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# A Review on Utilization of recycle aggregate and waste glass in the Enhance of concrete properties

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**Abstract:**
Millions of tonnes of recycle aggregate and glass garbage are produced each year, which causes enormous issues with the global ecology. Utilising recycled aggregates made from construction and demolition waste can help protect natural aggregate supplies, lessen the need for landfill space, and promote sustainable building practises. Silica makes up a large portion of the glass. Its application in concrete might be a good way to address environmental and economic issues. Recycled aggregate (RA) and waste glass powder concrete (WG) are thoroughly reviewed in terms of their history, processes for recycling, reusing, manufacturing, physical, mechanical and durability properties of the materials. Fresh concrete workability, physical property (such as density), mechanical characteristics (such as compressive, flexural, and splitting tensile strength as well as elastic modulus), and durability property (such as Impermeability, Chloride penetration and carbonation resistance). Municipal waste glass, plastic, and demolition concrete from structure member of buildings and bridge concrete block make up the majority of this waste. After being used once, all of these are difficult to dispose of into land. The reuse of such waste in the production of concrete is known to be an extremely successful means of controlling these kinds of situations. Some of the elements of the concrete can be replaced completely or partially with these wastes. In addition to contributing in the management of solid waste, recycling these waste materials for use in concrete helps to protect the availability of natural resources. This review paper will explain how waste materials are used as resources in the manufacturing of concrete.

***Key Words:*** *Recycle Aggregate, Workability, Compressive, Tensile, Flexural, Durability.*

## 1. Introduction:

Using recycled aggregate concrete (RAC) helps the construction industry consume less energy and natural resources. However, adding recycled concrete aggregates (RCA) to the mix during the production of concrete typically makes it more difficult to maintain the qualities of both fresh and hardened concrete [1]. In order to make space to build better infrastructure in their place, many old structures and concrete pavements are being demolished. This demolition generates a lot of garbage, most of which is land filled. Processing this C&DW and using it as RA in concrete reduces the amount of materials that are land filled and has a minimal negative impact on the environment when manufacturing natural aggregates [2]. Since the early 1900s, concrete has dominated the market for construction materials as the most popular building and construction material (Walberg, 2016). According to Warburton (2020)[3], concrete is responsible for 8% of all worldwide carbon dioxide emissions. Concrete is a composite material made of cement paste, which is a mixture of water and Portland cement, and aggregates, such as sand, gravel, or crushed stones. In the last 20 years, the amount of cement produced worldwide has tripled, rising from 1.10 billion tonnes to 3.27 billion tonnes (Verein Deutscher, 2019) [4]. However, our earlier research revealed that using too much glass aggregates would cause concrete to weaken when samples were placed at 600°C because the partially melted glass could not withstand the loading.To fully utilise the improvement of high temperature resistance by the glass aggregates, just a 15% replacement of natural aggregates with the latter could be utilised. There have also been attempts to substitute coarse and/or fine particles in concrete using crushed waste glass [6,7]. It shows that depending on the replacement ratio, replacing aggregate with waste glass usually results in a decrease in concrete strength.Concrete loses strength when its waste glass content rises in compressive, tensile, and flexural tests. The compressive and flexural properties of concrete are shown to be less affected by employing waste glass as fine aggregate than as coarse aggregate [8]. Every year, garbage production increases at a higher rate than the population. These wastes may be biodegradable or inert. Due to material non-decomposition, non-biodegradable trash persists for many years, creating a challenge with solid disposal. Waste handling and management issues are a global issue, particularly in nations with dense populations. Recently, various waste materials have been used as building materials, including glass, plastic, and crushed concrete [9]. As a result, using additional trash as a concrete ingredient has lowered the pressure on the natural source of concrete ingredients like aggregates and sand to a manageable level. Concrete is the second-least consumed material globally in the construction industry and is preferred in almost all civil engineering projects. In light of this, a variety of industrial waste streams are currently being utilised in the production of environmentally friendly materials that can replace conventional building materials. Due to its physical properties and chemical makeup, glass is seen to be the most acceptable alternative to other types of industrial waste as an aggregate. [10] .Recycled glass may also be acceptable for use in a variety of applications, such as concrete, bricks, and highway engineering projects, according to earlier research. Particularly after 2012, when analogue TV broadcasting in South Korea came to an end and systems were converted to digital TV broadcasting, a sizable number of CRT TVs and monitors were scrapped and replaced with LCD panels. By 2020, it is anticipated that there would be around 10 million pieces of electronic garbage, including waste CRT glass from CRT TVs and monitors, up from 910,000 pieces in 2012 to 970,000 pieces. The research study examined the strength behaviour of different replacement percentages ranging from 0% to 20% in glass and ceramic waste. Their investigation found that 20% of the cement may be removed, providing a sustainable alternative. Their analysis came to the conclusion that replacing garbage protects the environment and reduces waste [11]. In 2018, the building and construction industry was in charge of 39% of the process' energy and carbon dioxide (CO2) emissions, as well as 36% of the final energy consumption. Of this, 11% was attributable to the manufacturing of goods and materials used in construction, such as glass, cement, and steel [12]. The energy-intensive process of producing cement accounts for 3% of global total energy consumption and 5% of industrial energy consumption. Additionally, the decarbonization process used to produce cement produces roughly 0.9 tonnes of CO2, which is released into the environment. Consequently, it's necessary to explore for materials that can be used in place of cement or aggregate.

Concrete manufacture uses recycled resources to reduce energy use and create a more environmentally friendly product. A promising strategy to combat resource depletion and environmental contamination is the recycling of construction waste as recycled aggregates (RA) in concrete constructions [13].The use of RA can result in a 20% reduction in CO2 emissions and a 60% reduction in the consumption of natural aggregate resources [17]. Additionally, many nations around the world are pushing the use of wastes as new building materials. Although RA in concrete has been the subject of numerous investigations, the structural application of recycled aggregate concrete (RAC) is still constrained due to its subpar durability performance. The two main causes of the greater porosity and water absorption of RA are old mortar adhered to the surface and the interfacial transition zone (ITZ) between old mortar and parent aggregate [25]. As a result, RAC exhibits inferior durability properties compared to NAC, including poor chloride ion permeability low resistance to carbonation higher water absorption, and low resistance to acid and sulphate attack [17] which prohibits the use of RAC as structural concrete and limits its use to low-grade applications (such as road base material, etc.) [103]. It is well recognised that using different by-product materials such fly ash, ground granulated blast furnace slag, rice husk ash and silica fume in concrete has positive effects on the environment, the economy and engineering [14]. Therefore, there is a significant chance that research on the utilisation of diverse waste products and their application as building materials in various ways will have positive effects on the environment, technology, and economy. Despite the fact that studies on waste glass as a building material have been ongoing since the 1960s. The current research trend suggests that waste glass may be suitable for construction due to its adaptable size, shape, chemical composition, and widespread availability when compared to other SCMs. The building industry is currently focused on two key issues: energy reduction and environmental preservation. The use of cement, a type of high-performing building cementitious materials, is widespread throughout the world. However, the energy required for its production contributes for 12–15% of total industrial energy use and about 6-8% of carbon dioxide emissions globally [15]. Due to the gradual depletion of natural resources and the rising awareness of sustainable development, the shortage of natural aggregates has also grown to be a very difficult problem. According to previous research, China alone accounted for half of the worldwide new aggregate demand between 2010 and 2015, which totaled more than 820 million tonnes [106]. In the early stages of reclamation, CDW has been used primarily for the construction of roadbed infrastructure. For example, CDW has been crushed to an aggregate size for use in road layers as well as some sidewalks and pavements made of lower-grade concrete or crushed as a bulk filler for the underlying pavement layer. Large amounts of energy and raw materials are consumed by the concrete industry. As a result, using industrial wastes as admixtures in building has positive effects on the environment as well as the economy [16]. One of the most difficult environmental issues in nations that are developing quickly is the handling of hazardous waste. Nowadays, a lot of research is being done on eco-friendly materials to reduce the negative environmental effects of the construction sector and to conserve natural resources. Similar problems with capacity and the environment are caused by depositing demolition concrete waste in landfills [45].

