Evaluating the Durability and Suitability of Various Aggregate Types for Construction Applications

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Abstract

In this study, we compare the properties of cement concrete and geopolymer concrete. Geopolymer concrete, an eco-friendly and green construction material, is investigated as a potential replacement for traditional cement concrete. In geopolymer concrete, cement is completely replaced by alternative materials. We employ Ground Granulated Blast Furnace Slag (GGBFS) and fly ash by-products for this research. Aggregates play a crucial role in determining the durability and strength of both cement and geopolymer concrete. The durability of four different types of aggregates, sourced from various locations. By subjecting these aggregates to various durability tests, we aim to identify the most suitable aggregate for construction purposes, considering both natural and artificial stone quarry aggregates. To assess the durability of the selected aggregates, several tests were conducted. The findings of this comprehensive study reveal that the black stone aggregate sample, obtained from a specific location, exhibits superior durability across all tested aspects compared to the other aggregate samples.

Keywords: Geopolymer concrete, Sintered Flyash Aggregate, Natural aggregate, red aggregate, and Durability.

1. Introduction

Geopolymer concrete has emerged as an eco-friendly alternative to conventional Portland cement concrete, offering a reduced carbon footprint and enhanced mechanical properties [1]. However, a key challenge in geopolymer concrete technology is the development of lightweight versions with improved strength characteristics. Lightweight concrete provides benefits such as better thermal insulation, reduced dead load, and increased design flexibility, making it highly desirable for various construction applications [2]. This study aims to improve the strength of lightweight geopolymer concrete by incorporating sintered flyash aggregates. Over the past century, concrete has become an increasingly important construction material, with lightweight concrete (LWC) being successfully utilized in numerous projects, including long-span bridges, high-rise frames, and offshore structures [3], [4], [5], [6]. This success can be attributed to the many advantages offered by LWC, such as reduced weight, higher strength-to-weight ratio, cost-effective construction, enhanced durability, increased tensile strain capacity, minimal thermal expansion, improved heat and sound insulation, and better fire resistance [7], [8], [9]. According to the American Concrete Institute (ACI) 213R-03 [7], structural lightweight concrete should have a density between 1120 and 1920 kg/m3 and a compressive strength exceeding 17 MPa. Researchers have been focusing on developing durable and strong LWC with sustainable properties.

Additionally, the large quantities of flyash generated by coal combustion in thermal power plants pose a potential threat to land and water, affecting the ecological cycle [10]. In India, annual flyash production is estimated at 166 million tons, with only 56 percent being properly managed, raising societal concerns [11]. Utilizing flyash as a construction material in the building industry is a wise approach to waste disposal and environmental protection for future generations [12]. Initially, the primary focus was on using flyash as a replacement for cement. However, considering that aggregates make up approximately 70% of the concrete matrix volume, researchers are now exploring the use of flyash byproducts as substitutes for natural coarse aggregate (NCA) and natural fine aggregate (NFA) [13]. Sintered flyash aggregate (SFA) is a lightweight artificial aggregate that can be produced from flyash through a sintering process, with 90–100% of the material used being flyash [14]. The production of SFA from flyash involves mixing raw materials, forming pellets, and sintering these pellets at high temperatures [15]. The raw materials, such as flyash and pulverized coal, are combined with water and a suitable binder, like bentonite, cement, or lime, to create a homogeneous slurry. This mixture is then fed into a pelletizer, a rotating disk that shapes the slurry into pellets. The pelletizer's speed and angle directly influence the pellet size. Finally, the pellets are sintered at temperatures ranging from 1100 to 1300 °C and cooled to obtain the desired SFA [15]. Using SFA offers several advantages over traditional aggregate, including faster construction, reduced transportation costs, and a decrease in the project's overall weight [16]. The use of supplementary cementitious materials (SCMs) in high-strength concrete production for offshore construction is also highly beneficial [17], [18]. Currently, SFA and other lightweight aggregates are primarily used in non-structural applications, such as roof tiles, arrestor beds, and refractory materials [19]. Several studies have aimed to produce lightweight concrete with compressive strengths up to 54.8 MPa using 100% saturated fine aggregate (SFA) as lightweight aggregate (LWA) without supplementary cementitious materials (SCM). Other studies have demonstrated that incorporating SCMs, such as flyash, slag, silica fume, and limestone powder, can enhance the compressive strength of LWA concrete, although it may not meet the density requirements for LWC. Furthermore, research has shown that concrete made with a complete replacement of NCA with SFA exhibits better mechanical properties than conventional concrete [18]. Prominent researchers have also investigated the durability characteristics of SFA concrete, finding that it performs better than traditional concrete. Additionally, it has been observed that the microhardness of LWA concrete is higher than that of regular concrete. This study aims to compare the properties of cement concrete and geopolymer concrete, with a focus on the impact of aggregate particle size distribution on durability. By subjecting different types of aggregates to a range of durability tests, this research seeks to provide valuable insights into the performance of these materials and their potential for use in sustainable construction practices.

