

RESEARCH ARTICLE

Effect of waste glass powder and recycled fine aggregate in sustainable concrete

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Abstract

It is required to help improve concrete's efficiency through the use of waste while also preventing river sand and valuable area from becoming pollution dumpsites. Construction and demolition waste (CDW) has a wide range of possible uses in the construction sector and is quite ubiquitous. It is used as recycled aggregates (RA) in building supplies like mortar and concrete, however, is remaining relatively constrained. This is mostly because it lacks the strength and has more porosity and variability when compared to natural aggregates (NA). Countless research has been conducted with the goal of lowering CO₂ emissions, reducing NA exploitation, and enhancing the qualities of these RAs. This research study undertakes a complete experimental assessment to evaluate the impact of adding glass powder and recycled fine aggregates on the creation of sustainable concrete. The study looks at varied proportions of glass powder and recycled fine aggregates, ranging from 0% to 20% with 5% intervals. At a constant temperature of 20°C, the concrete samples are treated to various curing conditions, including both wet and dry curing. Curing times of 3, 7, 14, and 28 days are evaluated. This particular mixture demonstrates a significant increase of 7.2% - 10.76% in strength, indicating that the combined use of 20% GP and 20% RFA results in the highest enhancement of concrete strength among the tested mixtures. This research experiment can be drawn that the inclusion of GP and RFA in concrete gives a tremendous influence in the implementation of mechanical properties and durability for a sustainable concrete.

1. Introduction

Concrete has historically been the world's second most frequently used material after water because of its unique characteristics such as availability, access to its constituents, significant strength, high durability, and construction techniques [1]. It is also an important component of modern civil engineering structures. One of the most important materials for infrastructure development is concrete. With the accelerated development, numerous innovative structures are being constructed while the older ones are torn down and/or reused. Reusing construction materials and increasing the effectiveness of utilization have so emerged as prominent research areas is an efficient technique to increase building material sustainability and minimize environmental burden [2]. Researchers from all around the globe have recently focused on enhancing recycled aggregates in concrete and widening the uses for recycled concrete. The term "recycled aggregates"

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refers to crushed cement concrete or asphalt pavement made from construction waste that is utilized in subsequent construction projects. According to Bu et al. [3] There are two types of recycled aggregates: recycled coarse aggregate (RCA) and recycled fine aggregate (RFA).

As reported by Jesus et al. [4] recycled fine aggregate concrete (RFAC), which replaces sand in the concrete preparation process, has received less research than recycled coarse aggregate concrete (RCAC). The environment benefits with the implementation of RFA. However, because of its various limitations, RFA's application is limited in a range of ways. It was discovered that the prepared, new concrete's workability is decreased by RFA's high water absorption. The inclusion of waste glass powder is another way to mitigate environmental issues relating to proper disposal of waste materials such as glass. Glass is a 100% recyclable raw material. It may be reused without losing any value. Recycling and reusing waste glass as cement replacement helps in the preservation of landfill disposal and lowers the demand for cement extraction in the building industry.

According to Akhil et al. [5] in concrete, substituting cementitious materials like LCD waste glass for cement may be a practical solution to reduce environmental pollution by using less cement and by accommodating solid waste. The scientists did, however, determine that the inclusion of different forms of RA altered mortar performance in different ways owing to their properties.

According to the combined impact on concrete, Singh et al. [6] describes their assessment, which examines the sustainability of fine recycled aggregate with coarse natural aggregates and CRCA. In their studies, the actual concrete (made on-site and analyzed in the lab) was first reduced in size using a sledgehammer to between 50 and 70 mm, and then further with a jaw crusher (nominal maximum: 25 mm). Additionally, they were categorized according to IS 383 as coarse recycled concrete aggregate and fine recycled aggregate. While CRCA was further processed in an abrasion machine, FRCA was utilized directly in concrete.

Glass can be harmful when disposed of in landfills since it cannot decompose, and doing so can be expensive. But when waste glass is utilized to make concrete in place of cement, there are various perks in terms of energy efficiency, environmental impact, and cost considerations. Increased interactions between the glass particles and cement hydration processes are encouraged by using crushed waste glass as a cement substitute. This alternative not only helps to address the problems with glass disposal, but it also has benefits in terms of resource conservation and reduced environmental effect during the production of concrete [7]. The inclusion of waste glass has been studied as a supplementary element in the production of sustainable concrete. The protracted characteristic of concrete with waste glass powder against chloride absorption was found to be excellent. Since there is consideration of Sulfides, sulphates, and alkalis (that also incorporate more alkali to the concrete) are all environmental hazardous chemical components that raise the danger of ASR over the concrete lifespan. Alkali-silica reaction (ASR) can be reduced by adding a small amount of lime to a pozzolan of high properties.

A mixture of silicon dioxide, washing soda, and calcite (CaCO_3) melts to produce glass by heating it to a high temperature and then cooling it under controlled temperature. The main sources of waste glass are bottles, jars, windows, windshields, bulbs, cathode ray tubes, etc. The material kind of glass is well-known all across the world. Around 5000 BC, this material was discovered, and it has since been made in many different varieties for purpose.

Sobolev et al. [8] emphasize the inherent renewability of glass, noting that it can be recycled without any loss in quality, making it endlessly sustainable resources. The complexities arise in reusing glasses with multiple colors and addressing the variations in chemical composition among different glass types, as pointed out in the study by [9].

A glass is solid, non-crystalline, typically transparent, amorphous (meaning it lack long range order in the solid phases) material It is usually applied in everyday situations in many varieties such as windowpane,

container glass, bottles, headlight glass, tube glass, and other varieties of glasses. According to Shi et al. (10), soda-lime glass appears notably among these varieties, making up in excess of eighty percent of the total amount of waste glasses. Waste glass has drawn attention as a potential partial replacement for coarse aggregate, sand, and cement in the creation of concrete and mortar. In order to do this, waste glass must be crushed to a precise size and added to the concrete mixture. By doing this, the goal is to increase the sustainability of the building materials while reducing their negative effects on the environment.

A study was done empirically by Du et al. [11] to investigate how glass powder (GP) impacted the cement content. They altered the ratio of cement replacement, varying it from 0% to 60% by volume. Their data confirmed that if the cement replacement is less than 30%, the pozzolanic interaction between glass particles and cement hydration process restricts the cement substitution by not reducing the concrete compressive strength after 28 days. Additionally, with increasing glass powder concentration up to 60% cement replacement, the resistance to chloride ion and water penetration constantly rises. In view of their research at 60% substitute rate, the compressive strength remained at 85% but the electrical resistivity and water penetration depth were lowered by 95% and 80%, respectively compared to control mix.

