Pelletizing artificial geopolymer aggregates with industrial recycled materials to produce sustainable concrete.

Alaa Hussein Kamal[1], Taher A.Tawfik [2], A.Serag Faried[3]

[1]Researcher, Faculty of Engineering, Fayoum University, Fayoum, Egypt
[2] Lecturer, Department of Construction and Building Engineering, High Institute of Engineering, October 6 City, Egypt
[3] Assistant professor, Civil engineering department, Faculty of Engineering, Fayoum University, Fayoum, Egypt

---***---

Abstract – *The effect of using artificial cold-bonded coarse aggregate on the behavior of concrete based on both fly ash (FA) and ground granulated blast furnace slag (GGBFS) in addition to perlite is investigated in this study. Ordinary concrete is made with artificial coarse aggregates utilizing the fly ash-slag-perlite cold bonded process, which does not require the use of cement as a bonding agent. Three different combinations of manufactured coarse aggregate as a substitute for natural aggregate are as follows: 25%, 50%, and 75%. In the mixtures, dolomite was employed as a natural coarse aggregate concrete (NCA). During the sieve analysis, specific and unit weights were recorded. The specific and unit weights were determined. Furthermore, on the 7th and 28th days of curing with fresh tap water, a compressive test was performed. There are additional comparison studies between using natural coarse aggregate and employing varying ratios of artificial coarse aggregate. The results show that the mechanical and chemical properties of Slag and fly ash artificial aggregate generated by the cold bonded approach are comparable to natural aggregate, with the added benefit of recycling waste materials like slag and fly ash. By increasing the artificial aggregate content, the volume weight and compressive strength of Artificial Coarse Aggregate Concrete (ACAC) were also reduced. Compressive strength of (17.5 - 31.55) N/mm2 was obtained.*

***Key Words*:** recycled materials, Non-renewable resources, Cold bonded pelletization, GGBFS (Slag), Fly ash, sustainable concrete, Alkaline activator, Artificial aggregate

1. INTRODUCTION

Dedicated to addressing the issues raised by industrial waste materials, as well as the depletion of non-renewable aggregates resources, to keep all of the earth's environmental systems in balance; additionally, ecological integrity is maintained while natural resources are consumed by humans at a rate that allows them to replenish themselves, as a simple definition of environmental sustainability.

Concrete is a commonly used structural material all over the world due to its long-lasting and durable properties, as well as its adjustable compressive strength [1].

One of the most important properties of concrete is its versatility. Depending on the intended use, it can be produced in any pattern, color, and/or shape. Thanks to improvements in the construction industry, concrete is now available and practicable in any location and under any climatic conditions. [2]. Ordinary concrete components are mostly natural resources, with aggregate accounting for 70-80% of the percentage [3]. Sand is a fine aggregate that is also the third most utilized natural material after water and air [4]. Coarse aggregate includes materials such as gravel, lime, basalt, and dolomite. Coarse aggregate is likewise a natural and restricted resource that is being depleted as a result of its numerous uses in the construction sector [3].

In terms of natural aggregate consumption, artificial and recycled aggregates should be encouraged as a partial replacement for natural aggregates. Massive volumes of industrial solid wastes, sludges, reservoir sediments, and demolition wastes are recycled in the manufacturing of both concrete and aggregates in this context, which is a critical problem in driving waste management toward a more sustainable concrete construction future, in addition to more long-term development [5], [6]. The cement industry employs raw materials as the foundation of its manufacturing process and releases a considerable amount of hazardous CO_2 gas into the atmosphere, approximately 7% of which is harmful to the environment and promotes global warming [7]. Because of the multi-production, eco-friendly industries and recycling waste materials are two of the most difficult challenges today.

For example, fly ash is used in roughly 30% of low-tech applications such as fill building. as well as basic training in embankments, backfills, pavement foundations, and subbases; intermediate technical applications such as the manufacture of mixed cement, concrete pipes, and precast/lightweight concrete, prestressed good autoclaved aerated concrete, and bricks/blocks aggregate lightweight [9], [10]. In addition, to fly ash, Ground Granulated Blast Furnace Slag (GGBFS) is utilized as a partial replacement in cement paste [11]. A unique method of producing artificial lightweight aggregate was introduced into the literature around the turn of the century. The cold-bonding palletization approach was used on dry powder fly ash as an alternate method. Fly ash pellets are made by agglomerating fly ash particles in a tilted rotating pan at room temperature, using water as a wetting agent and Portland cement and/or lime as a binder. This method uses far less energy than autoclaving or sintering to produce artificial lightweight aggregate [12]. The initial phase in the manufacturing of cold-bonded aggregates (CBA) is agglomeration, which is performed by the use of waste and side-effect fine materials. When fines are agglomerated into bigger particles using either pressure or non-pressure agglomeration techniques [13]. Many characteristics influence the manufacturing process. For example, using low angles and high velocities in pelletizers restricts particle development routes, causing particles to clash with each other, and resulting in the formation of tiny aggregates with low efficiency [14]. As reviewed by Feras Tajra et al [15], many publications in cold bonded aggregate production use cement as a binder to obtain fresh pellets. They also outlined the benefits of cold-bonded aggregate. Bui L A et al. [16] published work on making cold-bonded lightweight aggregate using an alkaline solution for high-performance concrete utilizing various combinations of fly ash, slag, and rice husk ash. S. Geetha and K. Ramamurthy [17] also investigated the variables and characteristics of cold bonded aggregate production utilizing geopolymerised low-calcium bottom ash and an ambient temperature curing regime. Here comes the significance of employing a cement replacement to limit the amount of CO2 gas released into the atmosphere, as well as finding alternative resources for aggregate usage by recycling industrial waste materials. Due to the scarcity of research papers that used non-cementitious materials as a bonding agent in the production of artificial aggregate, an alkaline solution of (Na2SiO3) and (NaOH) molarity 8 ml was used in this study with water as an alternative bond material with slag and fly ash, as well as adding perlite powder to reduce the weight of artificial aggregate as a double advantage of reducing cement usage and thus con emissions. Using geopolymer concrete technology, we can also recycle waste materials with environmental benefits. Alkali activation is used to make geopolymer materials from industrial aluminosilicate waste materials such as fly ash (FA), ground granulated blast furnace slag (GGBS), metakaolin (MK), red mud (RM), and others. In terms of mechanical and chemical properties, geopolymer materials generated from Si/Al-rich minerals surpass regular concrete [18], [19]. Finally, the goal of this study is to investigate the effects of using non-Cementous cold-bonded aggregate as a partial replacement of natural coarse aggregate in concrete in terms of mechanical properties and durability.