In producing fresh concrete, recycled aggregate (RA) made from construction and demolition waste can completely or partially replace virgin material. About 60% of limestone resources might be saved and $CO_2$ emissions could be decreased by 15% to 20% by using waste concrete as RA [17,106]. Thus, using RA is crucial for resource conservation, environmental protection, and achieving the construction sector's sustainable growth. Recycled aggregate concrete (RAC) has been the subject of research for close to 70 years, but due to worries about its long-term durability, its usage in concrete constructions is still restricted. RAC has emerged as a popular study issue all over the world due to the depletion of natural aggregate resources and the rise in the production of waste concrete.

The capacity of concrete to face various forms of damage while preserving its strength and aesthetic integrity over the course of its exposure to the environment is known as durability.

Due of the mortar that has been bonded to the RA, RAC typically has lower durability than nature aggregate concrete (NAC). As a result, by improving the characteristics of RA and/or adding mineral admixtures, RAC performance can be increased.Research proved that treating RA with $CO_2$ can improve its density, decrease its water absorption, and raise its crushing value. Additionally, it can greatly lower the chloride ion diffusion coefficient and drying shrinkage of mortars made with $CO_2$-treated RA.

The contact is made more challenging by the presence of RA in new concrete. The application of $CO_2$ to RA improves both the newly generated ITZ between the old and new cement matrix as well as the old interfacial transition zone (ITZ) between adherent paste and aggregate.

Recent research suggests that $CO_2$ treatment is a very effective and promising method to enhance the general properties of RA and the durability of the resulting RAC. The review paper summarised the benefits and drawbacks of various techniques used to remove the adhered old mortar or to strengthen the weak surface layer of RA [18,19].

## 2. Assessment of the effect of Recycle Aggregate on concrete workability:

At increasing bentonite levels in both NAC and RAC, slump is reduced. Due to the availability of more free water in RAC than in NAC, RAC has a higher workability. As the amount of bentonite increased, the workability of RAC and NAC mixtures decreased [20]. The characteristic of freshly mixed concrete or mortar that defines how simple it is to mix, position, consolidate, and finish in a homogeneous state [21].

Since low workability concrete is difficult to mix effectively compact, it typically results in high porosity. Traditionally, the slump test has been used to assess how workable new concrete remains. Researchers have noted that fresh RAC consistently had a lower slump value than the corresponding NAC, which was primarily caused by the higher water absorption capacity and, in most cases, rougher surfaces and more irregular shapes of the RAs [22,23,24,28].

Therefore, more water is required throughout the concrete mixing process to attain a similar workability to NAC. In order to maintain the same workability (the slump value was preserved at 10±2 cm) throughout all RAC and NAC samples, [27] added 9-13% more water by weight to RAC using recycled concrete aggregate. Similar findings were reported in the study by [25], which showed that 5% to 15% more water was needed for the RAC mixing to attain the same workability as NAC.

Although recycled aggregate absorbs more water, from 1.5% to 4.6%, increasing water demand, artificial plasticizers can be employed to make up for this water loss. Because these particles are porous, this concrete quickly loses its capacity to be worked. Consequently, more water would be needed to attain the same workability [9].

The massive loss of the mortar was greatly increased by the addition of RCP. Mortars containing RCPs had slump loss rates ranging from 22.0 to 28.5% [29].

Due of RA's need for a significant volume of water to achieve the requisite slump, HPC incorporating RA is significantly less workable [16].

However, one study stated that RA might be used in place of natural aggregate without causing a rise in the demand for chemical admixtures.

A recent study by [40] on the use of recycled aggregate coarse (RAC) in shotcrete concrete found that employing RAC decreased the workability of concrete when using different water concentrations.

**3. Effects of Recycle Aggregate on unit weight and water absorption of concrete:**

The RA's water absorption and unit weight. According to earlier research, oven-dry, saturated, and surface-dried RA had densities of 2158 kg/m3 and 2323 kg/m3, respectively. In comparison to the comparable crushed gravel aggregate densities, which were 2470 kg/m3 and 2505 kg/m3, respectively, these findings were 12.6% and 7.3% lower [30].

The lower unit weight of concrete made with RA can be explained by the fact that RA particles typically have low-density old cement mortar following to their surfaces [31].

A maximum reduction in water absorption (i.e. 20%) is seen for the LC-RA compared to RA, which may be attributed to the LCRA's increased CO2 uptake yielding more reaction prduct (CaCO3) to fill the mortar's pores [13].

According to reports, RA absorbs water at a rate of 7.65% compared to crushed gravel's 1.42% [32].

Water absorption capacity of the concrete increases as the percentage replacement of recycled aggregates increases [33]

Other studies that claimed that the pores in RA may be to blame for the decreased unit weight offered a similar justification [34,35,36,37].

**4. Mechanical performance assessment of Recycle Aggregate on Concrete:**

At higher RCA replacement levels, RAC mechanical performance was seen. However, when comparing plain RAC to artificial fibre strengthened RAC, one 29 percent and 380 percent increases in toughness index and fracture energy, respectively, were noted for 1 percent fibre inclusion in RAC. Artificial fibre increases the RAC's post-cracking and mechanical performance, giving the concrete more ductility and energy absorption [38].

If recycled concrete aggregates are used in excess of 40%, compressive strength may be lowered. Additionally, the concrete's creep and drying shrinkage are increased. The 28-day compressive strength ratio might be referred to as the activity index of RP

according to the Chinese standard. The strength ratio refers to the ratio of the strength of the mortar containing RP to that of the control mortar at the same age.[39]
The type of crushing had a significant impact on the aggregates' shape. One might notice that RA's form is less angular. The weaker CRA properties resulted in greater losses in compressive strength in blends with w/c 0.45 and 0.35 [40].
Shape, angularity, and gradation are some of the characteristics involved [41,42,43,44].
Because RA particles have a somewhat rough substrate, there is a strong interfacial transition zone with the cement matrix, which gives concrete its high tensile resistance capacity. According to earlier research, RA with a larger form factor are advantageous for boosting concrete strength [45,46,47,48,49,50,51]. In order to achieve the design strength of concrete and improve its tensile resistance, RA with a reasonable particle gradation helps to reduce the amount of cement that is needed [24, 52,53,54,55]. As a result, interfacial aggregate-cement cohesiveness and the strength of the aggregates have a substantial impact on the mechanical properties of RA.The mechanical performance assessment of RA performed in past studies is summarised in Table 1.