In a recent research paper by Olabimtan and Mohammad [12], the emphasis was on the use of a bipartite mixture made of discarded glass powder and coal bottom ash as a cement substitute in the manufacture of sustainable mortar. The goal of the study was to determine whether this mixture had the ability to improve mortar materials' environmental performance. However, WGP and CBA proportions ranging from 0% to 20% with 5% intervals. The mortar samples are treated to a variety of curing requirement temperatures (20 °C), and curing times (7 and 28 days), all while keeping a constant water/cement ratio of 0.35. The research findings show that including WGP and CBA in the mortar formulation improves performance significantly, notably in terms of compressive and flexural strength. The use of WGP leads in compressive strength improvements ranging from 3.4% to 20.8% and flexural strength improvements ranging from 1.7% to 20.3%. Notably, a binary combination of 10% waste glass powder (WGP) and 10% coal bottom ash (CBA) led to a noteworthy improvement of 10.6% in flexural strength. Zeybek et al. [13] discovered that 20% of the cement content is the ideal replacement level for waste glass powder (WGP) in concrete. The combination of WGP with crushed glass particles, on the other hand, initially increased mechanical characteristics but later decreased due to reduced workability. As a replacement level, they recommend 10% WGP, which not only reinforces the concrete but also improves workability by successfully integrating waste glass particles. When adding micro powdered glass into cement-based materials, the risk of an alkali-silica aggregate reaction must also be considered. This phenomenon occurs due to a chemical reaction between the alkalis present in cement and the reactive minerals found in the aggregate. It emphasizes the importance of considering and addressing this reaction in the overall construction process. Geopolymer concrete (GPC) using waste glass aggregate (WGA) was the subject of research by Özkılıç et al. [14]. They discovered that a NaOH concentration of 16 and 10% glass aggregate produced sustainable GPC with the appropriate characteristics. To maximize the usage of waste materials in GPC, the researchers created strength models and carried out SEM investigation. In a separate research by Çelik et al. [15] The study investigated how the inclusion of waste glass powder (WGP) affected the workability and setting time of geopolymer concrete (GPC). The results indicated that the incorporation of WGP resulted in a decrease in workability and slump values. Additionally, higher concentrations of sodium hydroxide led to increased strength but reduced setting time and workability. After careful analysis, it was determined that a mixture containing 10% WGP and NaOH with a molarity of M13 offered the best combination of fresh properties and long-term hardening characteristics for GPC.

Previous research has demonstrated the benefits of waste glass powder in cement composites, but little emphasis has been paid to combining it with recycled aggregate as an alternative to cement and a substitute for fine aggregates. An in-depth analysis into the effects of waste glass powder and recycled fine aggregates on the production of sustainable concrete is required.

2. Materials and methods

2.1. Material

2.1.1. Portland cement

In the study mentioned, CEM III type cement was used to make concrete mixes. Standards set out by ASTM C150/C150M-21 [16] apply to this type of cement. According to ASTM specifications, concrete was prepared with 42.5-grade cement, which is meant to reach a minimum compressive strength of 42.5 (MPa) after 28 days of curing. The use of this specific type and grade of cement was likely chosen in order to meet certain strength requirements for the concrete.

2.1.2. Waste glass powder

A glass is solid, non-crystalline, typically transparent, amorphous (meaning it lack long range order in the solid phases) material. It is usually applied in everyday situations in many varieties such as windowpane, container glass, bottles, headlight glass, tube glass, and other varieties of glasses. Based on its chemical characteristics, glassware is classified as soda-lime glass among others. As stated by Saribiyik et al. [17] GP is a solid waste that is grinded employing sieves after being broken up and processed. It is utilized for route boundaries, reinforcing of composite materials, and outer layer modification by pulverizing, integrating glass powder and reinforcing fillers in the processing of polymer which minimizes its manufacturing demand. A fine waste glass powder, with a particle size below 90 μm , derived from a variety of colored wine bottles, was employed in the study. Bulbous narrow-necked bottles were sourced from various places, including wine stores, roadside trash, campus hostels, and house-to-house collection in Haspolat, Lefkosa, and Gonyeli, Northern Cyprus. To prepare the bottles for further use, they underwent soaking, washing, and drying processes to remove unwanted substances. Subsequently, the dried bottles were crushed using a machine called the Los Angeles Machine after undergoing extensive revolutions. The crushed material was then sieved to obtain waste glass powder with a size of 75 μm , matching the gradation of particles variation of the cement paste. This specific particle size was chosen to ensure a dense matrix with minimal voids. Fig. 1 illustrates the collection of bottles from different locations, the soaking process, the breaking of bottles, and the resulting glass powder after crushing and sieving.

2.1.3. Recycled fine aggregates

Recycled fine aggregate are sustainable material for construction. The utilization of recycled fine aggregate in concrete has a positive impact on the environment [18]. This material is obtained from previous concrete and also from crushed waste concrete. The process of crushing this type of waste material to form a recycled fine aggregate is shown Fig. 2.

2.1.4. Fine aggregate

Fine aggregate, which refers to any particle with a size less than 4.75 mm, is often used in concrete mixtures as a way to fill the voids between the larger coarse aggregate particles. In the study mentioned, the fine aggregate used was crushed limestone, which met ASTM C33/C33M-18 [19] standards. According to ASTM C136/C136M-19 [20] standards, screening was used to regulate the sand's particle size distribution. A sieve chart is presented. Using sand with a specific grain size distribution can help to ensure that the concrete has the desired properties, such as work ability and strength. The water absorption capacity of the fine aggregate, as well as its specific gravity, can also affect the properties of the concrete. The sand was utilized in an inclusive (SSD) state, as required by ASTM C2917a [21] to reduce the amount of water needed for mixing and lower the possibility of excessive absorption by the fine aggregate. Table 2 shows the physical properties

of sand. By effectively managing the properties of the fine aggregate, it becomes feasible to attain the desired qualities of the concrete.