2. Material Used

In this study, three types of aggregate are use in ordinary concrete and geopolymer concrete.

2.1 Natural Aggregate: - Two types of natural aggregate are use in both materials one is black aggregate and red aggregate.

2.2 Sintagg Sintered Flyash Aggregate: - Sintagg sintered flyash lightweight aggregates is made from the sintering process of flyash as per IS CODE 9142 PART 2 . Sintagg is formed into small round pellets, which are then processed to create aa very hard aggregate with a honeycombed internal spongy structure. These hard pellets can then be used as a superior, consistent, lightweight aggregate which is up to 50% lighter than natural aggregate.

2.3 Mix Design of M-50 Grade Concrete mix & Geopolymer Concrete: - Design of M-50 concrete mix as per IS:10262-2009, Concrete mix proportioning guidelines. In Geopolymer concrete mix Sodium hydroxide (solid) and sodium metasilicate (glass water) form. Sodium hydroxide and sodium metasilicate is a 1:2 ratio.

Table 1: Material Requirement for Concrete Block

Designation of Mix	**Aggregate**		**Cement**	**Water**	**Curing Condition**
	C.A (kg)	**Sand (kg)**			
Black aggregate	1220	552	406.07	170.5	Water Curing
Red aggregate	1160	552	406.07	170.5	Water Curing
Flyash aggregate	552	552	406.07	170.5	Water Curing

Table 2: Material Requirement for GPC Block (Ambient Temperature Curing Condition)

Designation of Mix	Aggregate		GGBS (kg)	Flyash (kg)	Alkaline solution	Sodium Hydroxide	Sodium hydroxide:
	C.A (kg)	Sand (kg)				Molarity (M)	Sodium Silicate
Black aggregate	1220	552	373.07	33	243.64	12.5 M	2
Red aggregate	1160	552	373.07	33	243.64	12.5 M	2
Flyash aggregate	552	552	373.07	33	243.64	12.5 M	2

3. Experimental programs

In this experimental study, we examined two different types of materials (ordinary concrete and geopolymer concrete), and both materials were cast with three types of aggregates used in this study. The study attempted to assess the durability behavior of ordinary concrete and geopolymer concrete. In both ordinary concrete and geopolymer concrete, three different types of aggregates were used. Samples of three different sources of materials were black aggregate, red aggregate, and flyash aggregate. The investigation involved three different programs to check durability behavior: sodium sulfate soundness test, proposed freeze-thaw test by water, and acid rain test. In this study, the behavior of geopolymer concretes and ordinary concrete exposed to about 400g per liter of technical grade anhydrous sodium sulfate conforming to IS 255 (1982) was added to tap water at room temperature with continued stirring. This solution was prepared at least two days prior to its use. Prior to use, the deposited undissolved crystals were filtered out. The solution was stored at a temperature of 27 ± 2°C. The second test was performed by preparing synthetic rainwater referring to US EPA 1312 (1994). A 60/40 weight mixture of sulfuric acid (H2SO4) and nitric acid was added to water to reduce the pH to 4.5. The pH of 4.5 was chosen referring to the pH values that could naturally occur according to US EPA 1312 (1994) specification. The third test was performed by using 3% sodium chloride in water, and this solution was used for freezing and thawing at -20°C.