2. MATERIALS AND METHOD

2.1. Materials

2.1.1. Raw Materials

This project made use of Ordinary Portland Cement (CEM I) grade 42.5 from the Bani-Swif factory. It was subjected to a battery of testing to ensure that it fulfilled Egyptian standards. It has a specific gravity of 3.11, a fineness of 3400 cm2/gm, an initial and final setting time of 80 minutes, and compression strength of 290 and 395 Kg/cm2 after 3, 7, and 28 days, respectively. When coupled with bottom ash that is far away from the boiler's rock bottom, fly ash is called coal ash and is employed in various industrial and construction areas [7]. For chemical products, we obtain fly ash from the Sika firm. We also obtain used slag from Alexandria iron manufacturers (Ezz steel). Figure 1 depicts the XRD pattern for GGBFS. Finally, as a lightweight material, we used perlite powder from ECP on 6 October City. Tables 1 and 2 lists all of the properties.

Table -1: The chemical analysis of materials used

Items (% wt)	Symbol	Cement	Fly ash	GGBFS	Perlite
Calcium oxide	CaO	62.50	5.50	34,16	1.15
Silicon dioxide	SiO_2	20.70	40.20	20,66	73.2
Ferrous oxide	FeO	___	___	0,32	___
Iron oxide	Fe_2O_3	3.01	32.70	0,06	1.60
iron	Fe tot	___	___	0,46	___
Magnesium xide	MnO	___	___	0,05	___
Manganese xide	MgO	0.64	8.00	9,44	0.55
Phosphorus entoxide	P_2O_5	___	___	0,01	___
Sulfur	S	___	___	1,47	___
Chromic oxide	Cr_2O_3	___	___	0,00	___
Aluminum xide	Al_2O_3	5.40	26.50	10,13	15.04
Sodium oxide	Na_2O	0.11	34.90	___	3.60
Potassium xide	K_2O	___	___	___	4.10
Sulfur trioxide	SO_3	2.30	___	___	___
carbon	C		___	1,01	___
Free lime	F. L	2.65	___		___
Loss of ignition	LOI	2.27	___	___	4.20

Table -2: The physical properties of materials used

Items (%wt)	Cement	Fly ash	GGBFS	Perlite
Specific gravity	3.11	2.25	2.68	2.2
Mean particle size (μm)	___	23.4	15.2	___
Surface area (cm^2/g)	3420	3110	4320	___
Bulk density (gm/cm^3)	___	___	___	1.1

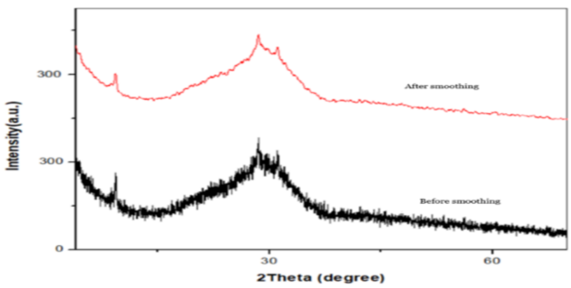

Chart -1: XRD pattern of used GGBFS

2.1.2. Natural Aggregate

The characteristics of crushed dolomite (NCA) size number 1 were acquired from the El Minya quarry and used in this study. To ensure that all dust was removed from the coarse aggregates, they were washed with water before being used. A fine aggregate pass from a 4.75 mm Sieve sand (NFA) from the Helwan quarry was also used as a fine aggregate. It was clean and free of contaminants and organic debris. ASTM C128 and ASTM C127 standards were also met. Table 3 lists the parameters of the natural aggregate used in this study.

Table -3: The physical properties of natural aggregate.

Items (%wt)	Natural sand	Crushed dolomite
Specific gravity	2.52	2.65
Fineness modulus	2.4	2.98
Bulk density (t/m^3)	1.75	1.55
Crushing strength (%)	___	19.3
Absorption (%)	1.7	1.9
Total moisture content (%)	0.1	0.5

2.1.3. Artificial Coarse aggregate

We present a method for producing artificial aggregate and conduct experimental testing to confirm the properties of one of our thesis's most efficient elements. To begin with, making the pelletization disc was a bit challenging, so we used a novel technique and simple method to make the artificial aggregate using a tool that already existed in the lab small mixer. We employed geopolymer reaction to encapsulate waste materials such as fly ash FA, ground-granulated blast-furnace slag GGBFS, and perlite powder PP to manufacture artificial aggregate, and we tried to discover a suitable composition to generate a nice aggregate. Many studies employed regular Portland cement as a binder in the cold bonded aggregate, thus we need to lower the cement percentage in the construction process as it is one of the primary causes of CO2 emissions into the atmosphere. In the geopolymerization process, we use sodium silicate and sodium hydroxide as binders.

A mini mixer is a suitable, available, and economic tool to produce artificial aggregate using a cold-bonded pelletization process compared to a pelletization machine as we described previously the most important factors affecting the cold-bonded pelletization process which we use a modified method to produce artificial aggregate using the mini mixer are the speed and angle of the pelletization disk. Many researchers found that the best speed is from 20 – 40 rpm/min [15], [20] so the speed of the mini mixer is speed is 30 rpm/min approximately. Also, the angle of the pelletization disk used was between 70-90. the mini mixer drum diameter was 70 cm. The duration of pelletization was between 4-5 min. the next Table 4. shows the mixture of the materials used in producing the artificial aggregate Steps of the manufacturing process using the mini mixer.

Table -4: The content of artificial aggregate raw material.