**Table 1. Compressive, Tensile and Flexural strength of recycled aggregate concrete at different different replacement proportion with Natural Aggregate.**

| A summary of earlier research on the mechanical properties of RA concrete. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Reference** | **Type of Materials** | **Type of Aggregate and Replacement %.** | | **Outcomes after 28 days** | | | **Density Kg/m³** | **Remark** |
| | | **CA** | **FA** | **Compressive Strength MPa** | **Tensile Strength MPa** | **Flexural Strength MPa** | | |
| [57] | RCA-L | 100 | - | 60 | 4.1 | 6.9 | 2017 | |
| | RCA-F | 100 | - | 47.1 | 3.1 | 6.6 | 2033 | |
| | RCA-T | 100 | - | 62.2 | 3.1 | 7.2 | 2157 | |
| | RCA-F | 50 | - | 53.6 | 3.1 | 7.4 | 2076 | |
| | RCA-T | 50 | - | 64.2 | 2.9 | 7.2 | 2139 | |
| | RCA-F | 100 | 25 | 35.6 | 2.0 | 6.3 | 2000 | |
| | RCA-T | 100 | 25 | 50.8 | 3.0 | 6.2 | 2122 | |
| [51] | RA | 25 | 25 | 68.9 | 3.71 | - | - | |
| | | 50 | 50 | 63.8 | 3.46 | - | - | |
| | | 100 | 100 | 61 | 2.82 | - | - | |
| | | 100 | 0 | 66.9 | 3.78 | - | - | |
| [58] | RA | 25 | - | 77 | - | 8 | 2380 | |
| | | 50 | - | 79 | - | 8 | 2350 | |
| [59] | RA | - | 30 | 57.3 | 3.65 | - | 2165 | |
| | | - | 100 | 54.8 | 2.95 | - | - | |
| [60] | RA | 15 | - | 32.7 | 3.0 | 9.7 | - | |
| | | 30 | - | 31.7 | 2.7 | 9.0 | - | |
| | | 50 | - | 29.0 | 2.7 | 8.9 | - | |
| [61] | RA | - | 10 | 25.09 | - | 5.04 | 1970 | |
| | | - | - | 22.68 | - | 4.83 | 2020 | |
| | | - | - | 30.16 | - | 4.99 | 1990 | |
| | | - | - | 33.44 | - | 5.77 | 2040 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | - | 20 | 24.04 | - | 5.34 | 1960 | |
| | | - | - | 22.88 | - | 5.89 | 1920 | |
| | | - | - | 31.59 | - | 5.22 | 1980 | |
| | | - | - | 31.51 | - | 4.72 | 1960 | |
| | | - | 30 | 24.76 | - | 5.41 | 1970 | |
| | | - | - | 25.28 | - | 4.61 | 1960 | |
| | | - | - | 29.56 | - | 5.67 | 2030 | |
| | | - | - | 26.02 | - | 6.15 | 1960 | |
| [40] | RA | 100 | - | 49.11 | - | - | 2230 | |
| [62] | RA | 20 | - | 47.50 | 3.96 | - | 2340.6 | |
| | | 50 | - | 46.10 | 3.61 | - | 2315.2 | |
| | | 100 | - | 42.70 | 3.63 | - | 2244.4 | |
| [63] | RA | 50 | 0 | 34.9 | 2.6 | - | 2251± 11 | |
| | | 50 | 10 | 32.8 | 2.5 | - | 2244± 12 | |
| | | 50 | 25 | 23.3 | 1.6 | - | 2219± 10 | |
| [33] | RA | 10 | - | 36.22 | 4.07 | - | - | |
| | | 15 | - | 35.77 | 4.00 | - | - | |
| | | 20 | - | 34.95 | 3.98 | - | - | |
| | | 25 | - | 34.50 | 3.96 | - | - | |
| | | 50 | - | 32.44 | 3.23 | - | - | |
| | | 75 | - | 27.60 | 2.70 | - | - | |

**CA- Coarse Aggregate, FA- Fine Aggregate, RA-Recycle Aggregate, RCA-L - Recycle Aggregate crushed in Laboratory, RAC-F- Recycle Aggregate crushed at field, RCA-T-Recycled Aggregate crushed at field and Treated.**

## 5. Assessment of the effect of waste glass powder as fine aggregate on concrete workability:

The W/B ratio and the waste glass substitution ratio affect the concrete slump value. Regardless of the W/B ratio, the droop of the concrete increased as the waste glass substitution ratio increased, and it decreased as the W/B ratio increased. [14]

The results show that the workability of concrete built with glass waste powder as fine aggregate deteriorated with an increase in replacement percentage and water cement ratio. In this study, every assessed slump was a real slump [24].

With the replacement of the fine aggregate (binder) and coarse aggregate with WGP and WEP, respectively, slump has gradually decreased. This has been shown as the percentage of WGP and WEP has increased. Here, the increase in integrity provided by the WGP was either offset by the simultaneous replacement of WEP or resulted in a loss of integrity, which caused a fall in slump value [31].

In contrast to non-vibrated mortar, mortar manufactured with 35% and 60% replacement exhibits a modest decrease in flow. The flow value drops when glass powder replacement goes from 35% to 60% [64].

With increases in waste glass content, the slumps of waste glass concrete specimens decreased, which is thought to be influenced by the grain morphologies of the waste glass. These combinations still have good workability despite the slump of these mixtures declining [65].

Despite having zero absorption, the workability of regular concrete without plasticizer decreases as the rate of glass powder increases; this phenomenon could be explained by the high surface tension created by the finesses and high surface area of this powder, which captures the necessary amount of water for consistency [66].

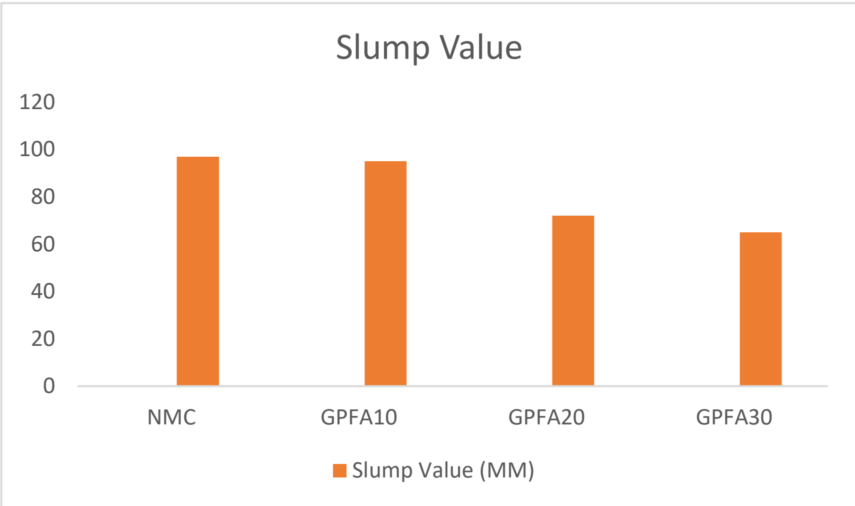
It was confirmed that, without modifying the water content, the slump values of concrete at various glass replacement levels stayed within the desired slump range of 100-125 mm [73].

**Table 2. Effect Of Concrete Slump Value By Replacing Of Coarse aggregate, Fine Aggregate And Cement Replaced By Recycle Aggregate And Waste Glass Powder.**

| Reference | Species identification | Replacement level of aggregate (%) | Slump Value (MM) | Remarks |
|---|---|---|---|---|
| [68] | RA | 0 | 19 | M 15 (1:2:4) |
| | | 25 | 11 | |
| | | 50 | 9 | |
| | | 75 | 7 | |
| | | 100 | 5 | |
| | | 0 | 21 | M 20 (1:1.5:3) |
| | | 25 | 17 | |
| | | 50 | 15 | |
| | | 75 | 14 | |
| | | 100 | 6 | |
| [14] | Waste Glass | 35-0 | 105 | W/B |
| | | 35-50 | 205 | |
| | | 35-100 | 300 | |
| | | 45-0 | 100 | |
| | | 45-50 | 155 | |
| | | 45-100 | 215 | |
| | | 55-0 | 130 | |
| | | 55-50 | 180 | |
| | | 55-100 | 190 | |
| [24] | NMC | 0 | 97 | |
| | GPFA10 | 10 | 95 | |
| | GPFA20 | 20 | 72 | |
| | GPFA30 | 30 | 65 | |
| [26] | Design Mix | 0 | 35 ± 3 | Fine Aggregate replaced by Glass Powder |
| | M 1 | 5 | 40 ± 4 | |
| | M 2 | 10 | 20 ± 3 | |
| | M 3 | 15 | 25 ± 4 | |
| | M 4 | 20 | 21± 4 | |
| [40] | C0.45RA | 100 | 138 | |
| | C0.35RA | 100 | 110 | |
| [63] | NAC | 0 | 65 ± 2.8 | |
| | N10/0 | 10/0 | 74 ± 2.5 | |

| | | | | |
|---|---|---|---|---|
| | N25/0 | 25/0 | 65 ± 3.7 | |
| | RA-CDW | 0 | 75 ± 3.1 | |
| | R10/50 | 10/50 | 61 ± 3.7 | |
| | R25/50 | 25/50 | 63 ± 4.2 | |