Following the commencement of exposure to different types of durability tests on both types of material effect on it and was measuring:

- Compressive strength
- Weight loss
- Chemical composition

3.1 Materials specifications

Two different types of materials like ordinary concrete and geopolymer concrete with three type of aggregate used in both materials. In ordinary concrete use, OPC and geopolymer concrete use GGBS with Flyash (class F). The chemical composition of GGBS, Class-F Flyash, flyash aggregate, red stone aggregate, and black aggregate were determined by X-ray diffraction (XRD) technique. In geopolymer concrete binding materials like GGBS and flyash were activated by using alkaline liquid. The alkaline liquid is the combination of Na2SiO3 and 12.5 M NaOH. In this research the sodium hydroxide vs sodium silicate ratio is 2.5 Alkaline solution vs binder content ratio is 0.6.

4. Results and Discussion

4.1 Sodium Sulphate Soundness Test:- This test has been performed according to test procedure in the laboratory and the following observations are made:

Table 3: SSST Observations Samples (Red Stone, Black Stone, and Flyash Aggregate)

Retained on sieve (mm)	Initial weight (grams)			Final weight (grams)			Percentage loss (%)		
	Red Stone	Black Stone	Flyash Aggregate	Red Stone	Black Stone	Flyash Aggregate	Red Stone	Black Stone	Flyash Aggregate
12.5	180.72	202.39	107.78	178.39	199.2	106.61	1.29	1.58	1.09
10	100.4	118.97	112.51	98.2	114.57	111.24	2.19	3.7	1.13
8	98.85	119.8	111.65	95.43	114.78	109.35	3.46	4.19	2.06
4.75	103.84	91.07	86.89	98.36	86.13	84.54	5.28	5.42	2.7

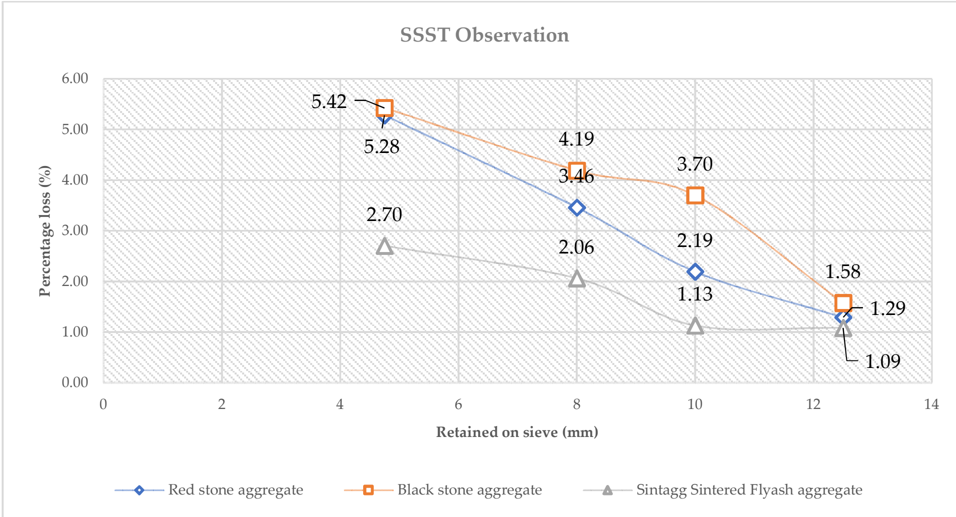

Figure 1 Comparison of test results of SSST

Graph above shows variation of percentage loss of weight of aggregate sample under action of Sodium Sulphate. From the graph it can be properly seen that sample obtained from Sintagg Sintered Flyash aggregate is more durable against attack of sodium sulphate. Hence Sintagg sintered flyash aggregate provides better results as compared to other aggregate.