Items(%wt)	GGBFS	Fly Ash	Perlite	Solution/Binder
Mix (1)	3.5 kg	___	___	0.30
Mix (2)	3.5 kg	___	2 liters	0.40
Mix (3)	___	3.5 kg	2 liters	0.45

2.1.3.1. The Steps of the manufacturing process using the mini mixer

As described here the processing procedures is the high affect the quality of cold bonded aggregate so here are the steps followed in manufacturing the artificial aggregate, First, the alkaline solution was prepared by mixing sodium silicate and sodium hydroxide and left for 24 hours in a room temperature (a), Second the mini mixer set at 70 degrees (b), Third raw materials are prepared and charged to the drum (c), Fourth the mini mixer was turned on for two minutes to mix the raw materials (d), Fifth the alkaline solution was added gradually (e), Sixth the mixer was set to 90 degrees and let it turned on until the fresh pellets are formed and before mud fresh pellets are created (f), finally uncharged the mixer from fresh pellets to a plate then curing regime in the air for 24 hrs (g) followed by in the oven for 24 hrs at 80 C.

Fig -1: Steps of manufacturing the coarse aggregates

2.1.3.2. Test Procedures on artificial coarse aggregate

After curing the three types of ACA we conducted some tests according to ASTM C128 and ASTM C127to ensure the quality of the produced aggregate as a mechanical and chemical such as granular gradient, specific gravity, volume weight, crushing strength, water absorption, and chemical test. the mechanical parameters' speed, angle, and duration as we described before highly affect the mechanical properties of the cold-bonded aggregate [21]. consequently, the combination of these parameters helps us to produce a multi-granular size of the cold-bonded aggregate differing between 4 – 20 mm.

Besides physical and chemical properties we used the SEM analysis to get high-resolution images to check for surface cracks, defects, impurities, or corrosion in a variety of materials also EDAX checks are done to have a better understanding of the material on the surface. The elemental composition of a sample may be determined quantitatively via EDX analysis with the technology of mapping we were able to draw multiple color pictures illustrating the concentration of chemical members in the produced ACA Also the characteristics are tabulated in Table 5.

Table -5 The physical & Chemical characteristics of produced ACA.

Items (%wt)	Volume weight	Specific gravity	Crushing Strength %	Absorption %	Chemical Cl and So4 %
Mix (1)	1.26	2.22	24.80	3.09	0.009, 0.13
Mix (2)	1.20	2.10	26.90	5.00	0.003,0.053
Mix (3)	1.08	1.90	23.10	9.00	0.043,0.064