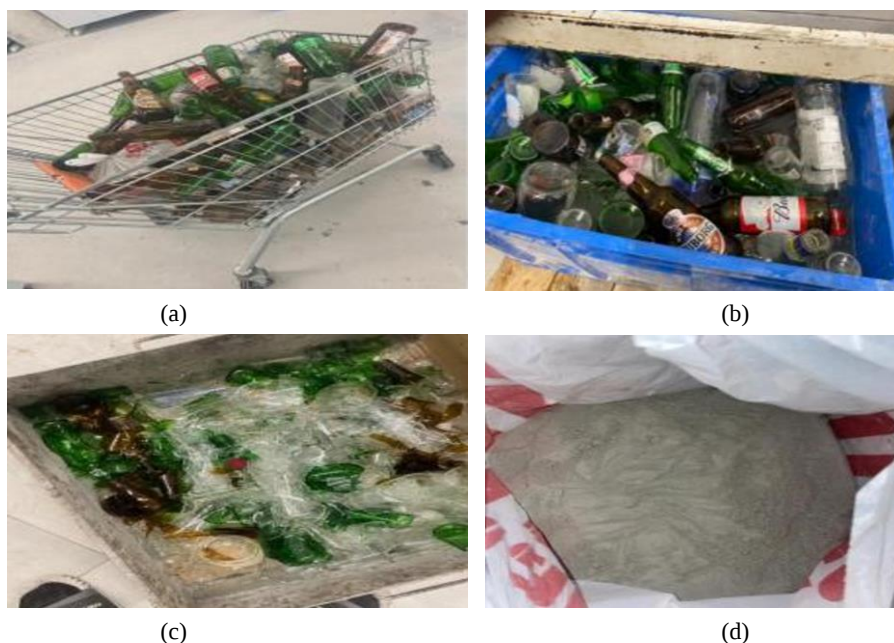


Fig. 1. (a) The photograph displays a collection of bottles that have been gathered from various sources and transported to the laboratory for further analysis and processing; (b) This image illustrates the careful treatment of the bottles, including soaking, washing, and thorough cleaning to eliminate any label papers and dust; (c) The visual depiction showcases the mechanical breaking of the bottles, a necessary step to facilitate their subsequent crushing using the Los Angeles machine

Table 1. Chemical constituents of the cement and mineral admixture

Chemical Compound	Cement	Glass
CaO	52.0-58.0	10.79
SiO ₂	14.0-17.0	72.14
Al ₂ O ₃	3.0-5.50	-
Fe ₂ O ₃	2.0 – 3.0	0.34
SO ₃	2.0-3.0	-
K ₂ O	0.5 – 0.9	0.64
Na ₂ O	0.2 – 0.4	13.12
TiO ₂	-	0.07
MgO	1.5-2.5	1.57
MnO	-	-
Cr ₂ O ₃	-	0.22
Loss ON IGNITION	-	-
Insoluble residue	2.0-5.0	



Fig. 2. (e) shows the recycled aggregate crushed using the compressive strength machine in the laboratory; (f) shows the recycled fine aggregate after crushed and sieved that passes through sieve 4.75 m

Table 2. Sand properties used in the study

Properties	Value	ASTM Standard	Ref
Specific gravity (SSD)	2.66	C128-15	[22]
Water absorption (%)	1.32	C128-15	[22]
Compact bulk density (Kg/m^3)	1728	C29/C29M-17a	[21]
Loss bulk density (Kg/m^3)	1576	C29/C29M-17a	[21]
Fineness modulus	2.79	C33/C33M-18	[19]
Moisture content (%)	0.1	C566-19	[19]

2.1.5. Coarse aggregate

The use of different sizes of coarse aggregate can affect the properties of the concrete, such as its strength and workability. By performing a sieve analysis and controlling the gradation of the coarse aggregates, it is possible to ensure that the concrete has the desired characteristics. The ASTM C136M-14 [23] and C33M-16 [24] standards provide guidelines for determining and controlling the gradation of coarse aggregates in concrete mixtures.

2.1.6. Mixing water

Tap water that was safe to drink and devoid of any chemicals, alkaline solutions, lubricants, or organic compounds was used in all of the concrete preparations and curing procedures employed in this investigation.

2.2. Methods

2.2.1. Mix proportions

Mix design is the computation of the amounts and proportions of essential elements necessities in concrete mixes to achieve the desired characteristic strength, particular material properties, and workability. The Mix Proportion in this study are presented in Table 3 and Table 4 using the design of experiment approach, 4 different mixtures were created to examine the impacts of replacement cement with waste glass powder and recycled fine aggregate as a substitute for fine aggregates. A control mix is included in this set of mixes. An optimum percentage is obtained at 20 %.

2.2.2. Curing

Following a 24-hour duration, the mix were extracted from the mold and subjected to a curing process aimed at ensuring the desired mechanical and durability characteristics. Which ranges from 7 to 28 days, the curing procedure included a variety of conditions, including submersion in a water bath, drying in an oven, and ambient natural curing. Fig. 3 shows the samples that were produced and were cured after 7 and 28 days.

2.2.3. Slump test

The slump test is a procedure used for evaluating the workability or consistency of fresh concrete. It quantifies the amount of settlement or "slump" that happens when a cone-shaped sample of concrete is treated to standardized methods. The American Society for Testing and Materials (ASTM) has produced a standard, ASTM C143 [25] for conducting the slump test. This test was also used to compare mixtures that were made based on the quantity of transportable moisture that was present in the matrix. Fig. 4 shows the slump test of one if the concrete mixture. The following approach was used for this test:

1. Start by preparing the concrete sample, ensuring that it is fresh and well-mixed. In accordance with ASTM C143, fully mixing it after first confirming with the specimen and all the water has been added. Make sure the test location is clear of debris. Place the droop plate on a level surface that you can handle safely.
2. A damp cloth was used to wipe the slump, preventing the concrete from adhering to it.
3. Place the droop cone onto the flat board and stabilize it by standing on the edges. Maintain your position on the cone until it is completely filled and prepared for removal.
4. Ensure precise uniformity of the initial layer within the cone and fill it to a depth of 2 and 5/8 inches, corresponding to one-third of the cone's capacity.
5. Verify that the rod is moderately inclined to adequately reach the edges, and evenly tamp the layer exactly 25 times.
6. Ensure that the concrete layer is level by filling the second layer to a height of 6 and 1/8 inches (or 2/3 of the conical by weight)
7. Again, hit the specimen using the rod to the layer 25 times, making sure that each time you go through the first layer by an inch. While repeating this avoid tapping the cone side.
8. When the last layer is nearly full with concrete, pour it all the way to the top.
9. Compact using the rod 25 times and make sure it gets to the brim of the second layer by 1 inch. Do not tap the cone sides.
10. If the top layer begins to drop below the cone's rim, add some concrete to keep it over there. Remove any excessive concrete, but preserve your footing if you're still standing on the cone. Make sure the cone is filled by wiping the rim clean. You may optionally put a coin in the cone's center to watch where the center shifts when you raise it.
11. Holding the cone straight up without distorting, it should take the pulling procedure between three and seven seconds.
12. Put down the tamping rod over the slump cone in direction of the slumped concrete after turning it upside down next to it. To record the slump, take a measurement from the displaced center to the rod and round up to the nearest quarter inch. It must take 2.5 minutes to complete the slump process.
13. Wash the apparatus then remove the excessive concrete.

2.2.4. Compressive strength

The ability of concrete to withstand compressive forces without fracturing is referred to as compressive strength. It is assessed by incrementally increasing loads on concrete specimens until they fracture. The maximum load at which failure occurs is used to calculate compressive strength, which reflects a material's

ability to withstand loads while maintaining structural stability. By employing the compression testing apparatus depicted in Fig. 5, the experiment proceeded. The behavior of cement mortar substituted with GP and RFA under compressive load was investigated. The compressive strength test was conducted following the guidelines outlined in ASTM C109/C109M-20 [26]. The procedure for this test is as follows:

1. Prior to putting the specimen, the lower and top platters of the compression testing machine were scrupulously cleared in order to ensure continual interaction with the specimen.
2. Within the machine, the concrete was positioned in the middle of the bottom platen. The specimens' surfaces that came into touch with the top and bottom platens lined up with the sides that were next to the mold plates.
3. Throughout the experiment, the load rate on the testing device was held constant at 6 kN/s.
4. The machine automatically determined the compressive strength of the samples as they were being crushed.