4.2 Freeze Thaw Test:- This test has been performed in the laboratory according to the test procedure and the following observations are made:

Table 4: FTTW Observations Samples (Red Stone, Black Stone, and Flyash Aggregate)

Retained on sieve (mm)	Initial weight (grams)			Final weight (grams)			Percentage loss (%)		
	Red Stone	Black Stone	Flyash Aggregate	Red Stone	Black Stone	Flyash Aggregate	Red Stone	Black Stone	Flyash Aggregate
12.5	187.35	208.83	104.08	184.03	206.96	102.01	1.77	0.9	1.99
10	108.8	106.74	119.98	106.81	105.39	116.83	1.83	1.26	2.63
8	82.01	104.66	101.41	79.85	103.81	100.01	2.63	0.81	1.38
4.75	102.24	73.11	96.44	98.42	72.51	95.34	3.74	0.82	1.14

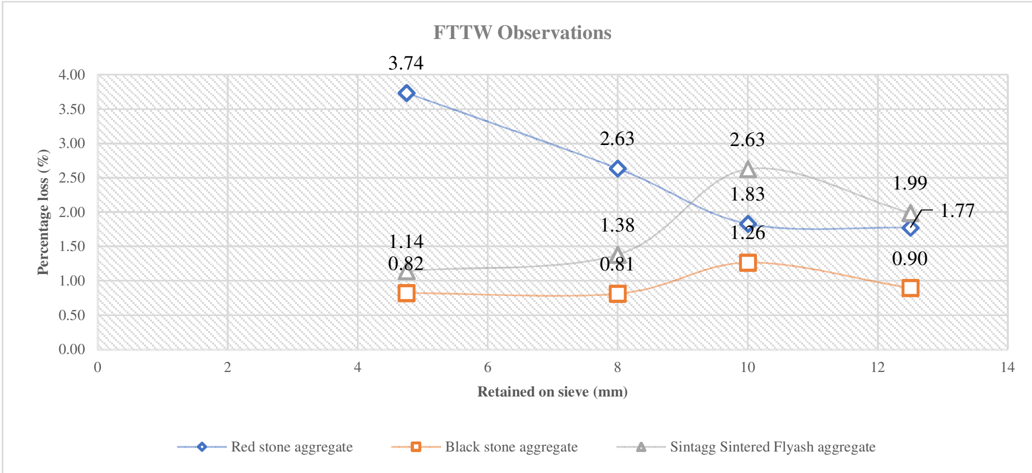

Figure 2 Comparison of test results of FTTW

Figure 2 shows percentage loss of weight of aggregates due to freezing and thawing, tested under freeze thaw test by water. Percentage loss of weight under various sieves is plotted in the above graph. Graph shows the comparison between three samples. From the above graph sample collected from black stone aggregate is more durable against action of freezing and thawing.

4.3 Acid Rain Test: This test has been performed in the laboratory according to test procedure and the following observations are made:

Table 5: ART Observations Sample no. (Red Stone, Black Stone, and Flyash Aggregate)

Retained on sieve (mm)	Initial weight (grams)			Final weight (grams)			Percentage loss (%)		
	Red Stone	Black Stone	Flyash Aggregate	Red Stone	Black Stone	Flyash Aggregate	Red Stone	Black Stone	Flyash Aggregate
12.5	199.52	205.84	105.41	195.02	201.85	103.49	2.26	1.94	1.82
10	104.58	119.74	109.81	102.02	117.32	107.6	2.45	2.02	2.01
8	87.55	105.51	104.62	85.34	102.89	102.34	2.52	2.48	2.18
4.75	104.28	76.83	97.42	100.23	74.34	94.76	3.88	3.24	2.73