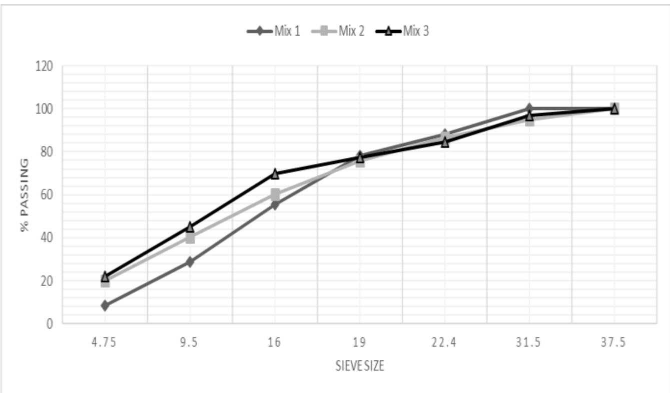

chart -2: Gradation curves of the Artificial Coarse Aggregate

Fig -2: Some tests on the ACA

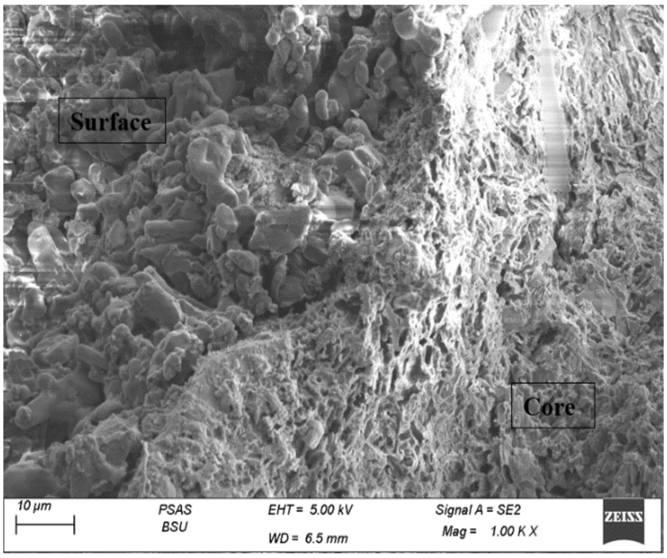

Fig -2: SEM analysis of Mix (1) ACA

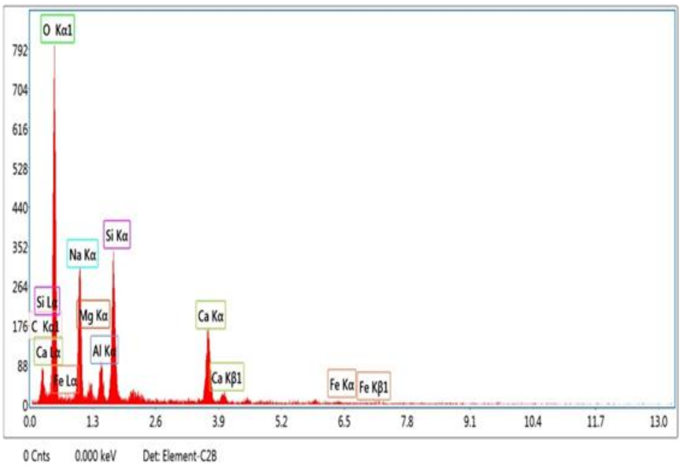

Fig -3 EDX analysis of Mix (1) ACA

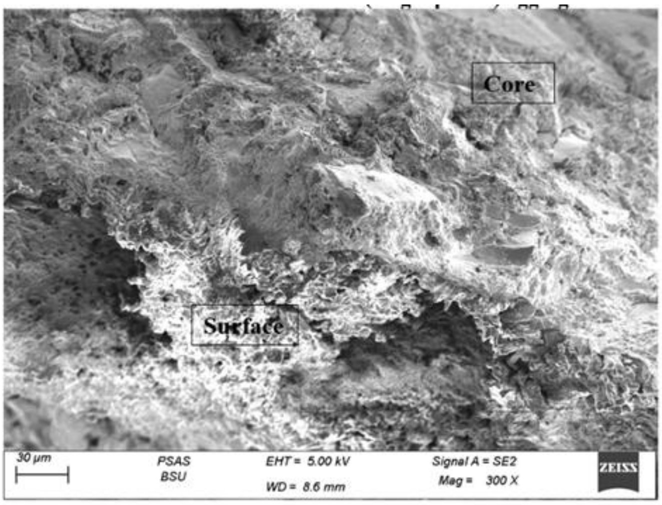

Fig -4: SEM analysis of Mix (2) ACA

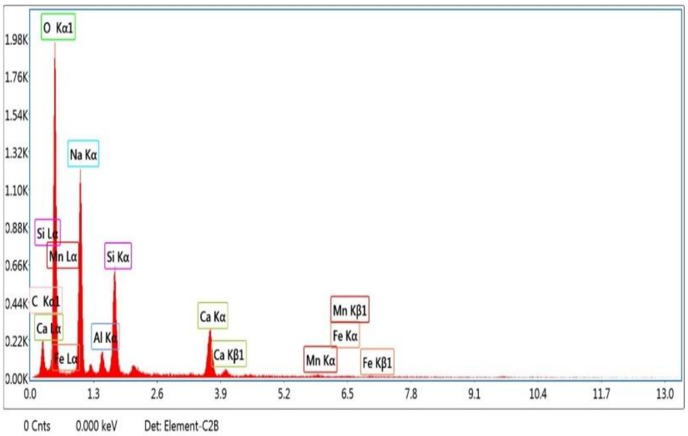

Fig -5 EDX analysis of Mix (2) ACA

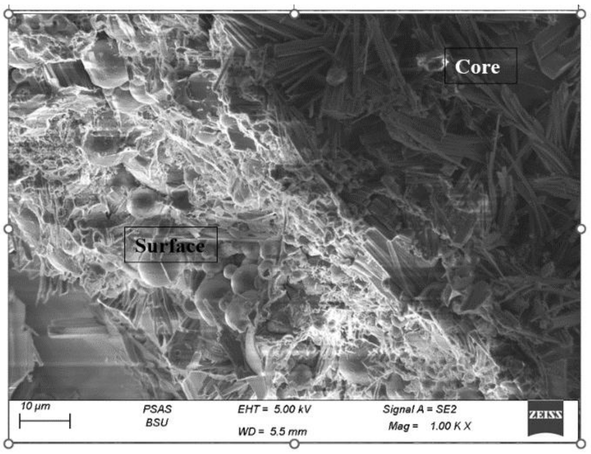

Fig -6: SEM analysis of Mix (3) ACA

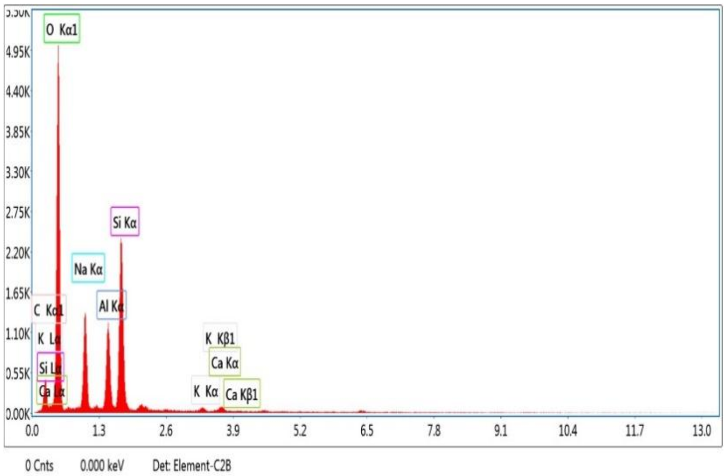

Fig -7: EDX analysis of Mix (3) ACA

2.2. Concrete Mixes & tests with ACA

According to ASTM C 192 mix design of concrete listed in Table 6. cubes which we used, curing regime and testing system for a different replacement to the natural coarse aggregate by the produced artificial cold bonded aggregate with ratios 25,50and 75 % respectively to know the difference in the properties of the concrete by this replacement and to make a comparative study between using natural and artificial coarse aggregate on the concrete physical, mechanical and durability properties besides the microstructure of the concrete.

It is noticed that we need more water in the mix design [22] due to the high absorption of the artificial aggregate used all samples and specimens were prepared and cast in the same way and conditions. after 24 hours from casting, we removed the samples from the cubic molds with dim of 100 x 100 x 100 mm, 100 x 100 x 500 beam, and 150 x 300-cylinder mold were used and execute the curing regime by putting the samples in an oven at 100 C for 24 hours or moved them to moist curing tank. after 7 or 28 days of curing, we pull up the specimens to be prepared for the tests.

Table -6 Concrete mix design

Series		NCA Kg/m³	ACA Kg/m 3	Sand Kg/m3	Cement Kg/m 3	Water Kg/m³	Extra wat er
Control mix		1292.78	0	695.92	350	157.5	—
Group (1)	M1-25%	969.58	323.2	695.92	350	157.5	3.09 % of ACA Wt
	M1-50%	646.39	646.39	695.92	350	157.5	
	M1-75%	323.2	969.58	695.92	350	157.5	
Group (2)	M2-25%	969.58	323.2	695.92	350	157.5	5.00 % of ACA Wt
	M2-50%	646.39	646.39	695.92	350	157.5	
	M2-75%	323.2	969.58	695.92	350	157.5	
Group (3)	M3-25%	969.58	323.2	695.92	350	157.5	9.00 % of ACA Wt
	M3-50%	646.39	646.39	695.92	350	157.5	
	M3-75%	323.2	969.58	695.92	350	157.5	

* NCA = Natural coarse aggregate.

* M1, M2 and M3 refers to (GGBFS), (GGBFS+ Perlite) and (Fly ash+ Perlite) respectively.

* ACA = Artificial coarse aggregate.

* (M1-25) 1 refers to the ACA mix containing GGBFS and 25 refers to ACA replacement ratio %.

Fig -8: Concrete specimen

2.2.1. Volume weight

Cube specimens of size 100x100x100mm were formed for the volume weight of concrete at various ratios of artificial coarse aggregates. After 24 hours, the specimens were remolded and weighted. Their average value is presented to compute volume weight using the following formulae: Volume weight = weight (g) / volume (cm3).