2.2.5. Splitting tensile strength

Tensile strength is essential and fundamental attribute of concrete. The load applied to concrete in axial form before failure is identified as tensile strength. Concrete is technically familiar for having better strength in compression than in a tension state this is associated with its brittle nature. When the concrete is subjected to tensile forces cracks will develop. Thus, it is important to observe the point at which the crack occurs in concrete. According to ASTM standard C496/C496M-11,[27] the following procedure was observed.

1. Excess water is dried off the surface of the specimen.
2. The bearing machine surfaces were thoroughly cleansed of any loose shingles or other peripheral substances existing on the specimen's plane that would come into touch with the platens.
3. The samples should be centrally in the machine, the loading piece was added at the top and bottom of the sample.
4. During loading, the upper and lower platen is parallel to each other.
5. The loading rate was 0.06 MPa/s, and the achieved strength was displaced by the machine.

Table 3. Nomenclature of concrete

Nomenclature	Cement (%)	GP (%)	Fine Aggregate	RFA (%)
Control Mix	100	0	100	0
GP 20% – RFA 0%	80	20	100	0
GP 0 – RFA 20%	100	0	80	20
GP 20 % - RFA 20 %	80	20	80	20
Control Mix	100	0	100	0

Table 4. Nomenclature of the mixes

Mix ID	W/C	Cement (kg/m ³)	Sand (kg/m ³)	Water (kg/m ³)	Coarse Aggregate	GP (kg/m ³)	RFA (kg/m ³)
CM	0.55	375	801	237.5	659	0	0
GP20	0.55	300	801	237.5	659	75	0
GP0-RFA20	0.55	375	640.8	237.5	659	0	160.2
GP20-RFA20	0.55	300	640.8	237.5	659	75	160.2

Note: CM Control mix, GP Glass powder, RFA Recycled fine aggregate W/C Water cement ratio.



Fig. 3. Cured specimens in lime water



Fig. 4. A slump test of concrete mixture



Fig. 5. A compressive strength machine

2.2.6. Ultrasonic pulse velocity

According to ASTM C597 [28] described ultrasonic pulse velocity test involves timing of the passage of a pulse of vibration energy through a concrete structure through conjugating the transmitting amplifier to one surface, the vibration energy is then introduced into the concrete. Concrete ultrasonic pulse propagation speed is measured using an ultrasonic pulse velocity tester. The testing devices is comprised of a pulse transmitter, a pair of transducers (transmitter and receiver), an amplifier, a time measurement circuit a time display unit, and a connecting cable and a gel as illustrated schematically in Fig. 6. An electro acoustical transducer positioned in contact with one surface of the concrete being tested generates a pulse of longitudinal vibration. A second transducer convert the vibration pulse into an electrical signal once it has traveled a predetermined distance in the concrete, allowing electronic timing circuit to calculate the pulse transit time.



Fig. 6. Ultrasonic pulse device

2.2.7. Microstructure

The micro structure was assessed by the use of a JSM6610LV Scanning Electron Microscope (SEM) to determine effects of using GP. The SEM was used to examine the overall microstructural characteristics, including the impact of GP on packing, gaps, granular size, and the interface transition zone (ITZ).

3. Results and discussion

3.1. Workability

The water-to-cement ratio (w/c) was kept constant at 0.55 for all four concrete mixtures that used recycled fine aggregate in place of natural fine aggregate and glass powder as a cement substitute. Thus, according to ASTM C143 [25], Fig. 7 shows the slump test findings, which provide a gauge of the fresh concrete's consistency and workability. The concrete qualities can be simulated by the use of glass powder and recycled fine aggregate as partial replacements for conventional concrete components, and the results of the slump test can reveal how these replacements affect the consistency and workability of the concrete. As it is evident from the figure, Glass Powder impact on the workability of fresh concrete is great. The workability of cement-based composites is a crucial variable since it determines how feasible it is to place and compact newly mixed concrete while retaining homogeneity. Several factors influenced the workability of the mixture, including W/C, aggregate characteristics, cement type, and pozzolanic materials have a significant influence on the slump because of their size distribution, pore volume, and water content. When producing the concrete samples for the slump test, consistent water to cement ratio of 0.55 was kept. The portion of cement substituted with glass powder resulted in an improvement in concrete workability compared to control mix, and while the portion of recycled fine aggregate as a partial replacement of fine aggregate reduced in workability. The highest slump measurement of 35 mm in Fig. 5 can be attributed to the presence of a 20% GP. This increase in slump is primarily due to the compacted nature of the GP particles, resulting in enhanced flow properties. The increase in the concrete flow with the inclusion of glass powder might be the effect of glass material which is cleaner in nature. On the other hand, employing 20% GP and 20% RFA gives a slight decrease in workability because of its higher moisture content, which can affect the workability and setting time of the concrete. It is indicated that the slump test ranges from 25 mm to 35 mm for all the different mixes.

3.2. Fresh density

The fresh density of the materials is obtained (2340- 2401) kg/m³ on a fresh concrete. Concrete density is purely dependent on the weight of the aggregate. Therefore, the cement modification may not even affect the cement's concrete structure [29]. The fresh simulated results for GP and RFA concrete are shown in Fig. 8.

These specimens' valuation is diminishing by 20% of GP compared to the control mix. The weight of the glass powder as a substitute to cement in relation to the control mix can be used to determine why there is a decline in the amount of glass powder in fresh concrete. However, the fresh density level variables of the cementitious materials, however, still show that they are closer to the control mix. Contrarily, the addition of recycled fine aggregate decreased the bulk density of fresh in comparison to the reference mix. In compared to Natural sand, both waste materials have a lower particle bulk density. With the addition of fine aggregate replacement with recycled fine aggregate and sanitary materials. Braga et al. [30] and Farinha et al. [31] achieved results that were comparable to RFA's.

3.3. Hardened density

The saturated surface dry density of the combinations of 3, 7, 14 and 28 days of age was obtained. As seen in Fig. 9 for 3days it ranges from (2339 – 2346) kg/m^3 while for 7-day ranges from (2340 – 2365) kg/m^3 on the 14 days the range was obtained to be (2345 – 2375) kg/m^3 and while the 28 days of dry density was observed to be from (2346 – 2365) kg/m^3 . The addition of waste glass powder and recycled fine aggregate to concrete can slightly increase its density due to the filling effect of these particles, which can help to reduce the amount of empty space within the mix. However, it is also possible for the addition of these materials to decrease the density of the concrete at 28 days, especially when a high percentage of recycled fine aggregate is used Pavlu et al. [32]. This decrease in density may be caused by a number of factors, including the improved packing of the various components of the concrete, the filling of voids and pores, and the production of additional C-S-H (calcium-silicate-hydrate) by the glass powder. These changes can help to improve the strength and other properties of the concrete.