**RA- Recycle Aggregate, GPFA- Glass powder as Fine Aggregate, FRCA-Fine Recycled Concrete Aggregate, C0.45RA- Recycle Aggregate concrete with w/c 0.45, C0.35RA- Recycle Aggregate concrete with w/c 0.35, RA-CDW aggregates both: from 0.56 to 0.60 in the NA mixes (NAC, N10/0 and N25/0) and from 0.59 to 0.63 in the RA-CDW mixes (R0/50, R10/50 and R25/50).**




**[24] Fig:1. Slump Value Of Concrete By Replacing Of Natural Aggregate With Recycle Aggregate.**

**6. Effects Of Waste Glass Powder On Unit Weight And Water Absorption Of Concrete:**

The density of mortar dropped as the amount of glass sand in it increased, however this effect is minimal (0.7-3.2% less dense than the reference sample). Due of the glass cullet's lower specific gravity than granite sand, the hardened density has decreased [26].

The porous/weak nature of RA compared to NA may be the cause of the higher water absorption observed for RAC than NAC [13].

The filler effect of the GP-38 micro meter particles, which makes it possible to fill the vacant spaces within the mortar matrix, is the main cause of the modest density increase with the reduction in the maximum size of the GP when the proportion of FRCA is fixed. The use of finer particles reduces both absorption and open porosity because the mortar matrices are made more compact [61].

Because the concrete produced was porous and less durable, replacing the coarse aggregate with WEP alone has resulted in higher water absorption and higher coulomb values. In such mixtures, lower strength values were noted.The filling impact of WGP particles on the high porosity region caused the increase in density to be seen. When compared to the control mix of 20% WGP with up to 15% WEP, specimens replaced with WGP alone showed an increase in density and a decrease in water absorption [31].

Due to the higher water absorption of MWG than cement particles, partial cement replacement with milled waste glass (MWG) results in an increase in concrete water absorption in a sulphate environment compared to that of typical concrete (by around 30% on average) [69].

In a similar way as glass and granite fines were increased to (Glass Powder) GP15, (Granite Powder) GrP30, and GP/GrP; 15/30, the percentage of water absorption decreased. The cause was a decrease in the porosity and voids of blended concrete brought on by the filler effect of smaller pieces of granite and glass [70].

## 7. Mechanical Performance Assessment Of Waste Glass Powder As Fine Aggregate Concrete:

When glass waste powder is used as the fine aggregate in nominal mix concrete, the compressive strength, splitting tensile strength, and flexural strength of the concrete are all increased by up to 20% [24].

### 7.1 Compressive Strength:

The utilisation of wasted glass in normal-strength concrete has received a lot of consideration in this investigation. When the percentage of glass waste powder replacement in concrete increased, the compressive strength values were substantially increased [24].

When compared to the control specimen, the cube compressive strength of specimens S5 to S8 treated with 5% to 20% WGP showed a progressive increase. The increase in percentages was detected between 1% and 5% [31, 67].

The compressive strength of PC declined at 28 days as the WGP content increased, increased gradually at 56 days, increased initially and then decreased at 112 days, and the 20% WGP was the turning point [71].

The results of tests with glass powder show that specimens' early compressive strengths are reduced, but that their constant growth rates in strength are increased. The growth rates of specimen strengths are rising steadily along with the increase in GP contents [64].

According to the test results, the concrete mix containing 20% waste glass fine aggregate had the greatest 28-day compressive strength value of 45.9 MPa, which reflects an increase in compressive strength of up to 4.23% in comparison to the control mix. All of the waste glass concrete mixes, with the exception of the 14-day concrete mixes, however, displayed compressive strength values that were marginally greater than those of the simple mixes [65].

Compressive strengths for early curing ages reduced as WGP content increased. However, when the PC's age increased, their strengths initially rose and subsequently fell as WGP content rose [71]. The flexural strengths of PC first increased and then declined with an increase in w/c. According to experimental findings, PC performance was at its best when w/c = 0.26 [71].

**Table 3. Compressive Strength Of Concrete, Fine Aggregate And Cement Replaced By Waste Glass Powder At Different Proportion.**

| Sr. No. | References | Specimen prepare by Fine Aggregate and Cement replaced by Waste Glass Powder. | | Compressive Strength | | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Fine Aggregate | Cement | 7 Days | 14 Days | 28 Days | 90 Days | |
| 1 | [24] | GP 10 | - | 17.33 | 20.35 | 26.88 | - | |
| 2 | | GP 20 | - | 18.22 | 21.55 | 27.11 | - | |
| 3 | | GP 30 | - | 16.65 | 19.56 | 22.76 | - | |
| 4 | [31] | GP 5 | - | - | - | 26.86 | - | |
| 5 | | GP 10 | - | - | - | 27.07 | - | |
| 6 | | GP 15 | - | - | - | 27.54 | - | |
| 7 | | GP 20 | - | - | - | 28 | - | |
| 8 | [64] | GP 10 | - | 39.7 | - | 48.6 | 55.81 | |
| 9 | | GP 25 | - | 35.8 | - | 42.4 | 52.48 | |
| 10 | | GP 35 | - | 31.0 | - | 41.8 | 52.05 | |
| 11 | | GP 60 | - | 15.3 | - | 28.6 | 37.07 | |
| 12 | [73] | GP 10 | - | 19.2 | - | 30.60 | - | |
| 13 | | GP 20 | - | 21.0 | - | 31.50 | - | |
| 14 | | GP 30 | - | 22.5 | - | 32.85 | - | |
| 15 | [65] | GP 10 | - | 34.6 | 39.1 | 40.3 | - | |
| 16 | | GP 15 | - | 32.0 | 38.3 | 42.0 | - | |
| 17 | | GP 20 | - | 31.7 | 38.0 | 45.9 | - | |
| 18 | [74] | GW 5 | - | 21.8 | 30.2 | 33.6 | - | |
| 19 | | GW10 | - | 20.8 | 28.9 | 32.1 | - | |
| 20 | | GW 15 | - | 19.7 | 27.3 | 30.3 | - | |
| 21 | | GW 20 | - | 17.8 | 24.6 | 27.5 | - | |
| 22 | [75] | GW 5 | - | 10.66 | - | 18.66 | - | |
| 23 | | GW10 | - | 10.22 | - | 17.58 | - | |
| 24 | | GW 15 | - | 8.14 | - | 17.03 | - | |
| 25 | | GW 20 | - | 8.14 | - | 15.85 | - | |
| 26 | [76] | - | GP10 | 28.3 | 31.1 | 36.0 | - | |
| 27 | | - | GP20 | 18.1 | 18.5 | 31.6 | - | |
| 28 | | - | GP30 | 16.9 | 17.3 | 29.6 | - | |
| 29 | [77] | - | GP 10 | 11.59 | 12.16 | 14.71 | - | |
| 30 | | - | GP 20 | 6.95 | 12.29 | 21.33 | - | |
| 31 | | - | GP 30 | 6.39 | 13.61 | 17 | - | |
| 32 | [78] | - | GP 10 | 21.64 | - | 30.40 | - | |
| 33 | | - | GP 20 | 28.08 | - | 31.63 | - | |
| 34 | | - | GP 30 | 28.88 | - | 34.16 | - | |
| 35 | | - | GP 40 | 27.91 | - | 31.11 | - | |

**GP- Glass Powder, GW- Waste Glass.**

### 7.2 Flexural Strength:

In cases where glass waste powder is used as fine aggregate in nominal mix concrete, the concrete flexural strength are increased by up to 20% [24].