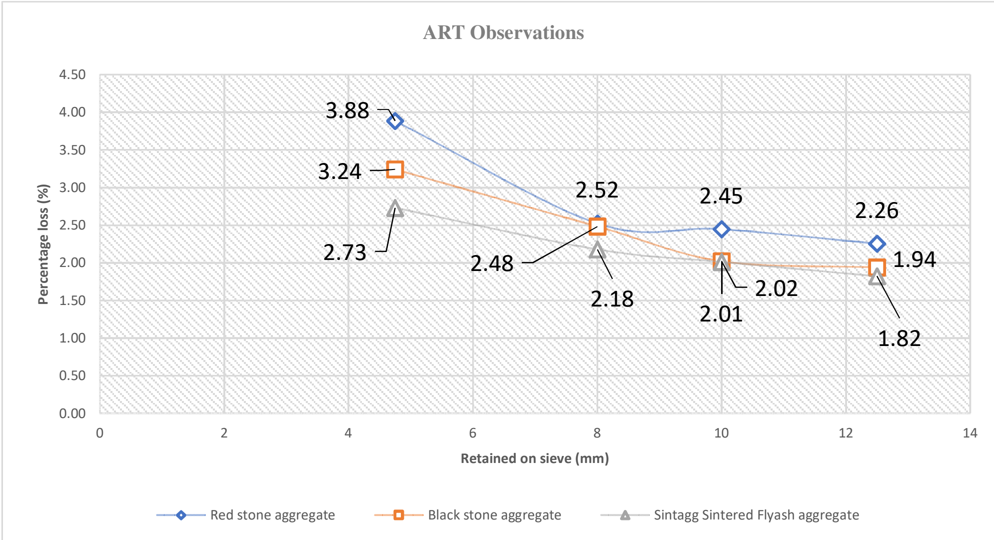

Figure 3 Comparison of test results of ART

Figure 3 shows the percentage weight loss in aggregate samples when tested under synthetic acid rain solution. The above graph is a plot between percentage weight loss and sieves of different sizes. From this graph result can be easily concluded by comparing the weight loss of aggregate samples over various sieves. On comparing the graph I found that the sample collected from sintagg sintered flyash aggregate is more durable against the attack of acid rain.

4.4 Impact value test: -

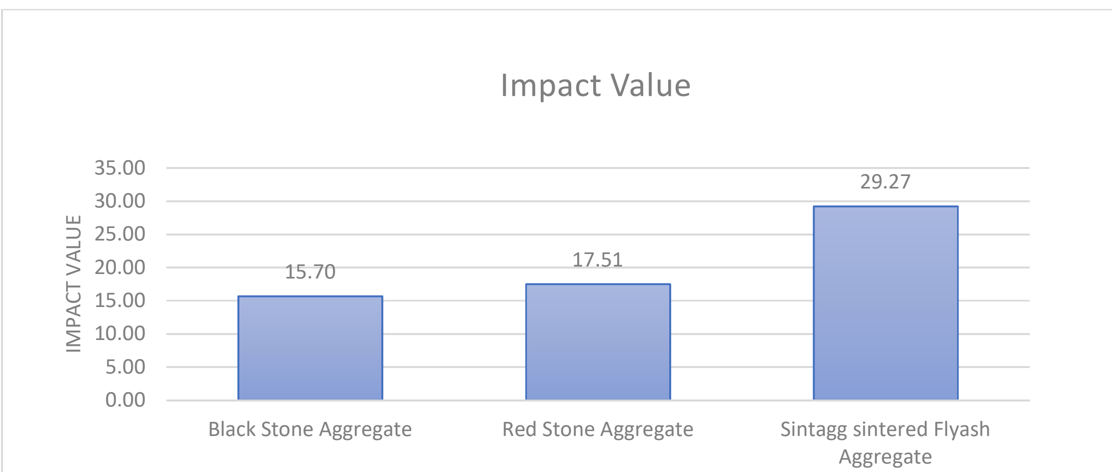

Figure 4 Comparison of test results of IVT

Figure 4 shows the result of Impact Value Test (IVT) conducted on two aggregate samples. The graph shows the values of three tests done on each sample. This graph clearly shows the comparison of impact value test results of three different aggregate samples. Clearly, it can be seen that, in all three tests sample obtained from black stone aggregate is more durable against Impact loading.