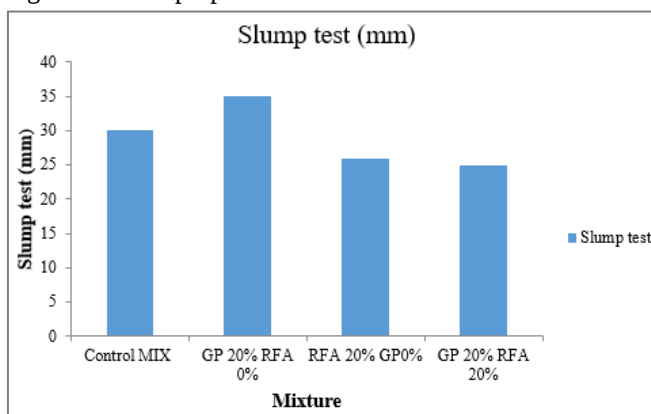


Fig. 7. The effect of GP and RFA on workability slump test with water/cement of the mixtures

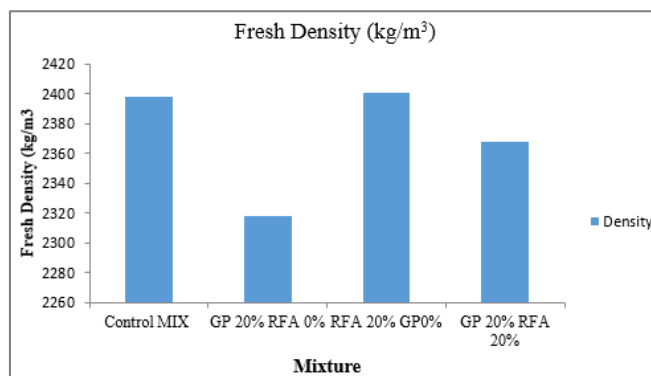


Fig. 8. Fresh density of mixtures

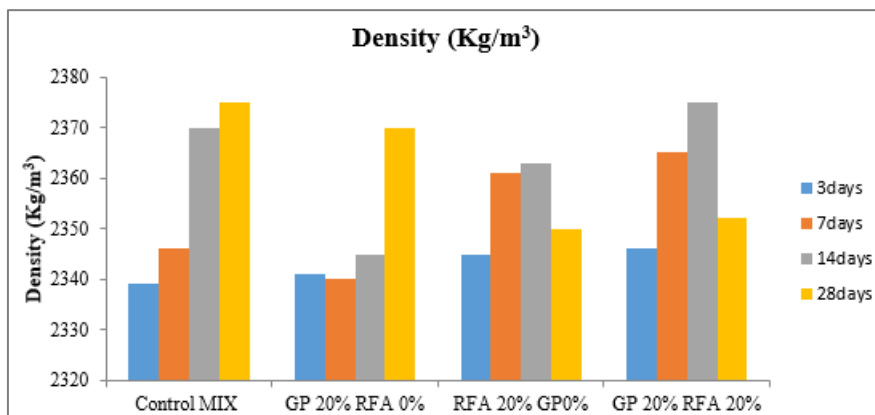


Fig. 9. Density of the mixtures at 3, 7, 14 and 28 days

3.4. Compressive strength

Fig. 10 reveal the average finding of two compressive strength specimens each combination at 3, 14 and 28 days for mixes containing WGP and RFA at various portion. The compressive strength of the control combination was 8.13, 14.75, 19.23 and 27.81 MPa at 3, 7, 14 and 28 days, respectively, as shown in the graph below. By the addition of 20 % of Glass Powder as a replacement of cement, a notable development of 7.2 % compared to the control mix was achieved and 20 % recycled fine aggregates and 20 % waste glass powder also has a notable development 8.2% of strength at 28 days of age was observed as compared to the control mixture, While the compressive Strength of GP20% RFA20% have an increase in strength compared to the control mix of 10.79%.

On the other hand, when waste glass powder was added at a 20% ratio and recycled fine aggregate at a 20% ratio, the compressive strength values surpassed those of the control mix. This can be attributed to the fact that the hydration process of glass powder, as a cementitious material, often starts slowly and then accelerates over time. According to Raydan et al. [33] 5% to 30 % waste glass powder of particle size of 75 micron gives excellent pozzolanic characteristics. Moreover, compressive strength of the specimens such as RFA and glass powder tends increases with respect to their age. It is apparent that a 20 percent replacement level will produce the optimum strength. However, the compressive strength trend indicates that substituting cement with more than a 20% replacement of GP results in reduced strength when compared to the control. There are several reasons that are thought to contribute to the improvement in strength seen in this situation. These factors may include: As an outcome, the cement particles undergo chemical changes, generation of heat, may have an acceleration reaction rate of the chemical activities (pozzolanic) of GP particles.

1. Inclusion of GP to cement composites can promote the early strength (3-7) days age by increasing the hydration reaction due to the high pozzolanic activity
2. Glass powder is used as a filler in concrete, which helps to lessen the overall amount of voids in the mortar.

By implementing RFA as fine aggregate substitute have an increase in strength by 8.2 % when replacing 20% of fine aggregates. Notwithstanding some investigations arrived to a different outcome, the inclusive of RFA to conventional concrete will lessen its compressive strength (Yaprka et al. [34], Geng et al. [35] and Bogas et al. [36]). This is dependent on an attribute of factors, the most notable among which is the degree of water required to boost the w/c in RFA mixtures in order to attain its same flowability as normal aggregate concrete. Thus, according Kou and Poon's [37] experiment, the mechanical properties of self-compacted concrete are unaltered when 25% to 50% of normal aggregate is replaced with RFA. As also stated by Ahmed

[38], the mechanical properties up to 50% substitution of normal aggregate with RFA was comparable to have a greater than that of the control mix.

With the addition of glass powder as a replacement of cement was also taken into observation. Increasing the proportion of recycled fine aggregate (RFA) in the concrete mix by up to 20% yields notable enhancements in strength. This increment maybe ascribed to the following reasons:

1. The Interlocking connection between the aggregate and the cement paste in the concrete may be improved by recycled aggregate's greater surface area. Additionally, recycled fine aggregate could include supplementary cementitious components like dry cement paste or mortar, which helps strengthen the concrete.
2. It is worth noting to keep in mind that using recycled aggregate in concrete can enhance compressive strength, based on a variety of factors, including the type and grading of the recycled aggregate, the proportion of recycled aggregate used in the mix, and the presence of impurities. The needed increase in strength can be attained by using a suitable amount of recycled fine aggregate, such as 20%.