2.2.2. Compressive strength

It is a mechanical test that we used to measure the maximum compressive load a material can afford. A gradually applied load compresses the test item, which is common in the shape of a cube, prism, or cylinder, between the platens of a compression-testing machine. Cubes are used in this test 100 x 100 x 100 mm after curing for 7 and 28 days. using the equation of unknown stress = $\sigma = (P)/A$ we could get the value of compressive strength easily where P is the load and A is the surface area under the load

3. Results and discussion

3.1. Volume weight

The maximum value was noticed to be 2.5 gm/cm3 for 25% replacement of M1 artificial aggregate with decreasing percentage of 0 % and the minimum value was 1.87 gm/cm3 for 75% replacement of M3 artificial aggregate with decreasing percentage of 25 %. As listed in table 7. A result of increasing the percentage of cold-bonded coarse aggregate in concrete is also due to the lightweight properties of perlite and fly ash compared to slag and normal coarse aggregate.

3.2. Compressive strength

The compressive strength of CBAC was 25 percent less than that of NAC when coarse NA was entirely substituted with coarse CBA [23] also Reducing water/binder ratios, has been shown to significantly improve the strength of CBAC concrete, particularly in concrete containing up to 18 percent CBA[24]. As listed in table 8 the maximum compressive strength value at 7 days was noticed to be 28.3 N/mm2 for 25% replacement of Fly ash+ Perlite artificial aggregate with decreasing percentage of 3 % and the minimum compressive strength value at 7 days was 7.60 N/mm2 for 75% replacement of GGBFS artificial aggregate with decreasing percentage of 74.0 %. The maximum compressive strength value at 28 days was noticed to be 31.5 N/mm2 for 25% replacement of GGBFS artificial aggregate with decreasing percentage of 1.90 % and the minimum compressive strength value at 28 days was 16.70 N/mm2 for 75% replacement of GGBFS artificial aggregate with decreasing percentage of 47.90 %. Due to the shortage in crushing strength also the weak core structure matrix of artificial aggregate consequently the more increasing the artificial aggregate the less compressive strength is achieved.

Table -7 Volume weight of all mixes used

Series		Volume weight gm/cm³	%Increasing And decreasing	ACA Volume weight gm/cm³
Control mix		2.5	___	___
Group (1)	M1-25%	2.5	0	1.26
	M1-50%	2.2	-12	
	M1-75%	2.11	-16	
Group (2)	M2-25%	2.42	-3	1.20
	M2-50%	2.28	-9	
	M2-75%	1.95	-22	
Group (3)	M3-25%	2.27	-9	1.08
	M3-50%	2.17	-13	
	M3-75%	1.87	-25	

Table -8. Compressive strength of all groups

Series		Compressive Strength after 7 days N/mm²	% Increasing And decreasing	Compressive Strength after 28 days N/mm²	%Increasing And decreasing
Control mix		29.2	___	32.10	___
Group (1)	M1-25%	27.9	-4.5	31.5	-1.9
	M1-50%	23.3	-20.2	26.9	-16.2
	M1-75%	7.6	-74.0	16.7	-47.9
Group (2)	M2-25%	24.1	-17.5	31.2	-2.8
	M2-50%	23.5	-19.5	29.4	-8.5
	M2-75%	13.7	-53.0	17.5	-45.5
Group (3)	M3-25%	28.3	-3.0	30.4	-5.3
	M3-50%	25.2	-13.7	29.1	-21.8
	M3-75%	15.3	-47.6	20.2	-37.1

