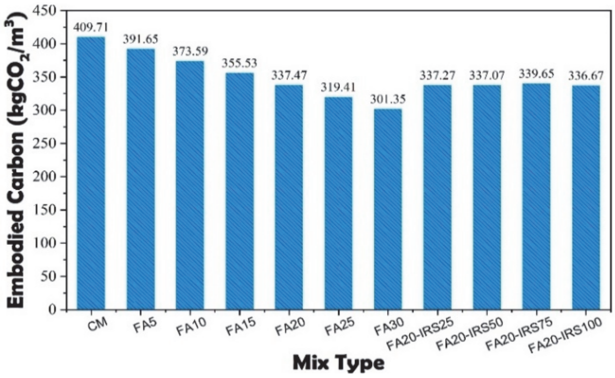

Figure 7 Total CO_2 emission for all mix types made with FA and IRS

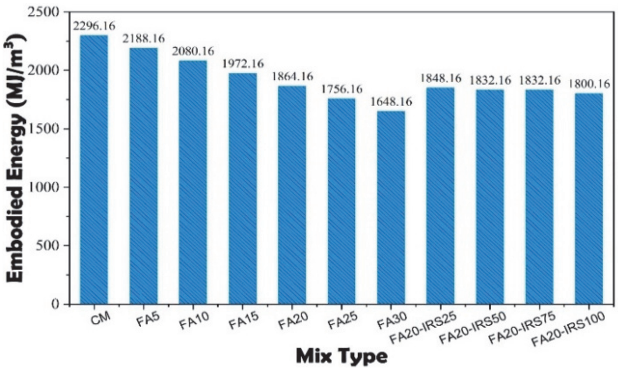

Figure 8 Total embodies energy for all mix types made with FA and IRS

Table 3 Sustainability of materials of AAC

S.no	Material	Embodied Energy / MJ/KG	Reference	Embodied Carbon Kg CO_2/kg	Reference
1	Cement	5.50	(Hammond et al. 2011)	0.93	Zhu 2011
2	Fly ash	0.10	(Kuruscu and Girgin 2014)	0.027	Tumer and collin 2013
3	Aluminum	20.1	Claes Fredriksson 2019	16.6	Claes Fredriksson 2019
4	Sand	0.08	(Hammond et al. 2011)	0.0139	Tumer and collin 2013
5	River Sand	0.07	Anshumali Mishra et al. 2023	0.012	Anshumali Mishra et al. 2023
6	Water	0.01	(Hammond et al. 2011)	0.000196	(Yang et al. 2013)

Table 4 Total CO2 emission for one cubic meter of AAC / kgCO_2/m^3

Materials	MIX										
	CM	FA5	FA10	FA15	FA20	FA25	FA30	FA20-IRS25	FA20-IRS50	FA20-IRS75	FA20-IRS100
Cement	372	353.4	334.8	316.2	297.6	279	260.4	297.6	297.6	297.6	297.6
Fly ash	0	0.54	1.08	1.62	2.16	2.7	3.24	2.16	2.16	2.16	2.16
Aluminum	26.56	25.232	23.904	22.576	0	19.92	17.264	21.248	21.248	21.248	21.248
Sand	11.12	11.12	11.12	11.12	11.12	11.12	11.12	8.34	5.56	5.56	0
IRS	_	_	_	_	_	_	_	2.58	5.16	7.74	10.32
Water	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Total	409.71	391.65	373.59	355.53	337.47	319.41	301.35	337.27	337.07	339.65	336.67

Table 5 Total embodied energy for 1 m^3

Material	Total embodied energy for one cubic meter of AAC / MJ/m^3										
	MIX										
	CM	FA5	FA10	FA15	FA20	FA25	FA30	FA20-IRS25	FA20-IRS50	FA20-IRS75	FA20-IRS100
Cement	2200	2090	1980	1870	1760	1650	1540	1760	1760	1760	1760
Fly ash	0	2	4	6	8	10	12	8	8	8	8
Alimuimun	32.16	32.16	32.16	32.16	32.16	32.16	32.16	32.16	32.16	32.16	32.16
Sand	64	64	64	64	64	64	64	48	32	32	0
IRS	_	_	_	_	_	_	_	14	28	14	56
Total	2296.16	2188.16	2080.16	1972.16	1864.16	1756.16	1648.16	1848.16	1832.16	1832.16	1800.16

4 CONCLUSION

In this study, fly ash and Indus River sand were replaced with cement and Fine aggregate respectively to investigate the mechanical and durability performance of AAC. Based on obtained test results the following conclusions can be drawn from this study.

1. The results indicate that the AAC samples' compressive strength rose when fly ash substituted cement up to 20% level and then declined when more fly ash was added. This concludes that the optimum Fly ash replacement percentage of cement in AAC is 20%.

2. Moreover, compressive strength further increased after the addition of IRS in the optimum 20% cement replacement with fly ash. It was observed that strength

increased with the increasing percentage of IRS and gave maximum compressive strength at 100% replacement. All in all, the maximum compressive strength achieved is 2.29 MPa, that is 37% more than the control mix (1.66 MPa).

3. The behavior of Split tensile strength after the replacement of cement and fine aggregate with fly ash and IRS was the same as compressive strength. Maximum split tensile strength was achieved at optimum fly ash percentage, which is 20%, used as a cement replacement along with 100% IRS used as a Fine aggregate replacement. The magnitude of the maximum split tensile strength is 0.55 MPa that is 44% greater than the controlled mix id (0.38 MPa).

4. The minimum dry density occurred was 1130 kg/m^3 at 30% cement replacement with Fly ash. However, the maximum dry density of 1180kg/m^3 was achieved at 100% replacement of fine aggregate with IRS.

5. The mixture in which Fly ash was substituted for 20% of the cement content and IRS was substituted 100% for Fine aggregate resulted in 21.69% decrease in embodied CO_2 when compared to the control mix, which produced Embodied carbon 409.71 KgCO$_2$/m^3. The mix ID OFA100IRS produced 336.67 KgCO$_2$/m^3.

6. Similarly, for embodied energy the mixture in which Fly ash was substituted for 20% of the cement content and IRS was substituted 100% for Fine aggregate resulted in 27.5% decrease. When compared to the control mix, which produced Embodied energy of 2296.16 MJ/m^3. The mix ID OFA100IRS produced 1800.16 MJ/m^3.

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Contact information:

Mohsin ALI, Lecturer
Department of Civil Engineering (TIEST), NED University of Engineering and Technology,
Karachi, Pakistan
E-mail: mohsinjani@neduet.edu.pk

Abdul Salam BULLER, Associate Professor
Department of Civil Engineering (TIEST), NED University of Engineering and Technology,
Karachi, Pakistan
E-mail: mohsinjani@neduet.edu.pk

Tariq ALI, Assistant Professor
Civil Engineering Department, The Islamia University of Bahawalpur,
Bahawalpur, Pakistan
E-mail: tariqdehraj@gmail.com

Samreen SHABBIR, Lecturer
Civil Engineering Department, Dawood University of Engineering and Technology, Pakistan
E-mail: samreen.shabbir@yahoo.com

Aqeel AHMED, Lecturer
Department of Civil, Environment and Transportation System
College of engineering and Technology, University of Sargodha
E-mail: aqeel.ahmed@uos.edu.pk

Jawad Ur REHMAN, Lecturer
Building & Architectural Engineering Department, Quaid-e-Awam University of Engineering Science & Technology,
Nawabshah, Sindh Pakistan
E-mail: jassociate86@gmail.com