The depicted data in Fig. 11 showcases the Strength Activity Index (SAI) of the tested mixtures, following the standard depict in the ASTM C618-19 [39] specification. SAI serves as a measure of the pozzolanic effectiveness of glass powder and recycled fine aggregates in the concrete. It quantifies the ratio of the strength exhibited by concrete or mortar containing these materials to the strength of a reference mixture at the same age. To meet the ASTM C618-19 criteria for pozzolanic qualification, the SAI must surpass 75%. By employing SAI, it is possible to assess the pozzolanic reaction rate of cement substitutes by comparing the relative compressive strength of the mixtures to that of the control mix. It can be seen from the figure that all of the mixtures are above the 75% limit as compared to the control mixture. However, GP 20%, RFA 20%, and 20%GP and 20% combinations produced as follows: 107.2 percent, 108.2 percent, and 110 percent, respectively, demonstrating that utilizing 20% GP 20 % RFA replacement is appropriate for compressive strength.

3.5. Splitting tensile strength

According ASTM C496 [40] standard for testing tensile strength in concrete, GP enhanced the splitting tensile strength of concrete by approximately 20%, after which the tensile splitting strength started to decline. The research conducted by Bharathi et al. [41] has supported this finding. According to these researchers, the strength from splitting tensile of specimens improves as percentage of substitution with GP and RFA replacement in fine aggregates increases [45]. The results peak at around 20% cement substitution and 20% substitution for fine aggregate. The cause for this elevation can be because:

1. The irregular shape of glass powder particles enhances the fracture resistance of concrete, making it more durable against splitting.
2. It is observed that glass powder contains silica, and carbon dioxide which is produced when cement is hydrated may mix with silica to form new cementitious compounds. These materials can increase the tensile strength of concrete by improving the microstructure of the material. According to the quantity previously mentioned, chemical reaction of the particles of cement generates heat which promotes the pozzolanicity of glass powder.

In recycled fine aggregates the splitting tensile of concrete enhanced a greater strength at each age compared to control mix, however, it is observed at 28 days the recycled fine aggregate have an increased in split tensile because

1. This is due to the possibility that recycled aggregate has a bigger surface area, which may strengthen the binding between the aggregate and cement paste in concrete. Recycled fine aggregate may also contain additional cementitious components, such as dry cement paste or mortar, which can increase the concrete's strength.

2. It is worth noting that the use of recycled fine aggregate in concrete may also have some drawbacks. For example, recycled aggregate have a higher moisture content, which can affect the workability and setting time of the concrete. Additionally, recycled aggregate may be more susceptible to contamination, which can negatively impact the quality of the concrete [42].

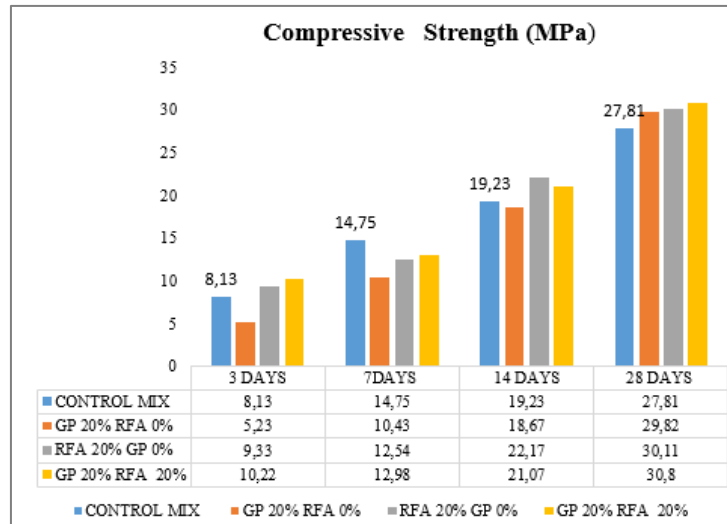


Fig. 10. The compressive strength of the mixtures

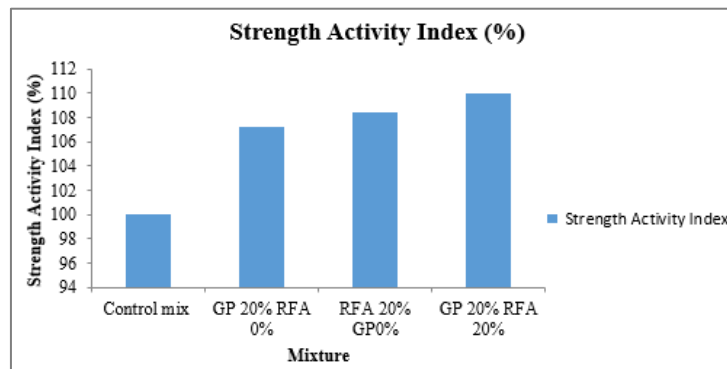


Fig. 11. Strength Activity Index of the mixtures

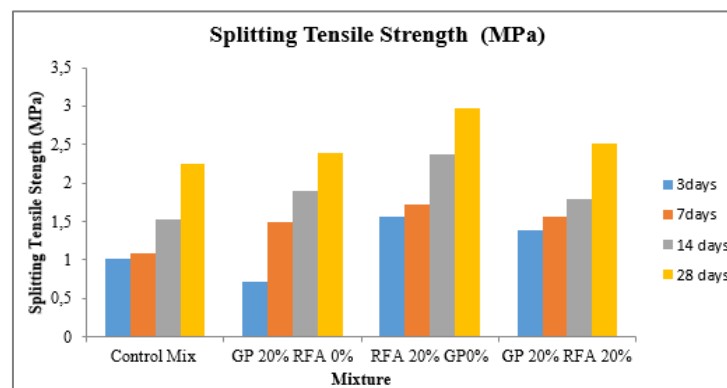


Fig. 12. Splitting tensile test

3.6. Ultrasonic pulse velocity

The UPV values for the concrete samples are at 3days, 7 days and 28 days of curing are shown in Fig. 13 and can be well describe according to ASTM C597[43]. Standard Test Method for Pulse Velocity through Concrete. Based on the figure, it is observed that pulse velocity for the reference is increased with the increasing age of concrete. However, 20% GP and 20% RFA increase at early but decline at a certain age. In the case of concrete made with glass powder or recycled aggregate increase in the early stages of curing due to the development of strength and stiffness in the material. However, as the concrete continues to cure and age, it is possible that the UPV decline slightly due to the gradual relaxation of stresses within the material. This is a common phenomenon that can occur in concrete as it ages and is not necessarily a cause for concern. It is important to note that UPV is just one of many properties that can be used to evaluate the performance of concrete and should be considered in conjunction with other factors. A non-destructive test to examine the quality and consistency of concrete is an ultrasonic pulse velocity (UPV). An excellent concrete should have a UPV between 4100 and 4700 m/s.