It may be noted that the flexural strength rose by 2.9% to 14.3% in comparison to the control sample with the addition of 5% to 20% weight percent of glass sand aggregate [26].

**Table 4. Flexural Strength Of Concrete, Fine Aggregate And Cement Replaced By Waste Glass Powder At Different Proportion.**

| Sr. No. | References | Specimen | | Flexural Strength | | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Fine Aggregate | Cement | 7 Days | 14 Days | 28 Days | 90 Days | |
| 1 | [24] | GP 10 | - | 2.61 | 3.95 | 4.01 | - | |
| 2 | | GP 20 | - | 2.65 | 3.95 | 4.60 | - | |
| 3 | | GP 30 | - | 2.30 | 3.54 | 3.90 | - | |
| 4 | [31] | GP 5 | - | - | - | 3.81 | - | |
| 5 | | GP 10 | - | - | - | 3.82 | - | |
| 6 | | GP 15 | - | - | - | 3.85 | - | |
| 7 | | GP 20 | - | - | - | 3.88 | - | |
| 8 | [79] | GP 10 | - | 5.71 | 5.76 | 6.23 | - | |
| 9 | | GP 20 | - | 6.75 | 7.11 | 7.75 | - | |
| 10 | | GP 30 | - | 4.87 | 5.61 | 6.03 | - | |
| 11 | | GP 40 | - | 4.27 | 5.02 | 5.19 | - | |
| 12 | [64] | GP 10 | - | 6.5 | - | 6.92 | 8.08 | |
| 13 | | GP 25 | - | 5.0 | - | 6.52 | 7.25 | |
| 14 | | GP 35 | | 5.4 | - | 6.90 | 7.41 | |
| 15 | | GP 60 | | 3.7 | - | 5.90 | 6.20 | |
| 16 | [76] | - | GP10 | 7.21 | 8.21 | 6.2 | - | |
| 17 | | - | GP20 | 8.07 | 8.6 | 10.1 | - | |
| 18 | | - | GP30 | 7.86 | 7.4 | 8.10 | - | |
| 19 | [78] | - | GP 10 | 6.35 | - | 7.65 | - | |
| 20 | | - | GP 20 | 6.7 | - | 9.15 | - | |
| 21 | | - | GP 30 | 7.3 | - | 10.2 | - | |
| 22 | | - | GP 40 | 6.45 | - | 8.55 | - | |

### 7.3 Split Tensile Strength:

The increase in split tensile strength of mortar with GSA compared to the control mix varied within from 11% to 29%, 3% to 14%, and 20% to 23%, respectively, with the addition of 5, 10, 15, and 20 wt.% glass aggregate [26].
When 25% glass sand was added, the splitting tensile strength somewhat rose, but as the glass sand percentage grew, the strength fell. However of the colour of the glass, the splitting tensile strength decreased with larger percentages of glass sand. The splitting tensile strength of clear glass sand cement declined steadily with glass content [80].
The average fall in tensile strength for concrete with 10%, 30%, 50%, and 100% replacement ratios, respectively, was 10.2%, 10.8%, 17.8%, and 33%. Tensile strength was observed to diminish as natural fine aggregates were increasingly replaced by RCA and as the water-to-cement ratio increased [81, 82, 83, 84].
When using lignosulfonate and changed polycarboxylates in an aqueous solution, respectively, the addition of superplasticizers improved the splitting tensile strength up to 26.6% and 52.8% [85].

**Table 5. Split Tensile Strength Of Concrete, Fine Aggregate And Cement Replaced By Waste Glass Powder At Different Proportion.**

| Sr. No. | References | Specimen | | Split Tensile Strength | | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Fine Aggregate | Cement | 7 Days | 14 Days | 28 Days | 90 Days | |
| 1 | [24] | GP 10 | - | 3.07 | 3.03 | 3.40 | - | |
| 2 | | GP 20 | - | 3.19 | 3.16 | 3.46 | - | |
| 3 | | GP 30 | - | 2.80 | 2.65 | 3.04 | - | |
| 4 | [26] | GP 5 | - | - | - | 4.93 | - | |
| 5 | | GP 10 | - | - | - | 4.98 | - | |
| 6 | | GP 15 | - | - | - | 5.02 | - | |
| 7 | | GP 20 | - | - | - | 5.06 | - | |
| 8 | [31] | GP 5 | - | - | - | 2.96 | - | |
| 9 | | GP 10 | - | - | - | 2.97 | - | |
| 10 | | GP 15 | - | - | - | 3.0 | - | |
| 11 | | GP 20 | - | - | - | 3.02 | - | |
| 12 | [73] | GP 10 | - | 2.50 | - | 2.65 | - | |
| 13 | | GP 20 | - | 3.40 | - | 3.50 | - | |
| 14 | | GP 30 | - | 3.91 | - | 2.50 | - | |
| 15 | [86] | - | GP 5 | 3.10 | - | 3.73 | - | |
| 16 | | - | GP 10 | 3.15 | - | 3.82 | - | |
| 17 | | - | GP 15 | 2.92 | - | 3.39 | - | |
| 18 | | - | GP 20 | 2.56 | - | 2.88 | - | |
| 19 | | - | GP 25 | 2.26 | - | 2.76 | - | |
| 20 | [78] | - | GP 10 | 2.01 | - | 2.29 | - | |
| 21 | | - | GP 20 | 2.18 | - | 2.70 | - | |
| 22 | | - | GP 30 | 2.75 | - | 3.26 | - | |
| 23 | | - | GP 40 | 2.10 | - | 2.58 | - | |
| 24 | [77] | - | GP 10 | 1.46 | 1.62 | 1.7 | - | |
| 25 | | - | GP 20 | 1.44 | 1.78 | 1.82 | - | |
| 26 | | - | GP 30 | 0.74 | 1.8 | 2.03 | - | |
| 27 | [76] | - | GP10 | 1.46 | 1.89 | 2.60 | - | |
| 28 | | - | GP20 | 1.66 | 1.93 | 2.51 | - | |
| 29 | | - | GP30 | 1.49 | 1.9 | 2.23 | - | |

**8. Durability Assessment Of The Effect Of Recycle Aggregate And Glass Powder On Concrete Impermeability:**

The impermeability of RAC is often less than that of NAC and is primarily determined by the RA content, w/c ratio, original strength of the waste concrete, curing age, and presence of mineral admixtures.

The impermeability of RAC reduced with an increase in the replacement ratio of RA, according to published studies [17, 89].

It has been observed that water permeability rises with the w/c ratio and the proportion of RA added. Although there is a substantial variation in these numbers, concrete tends to become less permeable as it ages and cures. Additionally, the maximum depth ever recorded generally correlates with the level of RA assimilation.In the case of this study, entire penetration (more than 90 mm) was present in all of the concretes at 72 hours under pressure, making it impossible to compare the findings of the various concretes due to the high permeability of the cement paste. The test was therefore repeated, but this time with only 24 hours of pressure [87]. Chloride ion penetration resistance is negatively impacted by replacing 100% of NA with RCA, although this trend can be halted by adding 20% of FA. Low permeability and excellent chloride ion penetration rate of RCA concrete may be attained with an FA incorporation above 35%, which also provides the necessary service life for concrete structures. This type of concrete is suitable for use in submerged constructions since carbonation does not take place in the presence of water [88].

The w/c ratio and the amount of RA included both affect water permeability. Although there is a substantial variation in these numbers, concrete tends to become less permeable as it ages and cures. All ages show a tendency for the curves to converge at water penetration values of about 30 mm and a w/c ratio under 0.45.It is established that in these circumstances, there aren't many differences between CC and RAC. The maximum depth ever discovered is typically correlated with RA incorporation levels [87].

When the w/c ratio is increased, the penetration depth, oxygen permeability, and water absorption of RAC all rise at constant RA ratios. When the w/c ratio was low, the permeability of RAC with fine RA was comparable to that of NAC [87, 90, 91, 92, 93].