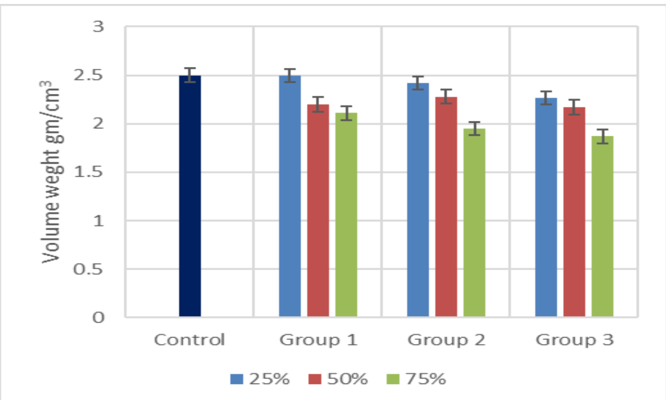

Fig -9: Volume weight comparison for all mixes used

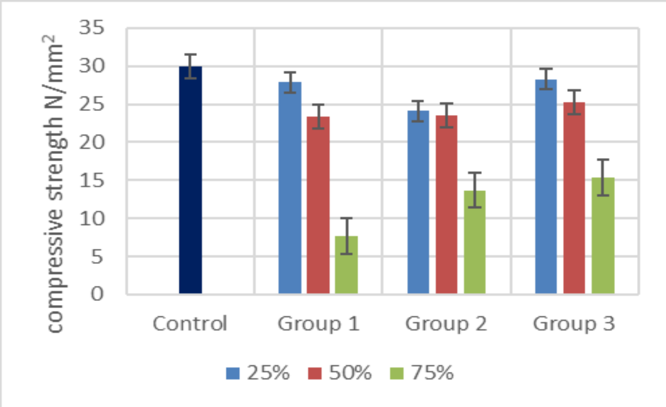

Fig -10: Compressive strength of group (1,2,3) at 7 days comparison

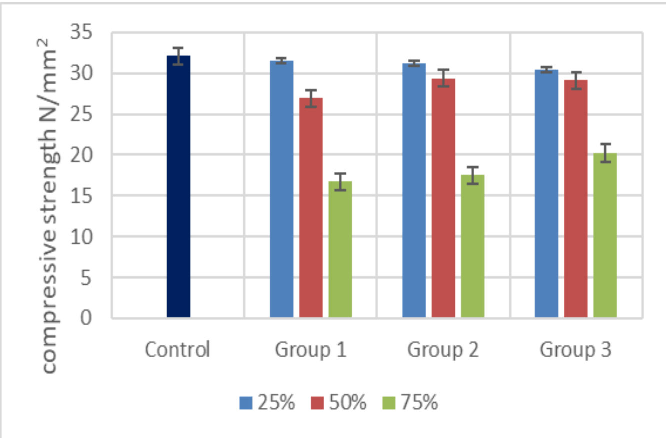

Fig -11: Compressive strength of group (1,2,3) at 28 days comparison

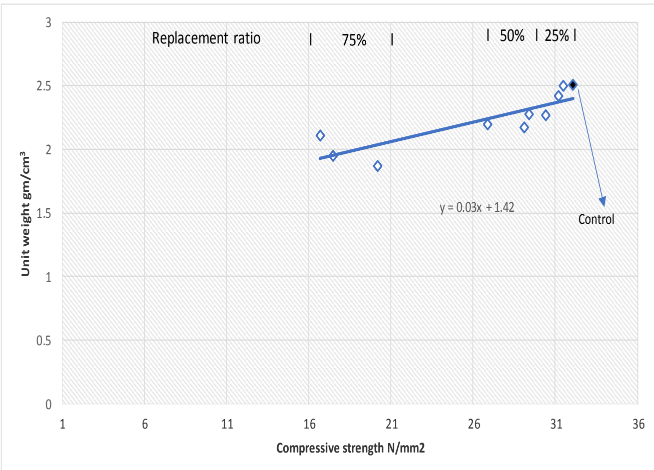

chart -3: Compressive and Unit weight correlation of all groups (1,2,3) at 28 days.

Figure 17. illustrate the relation between the compressive strength and unit weight at different ratios of replacement as the more the replacement ratio is conducted the less the unit weight of the concrete produced also the less compressive strength of concrete produced as a result of decreasing in crushing strength of the produced artificial coarse aggregate.

3.3. Microstructure of concrete

Concrete consists of the cement matrix, aggregate, and Interfacial Transition Zone between them it is known that ITZ influences the durability and mechanical properties of concrete so in normal concrete and due to big differences between aggregate and cement particles a weak area is created on the surface of aggregate. this area is containing a large amount of water and fewer cement particles which produce a weak ITZ leading to reduce bond between aggregate and cement paste [30].

In the next figures 17,18 and 19, we could see that ITZ almost overlaps with the artificial aggregate surface because of the pores and the sinuosity in the surface of aggregate mainly formed by the reaction between Sodium hydroxide and sodium silicate in the cold bonded process besides the cement hydration process output calcium hydroxide could interact with the raw material we used in producing aggregate.

The failure of the concrete under compression seems to occur away from the ITZ between artificial aggregate and the cement paste either in the core of the artificial aggregate or between the ITZ of natural aggregate as shown in figure 15 we see clearly the cracks appear in the sample was chosen after failure under compressive test machine.

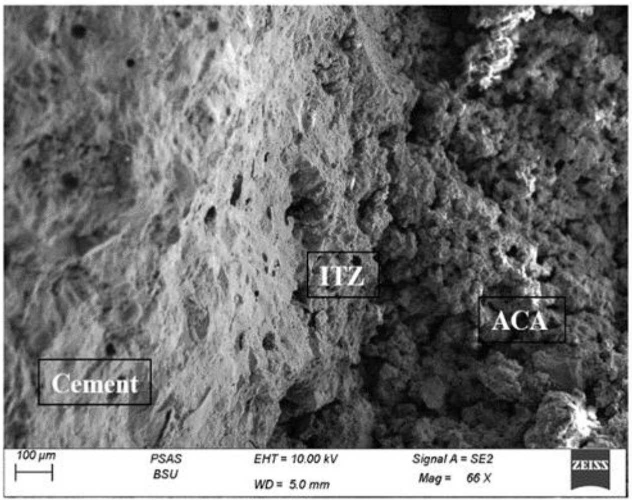

Fig -12: SEM analysis of Slag Mix (1) aggregate in concrete

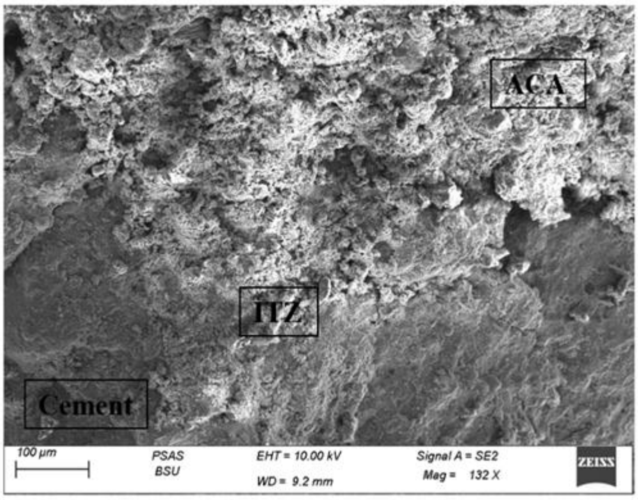

Fig -13: SEM analysis of Fly ash + perlite Mix (3) aggregate in concrete

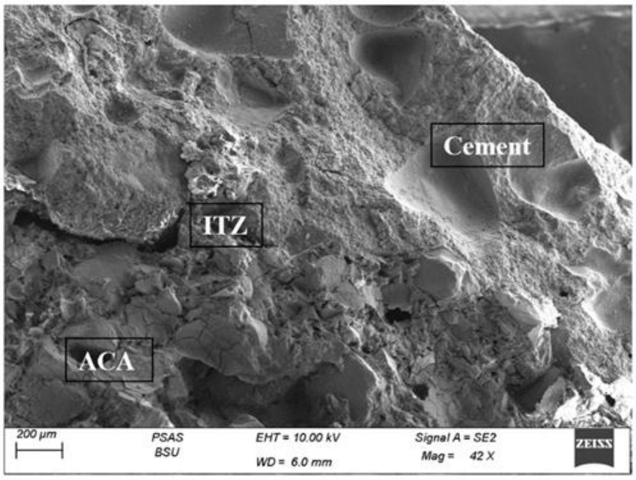

Fig -14:SEM analysis of Slag + perlite Mix (2) aggregate in concrete after compression failure

4. CONCLUSIONS

This study illustrates producing artificial coarse aggregate using waste materials such as Slag and Fly ash with cold bonded technology as a double solution to two main challenges we face, First recycling the waste materials which is a by-product of industrial processes all over the world. Second, stop the bleeding of natural resources of our motherland by investigating the influence of using this artificial aggregate as a coarse aggregate in the concrete industry as a substitution for natural coarse aggregate and how far this affects the behavior of concrete mechanical properties and its durability. This is conducted thus experimental plan using replacement strategy to find out gradually the differences in the concrete behavior in last figure 4.18 we could see that ITZ almost overlaps with the artificial aggregate surface because of the pores and the sinuosity in the surface of aggregate mainly formed by the reaction between Sodium hydroxide and sodium silicate in the cold bonded process besides the cement hydration process output calcium hydroxide could interact with the raw material we used in producing aggregate. Hence some points are listed below:

4.1. Artificial Coarse Aggregate

•Producing artificial aggregate with the traditional mini mixer is a suitable, economical, and easy technique with slag and fly ash as a base material besides being an eco-friendly recycling method and could not be just a waste material [13].