Fig.14 demonstrates a correlation involving Pulse Velocity and compressive strength. The figure shows that the correlation is inverted, which suggests that combinations with higher pulse velocity have lower compressive strength. The primary goal of this correlation is to comprehend the relationship between pulse velocity and concrete strength when exposed to mechanical characteristics. Additionally, this is done to monitor how concrete is developing strength.

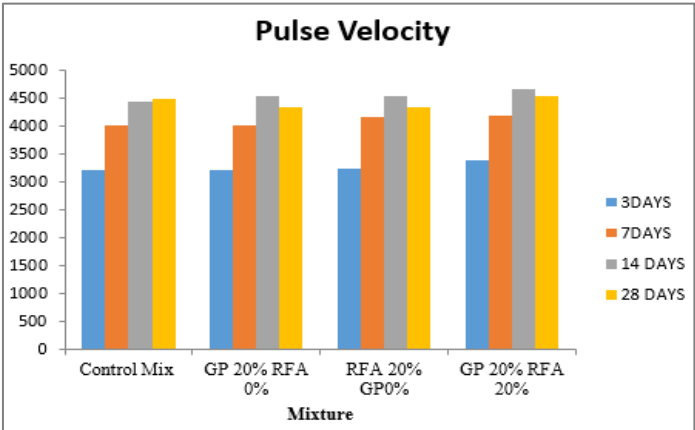


Fig. 13. Ultrasonic pulse velocity test results

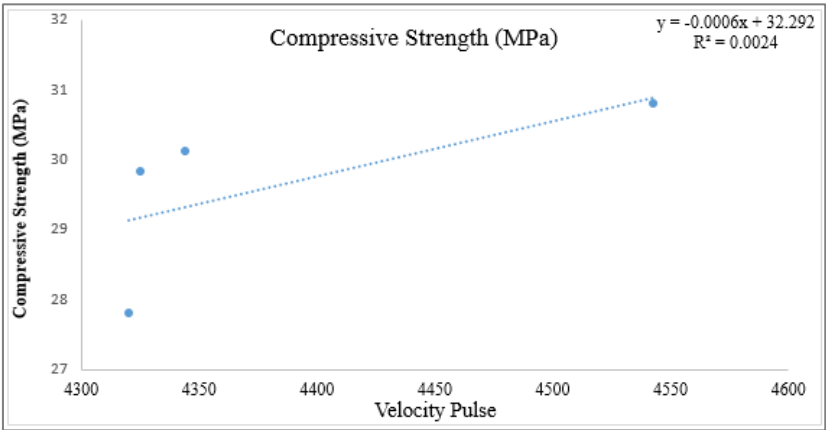


Fig. 10. Correlation of pulse velocity and compressive strength

3.7. X-ray diffraction, chemical analysis of waste glass powder

X-ray diffraction (XRD) investigation was used to analyze the crystalline phase found in discarded glass powder. The investigation was carried out on a Rigaku powder diffractometer, which used K Cu wavelength radiation and scanned from 2 to 90 locations (2 θ , Cu-K). The samples were dried and sieved through a 75 μ m sieve before scanning. The results of this approach, as shown in Fig. 15, revealed that the waste glass powder was primarily made up of Coesite, also known as silicon dioxide (SiO₂), which had the highest peak intensity in the XRD pattern.

3.8. SEM analysis

Scanning electron microscopy (SEM) was employed to examine the microstructural properties of the modified concrete and investigate its microscopic features. The scanning electron microscopic visuals were captured to investigate the impact of GP and the microstructure of concrete. Fig. 16 shows the SEM visuals which showcase the microstructure of GP powder. It is identified that the glass powder has a lower porosity compared in the control cement mix which helps in the compressive strength of concrete. The visual vividly portrays the effectiveness utilization of waste material as an efficient filler within the composition. SEM micrographs of the glass powder reveal that when securely packed within a developed pattern, it develops a viscous gel, which may help to identify the factors for the abrasion resistance and prove that glass powder can support environmental sustainability in the building sector [44]. Glass powder effectively fills the minuscule pores and interacts mechanically with other parts to increase compressive strength. Ettringite crystals in the shape of needles are evenly dispersed within the solid, well-developed gel that the hydration reactions have created and are encased by glass particles.

4. Conclusion

After an extensive series of experiments, thorough evaluations, and in-depth data analysis, it has been determined that incorporating GP and RFA as partial replacements for cement leads to optimal results. Specifically, at a replacement level of 20% and a fixed water-to-cement ratio of 0.55, the combination of GP and RFA exhibits exceptional performance in terms of both fresh properties, such as workability (measured by slump), and mechanical properties. The detailed findings derived from this study offer valuable and insightful information regarding the behavior and effectiveness of GP and RFA within the cement composite.

1. The findings of the slump test reveal details about the material's rheological behavior of the samples enhanced as the GP material replacing cement expand. GP of 20% has the highest workability because of the occurrence of its lightweight surface area which leads to an increase in flow. This has a significant impact on how easily fresh concrete can be worked. The workability of cement composites, which is a crucial factor, defines the capacity to place and consolidate freshly mixed concrete while retaining uniformity.
2. Several factors influenced the workability of the mixture, including the water-to-cement ratio (W/C) and the properties of the aggregates. Cement type and pozzolanic materials have a significant influence on the slump because of the arrangement of their particle diameter, their pore volume, and their capacity for absorption. The water to cement ratio of 0.55 was maintained throughout the production of the concrete samples for the slump test.
3. The flowability outcome indicates that the effect of recycled fine aggregates as a alternate of fine aggregates on the flow value of specimens reduced the workability and setting time of the concrete because of the high moisture content that absorb water which decrease in flow.
4. Compressive strength test explained that the development of the compressive strength continues with age. At fixed water cement ratio of 0.55, substituting 20% of the cement with GP enhanced a good compressive strength of the concrete. Because of its substantial pozzolanic activity, the insertion of

GP to cement composites can accelerate the hydration process and hence increase the early strength (3–7 days age).