4.5 Water absorption test: -

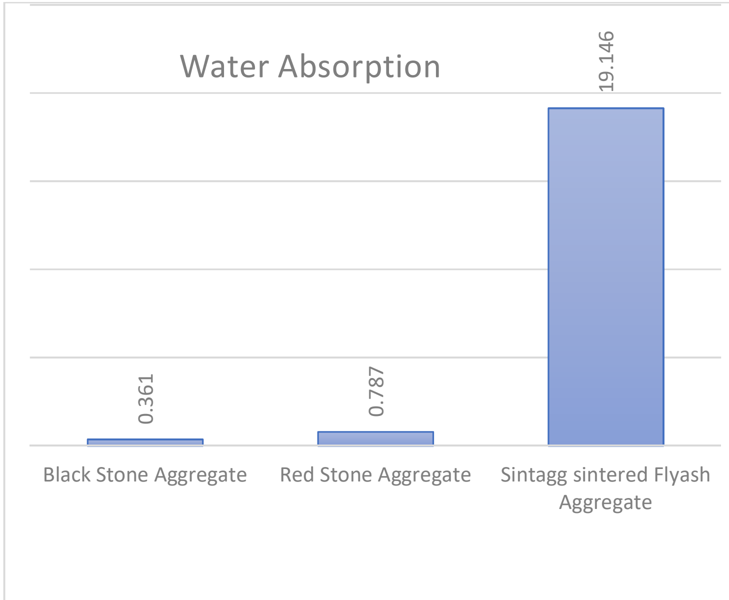

Figure 5 Comparison of test results of Water absorption Test

Figure 5 shows the percentage of water absorbed by three aggregate samples when tested twice. The test was conducted twice on each sample and compared. The above figure is a graphical comparison of three samples. From this graph, it can be seen that the sample collected from black stone aggregate seems to be more durable than another sample against water absorption in all three aggregates.

4.6 Compressive strength: -

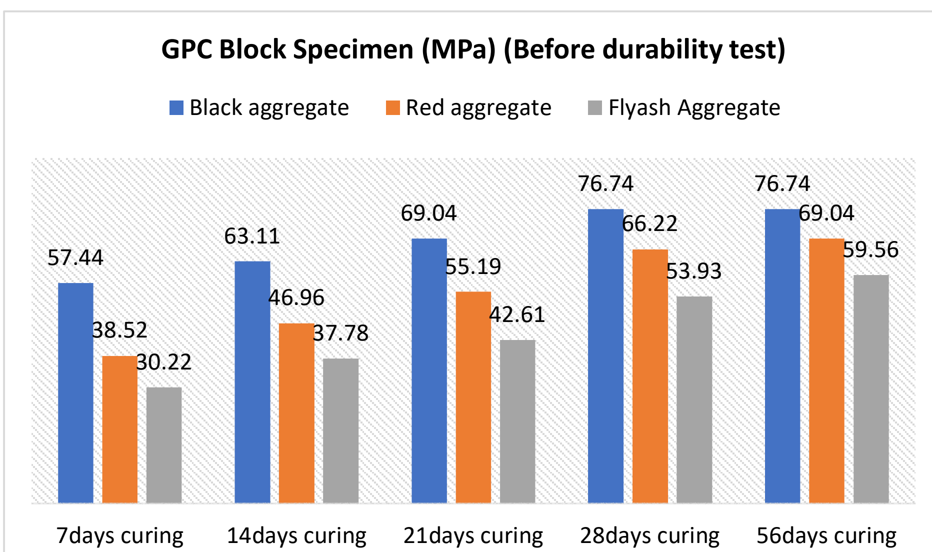

Figure 6: Compressive Strength of GPC Block Specimen (MPa) (After durability test)