•Artificial aggregate has a round shape and sinuosity surface which leads to high workability and consumes less cement content for bonding [5].

•The mechanical and chemical properties of Slag and fly ash artificial aggregate produced by the cold bonded technique are similar to the natural aggregate and with the benefit of recycling the waste materials such as slag and fly ash.

4.2. Concrete using artificial aggregate

•The compressive strength of Artificial Coarse Aggregate Concrete was decreased by increasing the artificial aggregate content.

•The volume weight of artificial aggregate concrete is decreased by increasing the artificial aggregate content.

• Semi-lightweight concrete is created when using a 75 % replacement ratio of artificial aggregate with Mix 2 (Slag + perlite) and Mix 3 (Fly ash + perlite)

•A good ITZ is created with artificial aggregate and cement paste due to overlapping between aggregate surface and cement particles[31].

•The failure of the compressive strength test occurs away from the ITZ between artificial aggregate and cement paste.

•Compressive strength between (17.5 – 31.55) N/mm2 could be achieved.

•The maximum compressive strength at 28 days was at a 25 %replacement ratio of group 1 (Slag) equal to 31.55 N/mm2 decreasing by 1.7% compared to the control mix as a result of a high density of ACA and low crushing strength.

•The compressive strength of slag group (1) at 7 days is approximately equal to 85 % of 28 days.

•The compressive strength of the slag+ perlite group (2) at 7 days is approximately equal to 75 % of 28 days.

•The compressive strength of Fly ash+ perlite group (3) at 7 days is approximately equal to 85 % of 28 days.

•Using a 50% replacement ratio of artificial aggregate with Mix 1, Mix 2, and Mix 3 results in similar compressive strength to the traditional concrete mix containing natural aggregate.

•Using more than 50% replacement ratio of artificial aggregate with Mix 1, Mix 2, and Mix 3 results in semi-lightweight concrete that could be used for non-structural purposes.

•Besides fly ash, Slag is a suitable waste material used in producing artificial aggregate.

REFERENCES

[1] [1] H. Unis Ahmed et al., “Geopolymer concrete as a cleaner construction material: An overview on materials and structural performances,” Cleaner Materials, vol. 5, 2022, doi: 10.1016/J.CLEMA.2022.100111.

[2] [2] T. R. Naik, “Sustainability of Concrete Construction,” Practice Periodical on Structural Design and Construction, vol. 13, no. 2, pp. 98–103, May 2008, doi: 10.1061/(ASCE)1084-0680(2008)13:2(98).

[3] [3] I. Sims and B. Brown, “Concrete Aggregates,” in Lea's Chemistry of Cement and Concrete, Elsevier, 1998, pp. 907–1015. doi: 10.1016/B978-075066256-7/50028-X.

[4] [4] Y. Cao, Y. Wang, Z. Zhang, and H. Wang, “Recycled sand from sandstone waste: A new source of high-quality fine aggregate,” Resour Conserv Recycl, vol. 179, Apr. 2022, doi: 10.1016/J.RESCONREC.2021.106116.

[5] [5] F. Colangelo and R. Cioffi, “Use of Cement Kiln Dust, Blast Furnace Slag and Marble Sludge in the Manufacture of Sustainable Artificial Aggregates by Means of Cold Bonding Pelletization,” Materials 2013, Vol. 6, Pages 3139-3159, vol. 6, no. 8, pp. 3139–3159, Jul. 2013, doi: 10.3390/MA6083139.

[6] [6] T. R. Naik, “Sustainability of Concrete Construction,” Practice Periodical on Structural Design and Construction, vol. 13, no. 2, pp. 98–103, May 2008, doi: 10.1061/(ASCE)1084-0680(2008)13:2(98).

[7] [7] N. Ali, J. Abbas, M. Anwer, S. K. Alwi, M. Anjum, and R. Raja, “The Greenhouse Gas Emissions Produced by Cement Production and Its Impact on Environment: A Review of Global Cement Processing,” International Journal of Research in Science, vol. 2, Jul. 2015.

[8] [8] S. Nandy, E. Fortunato, and R. Martins, “Green economy and waste management: An inevitable plan for materials science,” Progress in Natural Science: Materials International, vol. 32, no. 1, pp. 1–9, Feb. 2022, doi: 10.1016/J.PNSC.2022.01.001.

[9] [9] G. Baykal and A. G. Döven, "Utilization of fly ash by pelletization process; theory, application areas and research results," Resour Conserv Recycl, vol. 30, no. 1, pp. 59–77, Jul. 2000, doi: 10.1016/S0921-3449(00)00042-2.

[10] [10] C. R. Meesala, N. K. Verma, and S. Kumar, "Critical review on fly-ash based geopolymer concrete," Structural Concrete, vol. 21, no. 3, pp. 1013–1028, Jun. 2020, doi: 10.1002/suco.201900326.

[11] [11] Y. Liu, X. Zhou, C. Lv, Y. Yang, and T. Liu, "Use of Silica Fume and GGBS to Improve Frost Resistance of ECC with High-Volume Fly Ash," Advances in Civil Engineering, vol. 2018, 2018, doi: 10.1155/2018/7987589.

[12] [12] S. İpek, O. A. Ayodele, and K. Mermerdaş, "Influence of artificial aggregate on mechanical properties, fracture parameters and bond strength of concretes," Constr Build Mater, vol. 238, p. 117756, Mar. 2020, doi: 10.1016/J.CONBUILDMAT.2019.117756.