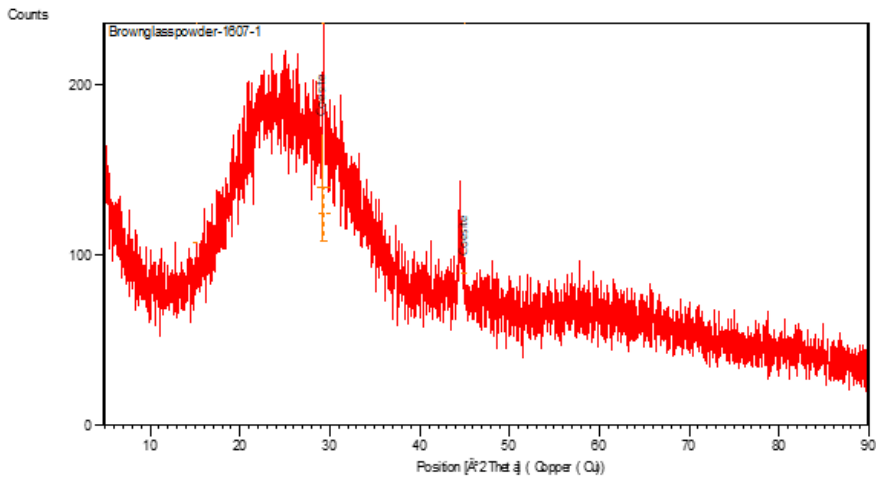


Fig. 15. XRD of glass powder

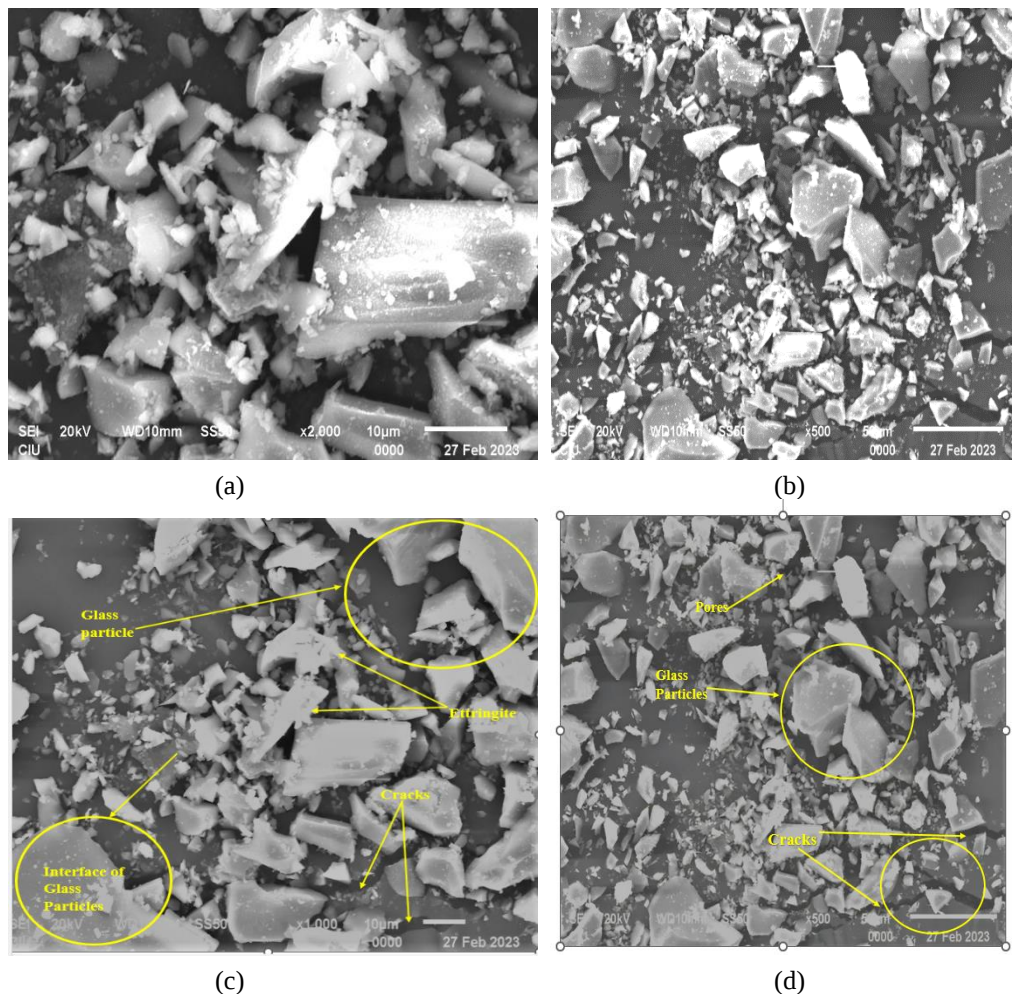


Fig. 16. SEM photomicrograph of waste glass powder

5. The study found that GP enhanced the splitting tensile strength of concrete by up to 20%, after which the splitting tensile strength started to decline. While in RFA the splitting tensile of concrete also enhanced a greater strength at each age compared to control mix, however, it is observed at 28 days the recycled fine aggregate have an increased in split tensile because to the possibility that recycled aggregate has a bigger surface area, which may strengthen the binding between the aggregate and cement paste in concrete.
6. Ultrasonic pulse velocity (UPV) is a measure of the speed at which ultrasonic waves travel through a material. In general, UPV tends to increase as the strength and stiffness of a material increases. In the case of concrete made with glass powder or recycled aggregate, it is possible that the UPV may increase in the early stages of curing due to the development of strength and stiffness in the material. However, as the concrete continues to cure and age, it is possible that the UPV may decline slightly due to the gradual relaxation of stresses within the material. This is a common phenomenon that can occur in concrete as it ages and is not necessarily a cause for concern. It is important to note that UPV is just one of many properties that can be used to evaluate the performance of concrete and should be considered in conjunction with other factors.
7. SEM analysis further validated that the utilization of GP in cement serves as a filler, effectively occupying micro pores and mechanically interacting with other components. This beneficial effect manifests in the increased compressive strength, improved Interfacial Transition Zone (ITZ), and the attainment of a denser and more compact microstructure.
8. Concrete can be made more durable and more resistant to chemical attack by using glass powder as a pozzolanic material.
9. The objective is to examine the impact of utilizing glass powder as a substitute for cement and recycled fine aggregates as a replacement for natural aggregates on structural steel. The aim is to determine the long-term sustainability of using glass powder and recycled fine aggregates in offshore constructions.

5. Recommendation

Due to constraints in time, available facilities, and limitations, it can be challenging to thoroughly investigate the properties of GP and RFA in cement composites. The relevance of studying these properties may be influenced by the time and resource constraints that impose limitations on the extent of the analysis.

1. To address environmental concerns, there is a clear rationale for increasing the implementing of glass in cement-based composites. Recent observations indicate a progressive depletion of natural aggregate resources, making it increasingly difficult to find economically viable quarries in certain countries. In light of this, the use of recycled aggregates as a sustainable alternative to natural aggregates

2. It is advantageous to utilize recycled fine aggregate in place of conventional aggregates because of its sustainable application and the preservation of natural resources.

3. Recycled aggregates can be used in various civil works, such as the construction of roads, bridges, and other infrastructure, where they can help to reduce the need for new materials and lower the overall environmental impact of the project.

Overall, it is recommended to continue researching and exploring the use of glass powder and recycled aggregates in concrete, steel, and other civil works, as they have the potential to improve the sustainability and environmental performance of these materials and construction processes.

Conflict of interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Data availability statement

No new data were created or analyzed in this study.

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