The particle size of RA and the impermeability of RAC were both correlated. Larger coarse aggregate results in a smaller surface area and more adherent mortar, which lowers the quantity of water used and increases concrete strength. It seems that there are two possible explanations: first, the flow path's tortuosity diminishes as coarse aggregate size increases, and second, the risk of bleeding falls as RA size increases. As the ratio of fine to coarse aggregates rises, so do the effective w/c ratio and air permeability of the RAC [94].

The source and crushing method for RA also have an impact on its impermeability. For instance, the water absorption of concrete made with 100% RA from Ambilei, a Portuguese waste recycling facility, increased by 22.8%, whereas the same specimens made with RA from Valnor, another Portuguese recycling facility, increased by 52.9% due to the presence of high clay content [95].

Due to RA1's higher cement paste content, specimens containing fine RA1 that were generated concurrently with coarse RA absorbed more water than specimens containing fine RA2 that were created using the same crushing procedure. It demonstrates that the production process can have a substantial impact on the performance and the physical characteristics of RA. Apart from that, the impermeability of concrete containing RA is greatly improved by the inclusion of ultra-fine ingredients such silica fume and metakaolin [42,43]. The microcrystalline nucleation effect that the fine mineral admixtures have on cement hydration speeds up cement hydration and the growth of hydration products [96,97].

The impermeability of RAC may be impacted by RA therapy.

In comparison to concrete without RA treatment, the water absorption of concrete treated with microbial carbonate decreased by around 38%, and the impermeability was even marginally higher than that of NAC [96].

**Table 6. Water Penetration Depth Analysis.**

| Reference | Substitution | Hours | 0% | 20% | 50% | 100% | Remarks |
|---|---|---|---|---|---|---|---|
| [89] | Water penetration | 72 H | >97 | >98 | >98 | >96 | |
| | | 24 H | 55 | >88 | 25 | 52 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| [99] | Mean Depth of water penetration | 24 H | 25 | - | 26 | 17 | Mix 1 |
| | | 24 H | 40 | - | 23 | 19 | Mix 2 |

## 9. Durability Assessment Of The Effect Of Recycle Aggregate And Glass Powder On Concrete Chloride Penetration Resistance:

One of the primary components that impact the resilience of concrete structures is the corrosion of the reinforcement caused by chloride. In general, RAC has a weaker resistance to chloride penetration than NAC [78]. In addition, it has been determined that RA produced at a low w/c ratio performs better than NAC in a chloride environment. This is likely because RAC contains more C-S-H gels, which help with chloride binding [100]. Carbonation and chloride penetration are the main causes of the reinforcement's depassivation. To control the service life of the reinforcement in concrete, it is crucial to measure this attribute using the diffusion coefficient [95].
As shown by the values of the determination coefficient of the carried out linear regressions (0.93 and 0.86 for the mixes with CRA and FRA respectively), the study result demonstrates that the increase of the chlorides diffusion coefficiency varies linearly with the replacement ratio of NA with RA [95]. Also, it implies that there is a 95% chance that the total passed charge of RAC with 100% coarse RA content will be around 2.07 times higher than that of NAC. Due to the increased proportion of adhering mortar and clay, the effect of fine RA on chloride penetration is more visible than that of coarse RA [59].
The chloride penetration resistance of RAC increases with curing age and decreases with w/c ratio, similar to regular concrete. Due to RA's lower water absorption, RAC made with RA from concrete with a higher original strength showed less chloride penetration than concrete made with RA from concrete with a lower strength.

## 10. Durability Assessment Of The Effect Of Recycle Aggregate And Glass Powder On Concrete Carbonation Resistance:

The introduction of carbon dioxide into concrete initiates the carbonation process. It interacts with the hydrated cement minerals to lower the alkalinity level when there is moisture present. Progressively moving from the outside to the inside, this procedure [95].
Reinforcement corrosion in reinforced concrete is caused by chloride ion intrusion and carbonation. Concrete is subjected to the physicochemical process known as carbonation, which encourages concrete's pH to be lowered through a sequence of chemical reactions that take place in the presence of CO2. Concrete allows CO2 to enter mostly by gradual diffusion from the surface to the interior. The concrete's permeability and moisture content affect the rate of carbonation [78].
The carbonation depth of RAC rises as the RA replacement ratio rises, just like it does for other characteristics [78].
However, it was shown that the carbonation depth decreased when the RA (whose content of adhering mortar was around 40%) replacement ratio was more than 70%. This might be explained by the increased cement content and slower carbonation rate in RA's highly adherent mortar, which contains more cement overall [101].
This study looked at how the environment impacted concrete with increasing coarse RCA content's performance in terms of durability. The specimens cured in the laboratory environment showed a deeper carbonation than those in the other settings included in the test programme because it was the driest, with an average relative

humidity of 60% and a temperature of 20degrees Celsius . When 100% coarse RCA were employed, at 91 days, these specimens clearly demonstrated a 30% rise in carbonation depth as the replacement amount increased [107,102]. To find out whether subjecting RAC to various environmental factors has any impact on the carbonation depth relative to that of the comparable NAC mixtures, other researchers have also conducted tests. The carbonation depths for all mixes rose correspondingly as specimens were cured in a dryer atmosphere [103].
The carbonation appears to be accelerated by the mineral additive that partially replaces cement (10% of the cement's mass). The recycled aggregate concrete performs less well in terms of carbonation resistance. In other words, the 10% (by mass) mineral admixture dosage has a greater detrimental impact than beneficial impact [104].
The carbonation behaviour of concrete is clearly affected by the size of the RA as well. Greater carbonation depths in concrete mixes made with fine RCA are more likely to be observed than in mixes made with coarse RCA. This is simply explained by the fine RCA's increased porosity, which results from the increased amount of mortar that was stuck and could not be separated during the recycling process [102]. Additionally, it has been noted that the overall carbonation resistance of SCC mixes based on LVFA and HVFA decreases when the RCA concentration rises. For LVFA-based SCC mixes, a maximum increase in carbonation depth of around 63% has been observed after 12 weeks of exposure. Similar to this, after 4 weeks of exposure, an increase in carbonation depth for SCC mixes based on HVFA approaches 53%. Similar to compressive strength, the addition of MK has had an impact on carbonation resistance [105]. The carbonation depth in mixtures containing fine and coarse RA from a CDW recycling plant was assessed in this study. They noticed that a complete replacement of the coarse NA resulted in a 100% increase in the carbonation depth at 28 days. On the other side, a 190% boost was brought on by completely replacing the NA (fine and coarse) [103]. This study demonstrates that integration of RA from concrete rather than ceramic RA is more harmful to concrete's carbonation resistance [105]. According to this research, the reserve of alkalinity is the primary element influencing the carbonation of RAC. Yes, the alkalinity slows the carbonation process, but another important component is the permeability of the concrete [89]. According to earlier research, the total RA's assimilation causes a 1.2–2.0 rise in carbonation depth [66].

**Table-7. Carbonation Depth Penetrations.**

| Reference | Substitution | Hours | 0% | 20% | 50% | 100% | Remarks |
|---|---|---|---|---|---|---|---|
| [107] | Carbonation Depth | 72 h | 9 | 10 | 10.2 | 11.6 | |

**Conclusions and recommendations:**

- In the process of reducing the requirement for the original components of concrete, using recycled concrete aggregate as a partial replacement for coarse aggregates in concrete also provides an approach for handling these environmental wastes.
- Numerous studies agree that recycling concrete and waste glass could be the best solution and significantly reduce land filling. Furthermore, reusing Recycle Aggregate and waste glass powder in the development of concrete can contribute

to the annual decline in waste delivered. Additionally, recycling and reuse would reduce CO2 emissions globally.