[13] [13] A. Sivakumar and P. Gomathi, "Pelletized fly ash lightweight aggregate concrete: A promising material," Journal of Civil Engineering and Construction Technology, vol. 3, no. 2, pp. 42–48, 2012, doi: 10.5897/JCECT11.088.

[14] [14] R. Manikandan and K. Ramamurthy, "Swelling Characteristic of Bentonite on Pelletization and Properties of Fly Ash Aggregates," Journal of Materials in Civil Engineering, vol. 21, no. 10, pp. 578–586, Sep. 2009, doi: 10.1061/(ASCE)0899-1561(2009)21:10(578).

[15] [15] F. Tajra, M. A. Elrahman, and D. Stephan, "The production and properties of cold-bonded aggregate and its applications in concrete: A review," Construction and Building Materials, vol. 225. Elsevier Ltd, pp. 29–43, Nov. 20, 2019. doi: 10.1016/j.conbuildmat.2019.07.219.

[16] [16] L. A. T. Bui, C. L. Hwang, C. T. Chen, K. L. Lin, and M. Y. Hsieh, "Manufacture and performance of cold bonded lightweight aggregate using alkaline activators for high performance concrete," Constr Build Mater, vol. 35, pp. 1056–1062, Oct. 2012, doi: 10.1016/j.conbuildmat.2012.04.032.

[17] [17] S. Geetha and K. Ramamurthy, "Properties of geopolymerised low-calcium bottom ash aggregate cured at ambient temperature," Cem Concr Compos, vol. 43, pp. 20–30, 2013, doi: 10.1016/j.cemconcomp.2013.06.007.

[18] [18] J. L. Provis, A. Palomo, and C. Shi, "Advances in understanding alkali-activated materials," Cem Concr Res, vol. 78, pp. 110–125, Dec. 2015, doi: 10.1016/J.CEMCONRES.2015.04.013.

[19] [19] F. A. Shilar, S. v. Ganachari, V. B. Patil, T. M. Y. Khan, and S. Dawood Abdul Khadar, "Molarity activity effect on mechanical and microstructure properties of geopolymer concrete: A review," Case Studies in Construction Materials, vol. 16, Jun. 2022, doi: 10.1016/J.CSCM.2022.E01014.

[20] [20] G. K. George and P. Revathi, "Production and Utilisation of Artificial Coarse Aggregate in Concrete - A Review," in IOP Conference Series: Materials Science and Engineering, Oct. 2020, vol. 936, no. 1. doi: 10.1088/1757-899X/936/1/012035.

[21] [21] R. Manikandan and K. Ramamurthy, "Influence of fineness of fly ash on the aggregate pelletization process," Cem Concr Compos, vol. 29, no. 6, pp. 456–464, Jul. 2007, doi: 10.1016/j.cemconcomp.2007.01.002.

[22] [22] P. Grübl, "Mix design of lightweight aggregate concrete for structural purposes," International Journal of Cement Composites and Lightweight Concrete, vol. 1, no. 2, pp. 63–69, Dec. 1979, doi: 10.1016/0262-5075(79)90012-5.

[23] [23] M. Gesoğlu, E. Güneyisi, T. Özturan, H. Ö. Öz, and D. S. Asaad, "Permeation characteristics of self compacting concrete made with partially substitution of natural aggregates with rounded lightweight aggregates," Constr Build Mater, vol. 59, pp. 1–9, May 2014, doi: 10.1016/J.CONBUILDMAT.2014.02.031.

[24] [24] N. U. Kockal and T. Ozturan, "Strength and elastic properties of structural lightweight concretes," Mater Des, vol. 32, no. 4, pp. 2396–2403, Apr. 2011, doi: 10.1016/J.MATDES.2010.12.053.

[25] [25] H. Yıldırım and T. Özturan, "Mechanical properties of lightweight concrete made with cold bonded fly ash pellets," pp. 23–25, 2013.

[26] [26] P. Tang and H. J. H. Brouwers, "The durability and environmental properties of self-compacting concrete incorporating cold bonded lightweight aggregates produced from combined industrial solid wastes," Constr Build Mater, vol. 167, pp. 271–285, Apr. 2018, doi: 10.1016/J.CONBUILDMAT.2018.02.035.

[27] [27] A. Terzić, L. Pezo, V. Mitić, and Z. Radojević, "Artificial fly ash based aggregates properties influence on lightweight concrete performances," Ceram Int, vol. 41, no. 2, pp. 2714–2726, Mar. 2015, doi: 10.1016/J.CERAMINT.2014.10.086.

[28] [28] E. Güneyisi, M. Gesoglu, T. Özturan, and S. _ Ipek, "Fracture behavior and mechanical properties of concrete with artificial lightweight aggregate and steel fiber," 2015, doi: 10.1016/j.conbuildmat.2015.03.054.

[29] [29] G. Joseph and K. Ramamurthy, "Influence of fly ash on strength and sorption characteristics of cold-bonded fly ash aggregate concrete," Constr Build Mater, vol. 23, no. 5, pp. 1862–1870, May 2009, doi: 10.1016/J.CONBUILDMAT.2008.09.018.

[30] [30] M. H. Zhang and O. E. Gjørv, "Microstructure of the interfacial zone between lightweight aggregate and cement paste," Cem Concr Res, vol. 20, no. 4, pp. 610–618, Jul. 1990, doi: 10.1016/0008-8846(90)90103-5.

[31] [31] X. Sun, B. Zhang, Q. Dai, and X. Yu, "Investigation of internal curing effects on microstructure and permeability of interface transition zones in cement mortar with SEM imaging, transport simulation and hydration modeling techniques," Constr Build Mater, vol. 76, pp. 366–379, Feb. 2015, doi: 10.1016/J.CONBUILDMAT.2014.12.014.

BIOGRAPHIES

Alaa Hussein Kamal Works as Civil Engineer at the Egyptian Ministry of water resources and irrigation also a researcher in the civil engineering department at Fayoum university.

2nd Author

Dr. Taher Anwar Tawfik is a Lecturer of Structural Engineering Civil Engineering Department High Institute of Engineering 6th October.

Dr. Ahmed Serag Farid is Assistant professor of Structural Engineering Civil Engineering Department Faculty of Engineering Fayoum University.