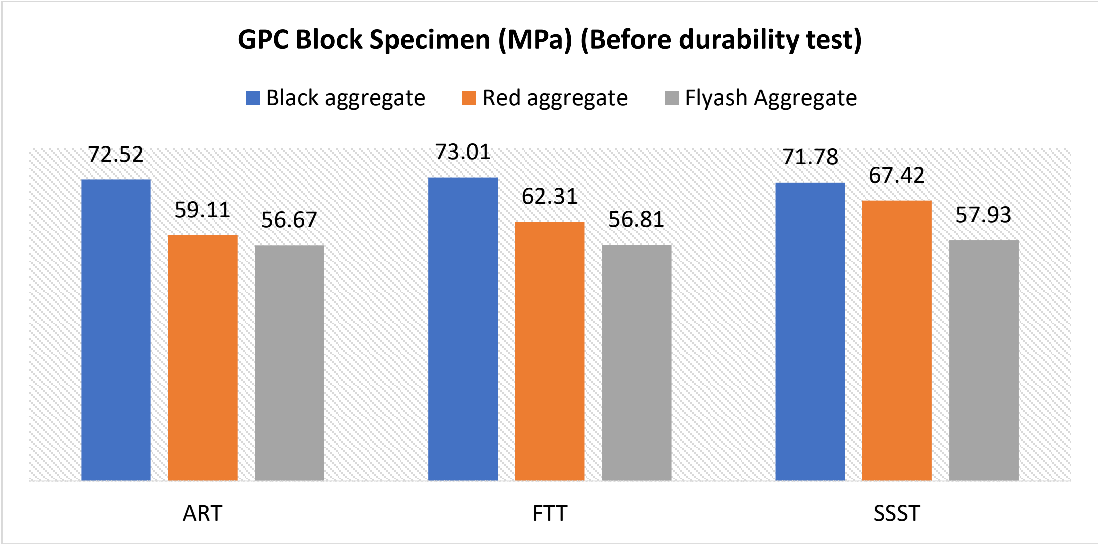

Figure 7: Compressive Strength of GPC Block Specimen (MPa) (Before durability test)

4.7 Strength declination

The strength declination of the samples exposed to different chemical solutions was estimated by measuring compressive strength. In the case of normal ambient-cured samples where voids are present, the samples will fail once the weakest part. In discrepancy, when samples are immersed in a chemical solution that causes the internal components of the concrete such as calcium to expand, the integrity of the samples will be enhanced. still, once the pressure produced by the expansion of the ettringite conformation exceeds the available voids and starts to cause internal cracks, the strength will decline.

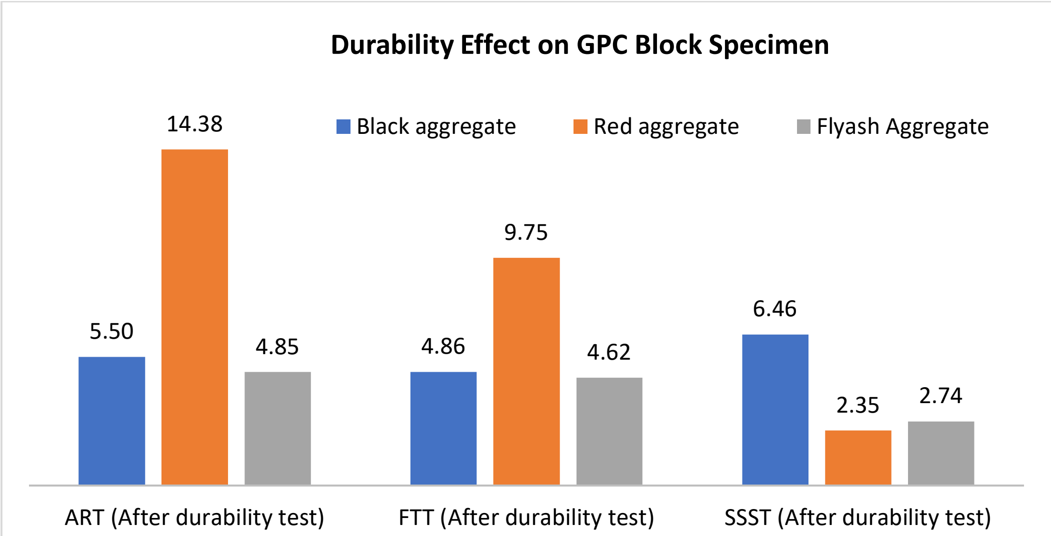

Figure 8: Compressive Strength Loss of GPC Block Specimen (MPa) (After durability test)

4.8 Mass loss

The weight-change results of the concrete exposed to sodium chloride, sodium sulphate, sodium sulphate and sulphuric acid solutions. Apart from these attacks' aggregates are susceptible to Acid attacks as well, which is also a major reason for deterioration of aggregates, causing damage to mix design. The weight of the immersed specimens in the chemical solutions tends to increase and then decrease. The initial increase of the weight can be attributed to

- The inclusion of the weight of the chemical particles that penetrated the concrete within the solution and resulted in an increase in the concrete weight, and
- The expansion of some elements in the concrete, which has a beneficial effect in terms of increasing the volume of the concrete.