- When Recycle concrete as coarse aggregate and glass waste powder is used as the fine aggregate in nominal mix concrete, the compressive strength, splitting tensile strength, and flexural strength of the concrete are all boosted by up to 20%.
- The utilisation of recycle concrete and glass waste powder in concrete provides additional environmental as well as technical benefits for all related industries.
- Concrete production costs can be decreased by replacing recycle concrete as coarse aggregate and glass waste powder as fine aggregate in part.
- To achieve a better result recycle concrete and glass waste powder, replace with coarse aggregate and fine aggregate by 20%. Up to 20% of natural coarse and fine aggregates savs form this replacement of recycle concrete as coarse aggregate and glass waste powder as fine aggregate.
- There is an increase in workability with the recycle aggregate and GP substitution, particularly mixes with 30% Recycle aggregate and Glass waste powder recorded the highest slump the value of which is almost double that for the control mix (0% recycle aggregate and glass waste powder).
- The amount of recycle aggregate and waste glass powder mortar is a major factor in determining and affecting the durability of recycle aggregate with waste glass powder concrete; the more adhered recycle aggregate and waste glass powder mortar there is, the higher the porosity and water absorption, which results in poorer durability performance of recycle aggregate with waste glass powder concrete.
- Due to the larger porosity of recycled aggregates, the durability of recycle aggregate with waste glass powder, when cast with the same water/cement ratio, is less than that of ordinary concrete. However, because of the reduced porosity of the fresh paste, which predominates in low water/cement ratio concretes, aggressive agents progress more slowly, giving control and recycled concretes a comparable behaviour for water permeability.
- The recycled aggregates with waste glass powder concrete , the carbonation depth reduced when the replacement was 20% or 50%. For recycle aggregate as coarse aggregate and waste glass powder as fine aggregate concrete, this better behavior also occurred when the replacement was 30%. This behaviour demonstrates that the chemical makeup of the concrete, as opposed to only its physical characteristics, greatly influences the carbonation depth.

**References:**

1. Baena M, Torres L, Turon A, Llorens M & Barris C, Construction and Building Materials, 106 (2016) 449.
2. Paluri Y, Mogili S, Mudavath H & Noolu V, Materials Today: Proceedings, 38, (2021), 2537.
3. Warburton, R., 2020. Global Warming Has Concrete Problem When It Comes to CO2 [16. Dec]Available from. https://www.ecori.org/climate-change/2019/10/4/globalwarming-has-a-co2ncrete-problem.
4. Verein Deutscher, Zementwerk., 2019. Global cement production from 1990 to 2030 (in million metric tons) [07.Mar]Available from. https://www.statista.com/statistics/ 373845/global-cement-production-forecast/.
5. Shuqing Yang S, Ling T C & Poon C S, Cement and Concrete Composites, 108 (2020) 103548.
6. Topc¸u I ˙ B & Canbaz M, Cement and Concrete Research, 34 (2004) 267.

7. Ling T C & Poon C S, Materials and Structures, 46 (2013) 25.
8. Yu X, Tao Z, Song T Y & Pan Z, Construction and Building Materials, 114 (2016) 737.
9. Gupta A, Gupta N , Shukla A, Goyal R & Kumar S, International Symposium on Fusion of Science and Technology, 804 (2020) 012034.
10. Kim I S, Choi S Y & Yang E I, Construction and Building Materials, 184 (2018) 269.
11. Arivalagan S & Sethuraman V S, Materials Today: Proceedings, 45 (2021) 6035.
12. Małek M, Łasica W, Jackowski M & Kadela M, Materials, 13 (2020) 3189.
13. Kazmi S M S, Munir M J, Wu Y F, Patnaikuni I, Zhou Y & Xing F, Construction and Building Materials, 264 (2020) 120284.
14. Khan M N N, Saha A K, Sarker P K, Journal of Building Engineering, 28 (2020) 101052.
15. Li S, Gao J, Li Q & Zhao X, Construction and Building Materials, 267 (2021) 120976.
16. Tayeh B A, Saffar D M A & Alyousef R, Journal of Materials Research and Technology, 9 (2020) 8469.
17. Guo H, Shi C, Guan X, Zhu J, Ding Y, Ling T C, Zhang H & Wang Y, Cement and Concrete Composites, 89 (2018) 251.
18. Shi C, Li Y, Zhang J, Li W, Chong L & Xie Z B, Journal of Cleaner Production, 112 (2016) 466.
19. Shi X H, Jiang P, Wang H Y, Zhang S H, Ji T, Liu W J & Zhou H Y, The Astrophysical Journal, 829 (2016) 1.
20. Masood B, Elahi A, Barbhuiya S & Ali B, Construction and Building Materials, 237 (2020) 117760.
21. (American Concrete Institute 2020) American Concrete Institute, 2020. Consistency, plastic consistency, and Workability [09.July]Available from. https://www.concrete.org/tools/frequentlyaskedquestions aspx?faqid=647.
22. (Smith, 2010, American Concrete Institute 2008,) James Trevor Smith (2010). Recycled Concrete Aggregate – A Viable Aggregate Source For Concrete Pavements. UWSpace. http://hdl.handle.net/10012/4900
23. Lotfia S, Deja J, Rem P, Mróz R, Roekel E V & Stelt H V D, Resources, Conservation and Recycling, 87 (2014) 117.
24. Kurda R, Brito J D & Silvestre JD, Journal of Building Engineering, 29 (2020) 101173.
25. Verian K P, Ashraf W & Cao Y, Resources, Conservation & Recycling, 133 (2018) 30.
26. Sturtevant, Jeffrey R., "Performance of rigid pavements containing recycled concrete aggregates" (2007). Master's Theses and Capstones. 349.
27. Wagih A M , Karmoty H Z E, Ebid M & Okba S H, Housing and Building National Research Center, 9 (2013) 193.
28. Verian K P, Ashraf W & Cao Y, Resources, Conservation and Recycling, 133 (2018) 30.
29. Li S, Gao J, Li Q & Zhao X, Construction and Building Materials, 267 (2021) 120976.
30. Tijani A I, Yang J & Dirar S, International Journal of Structural and Civil Engineering Research, 4 (2015) 347.
31. Balasubramanian B, Krishna G V T G , Saraswathy V & Srinivasan K, Construction and Building Materials, 278 (2021) 122400.
32. Barroqueiro T, Silva P R D & Brito J D, Materials, 12 (2019) 3565.

33. Surendar M, Ananthi G B G, Sharaniya M, Deepak M S & Soundarya T V, Materials Today: Proceedings, 44 (2021) 1723.
34. Behera M, Bhattacharyya S K, Minocha A K, Deoliya R & Maiti S, Construction and Building Materials, 68 (2014) 501.
35. Rao M C, Bhattacharyya S K & Barai S V, Construction and Building Materials, 25 (2011) 69.
36. Rao M C, S. K. Bhattacharyya S K & Barai S V, Materials and Structures, 44 (2011) 205.
37. Gonçalves T, Silva R V, Brito J D, Fernandez J M & Esquinas A R, Cement and Concrete Composites, 105 (2020) 103420.
38. Kazmi S M S, Munir M J , Wu Y F, Patnaikuni I, Zhou Y & Xing F, Cement and Concrete Composites, 104 (2019) 103398.
39. GB/T 1596–2017, Fly ash used for cement and concrete. General Administration of Quality Supervision, Inspection and Quarantine of PR China, Beijing, China, 2017.
40. Lavado J, Bogas J, Brito J D & Hawreen A, Construction and Building Materials, 233 (2020) 117322.
41. He Y, Zhang X, Zhang Y & ZhouY, Construction and Building Materials, 72 (2014) 270.
42. Rahal K, Building and Environment, 42 (2007) 407.
43. Batayneh M, Marie I & Asi I, Waste Management, 27 (2007) 1870.
44. Omrane M, Kenai S, Kadri E H & Mokhtar A A, Journal of Cleaner Production, 165 (2017) 415.
45. Rattanachu P, Tangchirapat W & Jaturapitakkul C, Journal of Materials in Civil Engineering, 31 (2019) 04019093.
46. Cui H Z, Lo T Y, Memon S A, Xing F & Shi X, Construction and Building Materials, 36 (2012) 1036.
47. Saffar D M A & Tayeh B A, International Journal of Engineering & Technology, 7 (2018) 67.
48. Babu V S, Mullick A K , Jain K K & Singh P K, Journal of Sustainable Cement-Based Materials, 4 (2015) 54.
49. Marie I & Quiasrawi H, Journal of Cleaner Production, 37 (2012) 243.
50. Saravanakumar P & Dhinakaran G, Journal of Materials in Civil Engineering, 25 (2013) 1127.
51. Pedro D, Brito J D, Evangelista L & Bravo M, Journal of Materials in Civil Engineering, 30 (2018) 04018324.
52. Etxeberria M, Marı´ A R & Va´zquez E, Materials and Structures, 40 (2007) 529.
53. Kou S C, Poon C S & Agrela F, Cement & Concrete Composites, 33 (2011) 788.
54. Poon C S, Shui Z H & Lam L, Construction and Building Materials, 18 (2004) 461.
55. Tegguer A D, Construction and Building Materials, 27 (2012) 112.
56. Kurda R, Brito J D & Silvestre J D, Journal of Building Engineering, 29 (2020) 101173.
57. Dimitriou G, Savva P & Petrou M F, Construction and Building Materials, 158 (2018) 228.
58. Abed M, Nemes R & Tayeh B A, Journal of King Saud University - Engineering Sciences, 32 (2020) 108.
59. Evangelista L & Brito J D, Cement and Concrete Composites, 32 (2010) 9.
60. KANG T, KIM W, KWAK Y K & HONG S G, IABSE Congress Report,18 (2012).

61. Letelier V, Jara B I H, Manosalva M & Moriconi G, Waste Management, 94 (2019) 107.
62. Ceia F, Raposo J, Guerra M, Júlio E & Brito J D, Construction and Building Materials, 109 (2016) 139.
63. Cantero B, Bravo M, Brito J D, Bosque I F S D & Medina C, Journal of Cleaner Production, 275 (2020) 122913.
64. Nahi S, Leklou N, Khelidj A, Oudjit M N & Zenati A, Construction and Building Materials, 262 (2020) 120875.
65. Ismail Z Z & Hashmi E A A, Waste Management, 29 (2009) 655.
66. Rahma A, Naber N E & Ismail S I, Cogent Engineering, 4 (2017) 1373415.
67. He Z H, Zhan P M, Du S G, Liu B J & Yuan W B, Composites Part B, 166 (2019) 13.
68. Husain A & Assas M M, International Journal of Civil and Environmental Engineering, 7 (2013) 37.
69. Mostofinejad D, Hosseini S M, Nosouhian F, Ozbakkaloglu T & Tehrani B N, Journal of Building Engineering, 29 (2020) 101182.
70. Jain K L, Sancheti G & Gupta L K, Construction and Building Materials, 252 (2020) 119075.
71. Li A Y, Qiao H, Li Q, Hakuzweyezu T & Chen B, Construction and Building Materials, 300 (2021) 123997.
72. He Z H, Zhan P M, Du S G, Liu B J & Yuan W B, Composites Part B, 166 (2019) 13.
73. Natarajan S, Ravichandran N, Basha N A S & Ponnusamy N, Materials Science and Engineering, 955 (2020) 012050.
74. Rani G Y, Krishna T J & Murali K, Materials Today: Proceedings, 46 (2021) 8817.
75. Bhat V V & Rao N B, International Journal of Engineering Trends and Technology, 16 (2014) 196.
76. Mounika M, Lalith B V, Rao V R & Lalitha G, International Journal of Civil Engineering and Technology, 8 (2017) 444.
77. Rahman S & Uddin M N, Civil Engineering and Architecture, 6 (2018) 149.
78. Mwizerwa F & Garg A, International Journal of Civil Engineering and Technology, 8 (2017) 1639.
79. Shoaei P, Ameri F, Musaeei H R, Ghasemi T & Ban C C, Construction and Building Materials, 251 (2020) 118991.
80. Tan K H & Du H, Cement & Concrete Composites, 35 (2013) 109.
81. Vieira C S, Pereira P M & Lopes M D L, Journal of Cleaner Production, 124 (2016) 1.
82. Khoshkenari A G, Shafigh P, Moghimi M & Mahmud H B, Materials and Design, 64 (2014) 345.
83. Kumar R, Minocha A K & Gurram S C B, Magazine of Concrete Research, 69 (2017) 1288.
84. Sarhat S R, Sustainable Construction Materials and Technologies (2007) 53.
85. Pereira P, Evangelista L & Brito J D, Cement and Concrete Composites, 34 (2012) 1044.
86. Ali A. Aliabdo A A , Abd Elmoaty M. Abd Elmoaty A E A E & Aboshama A Y, Construction and Building Materials, 124 (2016) 866.
87. Thomas C, Setién J, Polanco J A, Alaejos P & Juan M S D, Construction and Building Materials, 40 (2013) 1054.

88. Kurda R, Brito J D & Silvestre J D, Construction and Building Materials, 157 (2017) 554.
89. Thomas C, Setién J & Polanco J A, Construction and Building Materials, 114 (2016) 536.
90. Henry M, Pardo G, Nishimura T & Kato Y, Resources, Conservation and Recycling, 55 (2011) 1060.
91. Levy S M & Helene P, Cement and Concrete Research, 34 (2004) 1975.
92. Mas B, Cladera A, Bestard J, Muntaner D, López C E, Piña S & Prades J, Construction and Building Materials, 34 (2012) 430.
93. Zega C J & Maio Á A D, Waste Management, 31 (2011) 2336.
94. Basheer L, Basheer P A M & Long A E, Construction and Building Materials, 19 (2005) 682.
95. Bravo M, Brito J D, Pontes J &Evan gelista L, Construction and Building Materials, 77 (2015) 357.
96. Çakır Ö, Construction and Building Materials, 68 (2014) 17.
97. Singh M & Singh S P, Construction and Building Materials, 127 (2016) 828.
98. J, Vandevyvere B, Vanhessche S, Schoon J, Boon N & Belie N D, Journal of Cleaner Production, 156 (2017) 355.
99. Lage I M, Abella F M, Herrero C V& Ordóñez J L P, Construction and Building Materials, 37 (2012) 171.
100. Vázquez E, Barra M, Aponte D, Jiménez C & Valls S, Construction and Building Materials, 67 (2014) 61.
101. Lei B & Xiao J Z, Jounrnal of Building and Materials, 11 (2008) 605.
102. Silva R V, Neves R, Brito J D & Dhir R K, Cement & Concrete Composites, 62 (2015) 22.
103. Bodin F B & Zaharieva R H, Materials and Structures, 35 (2002) 504.
104. Zhuang X J, Bin L & Zeng Z C, Science China Technological Sciences, 55 (2012) 2609.
105. Gomes M & Brito J D, Materials and Structures, 42 (2009) 663.
106. Xiao J, Li W , Fan Y & Huang X, Construction and Building Materials, 31 (2012) 364.
107. Amorim P, Brito J D & Evangelista L, ACI Materials Journal, 109 (2012) 195.
108. Thakur S & Chauhan S R, Indian Journal of Engineering & Materials Sciences, 20 (2013) 539.
109. Thakur S & Chauhan S R, Indian Journal of Engineering & Materials Sciences, 22 (2015) 669.
110. Chauhan S R & Thakur S, Materials & Design, 51 (2013) 398.
111. Thakur S & Chauhan S R, Journal of Composite Materials, 48 (2013) 2831.
112. Umesh & Verma A, International Journal of Trend in Scientific Research and Development, 4 (2020) 1191.