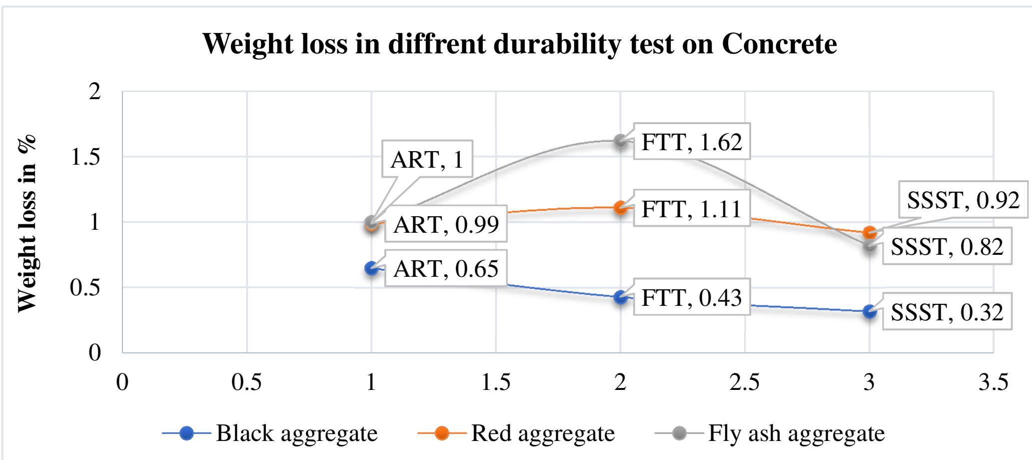

Figure 9: Compressive Strength Loss of Concrete Block Specimen (MPa)

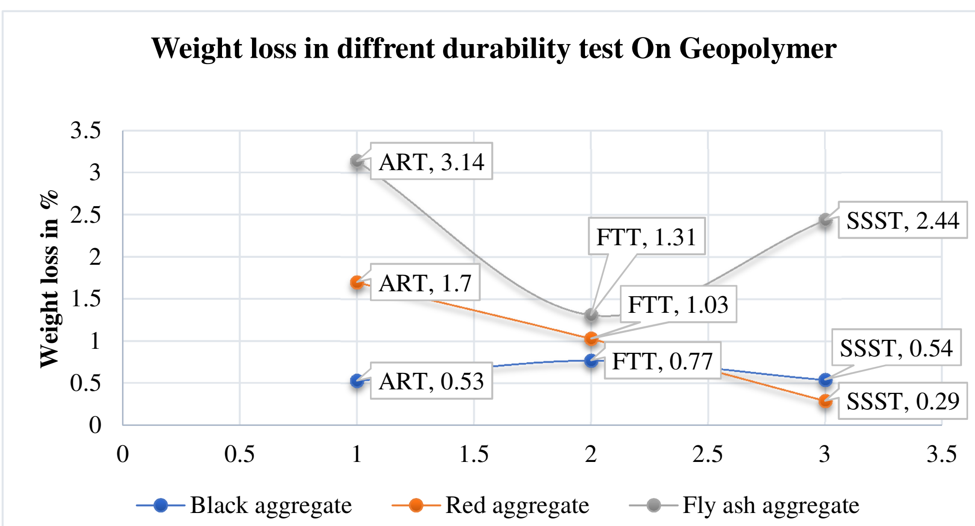

Figure 10: Compressive Strength Loss of GPC Block Specimen (MPa)

5. CONCLUSIONS

- This paper has presented the results of an experimental study that was undertaken to investigate the behavior of geopolymer concretes exposed to 5% sodium chloride, 5% sodium sulfate, and 3% sulphuric acid.
- The study attempted to assess the durability behavior of aggregate samples of three different types of aggregate to sodium sulphate soundness test and proposed freeze-thaw test by water. In addition, acid rain test, impact value test, and water absorption test were also performed and the changes in gradation at different stages have been studied.
- After the completion of all the tests and studying the behaviour of aggregates, it is concluded that black aggregate aggregates are found to be more durable. This sample gave good results in all the tests performed. All of these aggregates are in use for the construction and maintenance of pavement construction.
- Durability against Sodium Sulphate attack is tested in Sodium Sulphate Soundness Test. Hence, when used in pavement/mix design construction, aggregate samples from different types will give more durability against deterioration caused due to Sodium Sulphate.

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