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Impact of inclusion of lignocellulosic fibre, metal swarf and industrial waste by products to develop sustainable environment

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ABSTRACT

Day by day, the percentage of waste increased at an enormous rate due to the increase in population. Utilization of industrial waste in concrete not only prevents the duplication of natural resources but also helps to minimize waste disposal issues. One of the industrial byproducts used in geopolymer concrete is fly ash, which serves as the main source material and is highly rich in alumina and silica. In this study, Quarry rock dust is used as fine aggregate which replaces natural river sand. Recycled coarse aggregate and metal swarf was added in 50:50 proportion with respect to the volume of concrete to replace coarse aggregate. Alkaline activator solution, also called stimulator solution a combination of sodium hydroxide and sodium silicate, is added into the concrete. Polyethylene-based superplasticizer with 1% of the volume of fly ash is mixed into the concrete to increase its workability. Coir fibers (lignocellulosic fibers) are added to the concrete in percentages range from 0.2% to 1.2% at 0.2% interval. The specimens are tested for their compressive strength, water absorption, acid attack, and sulfate attack. Fibres below 0.6% dosage produced the optimum results.

Keywords: Ambient alkaline solution; Compressive strength; Geopolymer concrete; Lignocellulosic fibre; Metal swarf; Water absorption; Weight and strength loss.

1. INTRODUCTION

The GPC has become a perfect alternative to the world's sustainable construction industry because concrete demand is the second largest in the world after water [1]. The expansion of infrastructure accelerates the development of the country and society. So, concrete production will increase exponentially in the future with development [2, 3]. A comparable amount of carbon is emitted into the environment during the production of OPC cement. In the GPC, industrial solid waste, fly ash, and slag are used. Therefore, the need arises from further investigation into safe waste disposal and investigation into alternatives to cement products with reduced environmental impacts [4]. In these circumstances, geopolymer concrete is found to be one of the better alternatives in terms of reducing global warming, as it can reduce the CO_2 emissions caused by the cement industry by about 80%.

An eco-friendly concrete, such as geopolymer concrete, is found to be an alternative to cement concrete. Geopolymer concrete (GPC) is a sustainable construction material as it can reduce carbon dioxide emissions by utilizing industrial and agricultural waste by-products. Hence, in this context, to reduce global warming, the usage of cement can be minimized by replacing it with other materials such as fly ash, silica fume, red mud, ground granulated blast furnace slag, metakaolin, rice husk ash, corncob ash, sugarcane bagasse ash, etc. QRD is a calcium-rich waste material from the rock crushing industry that is produced as a cloud of unwanted dust during the manufacturing process of coarse aggregates [5, 6]. Based on global statistics, the unutilized and packed landfill.

The quantity of fly ash is 176 million metric tons, and that of GGBS is 200 million metric tons [7]. Several researchers have employed fly ash as the main base material for replacing the cement in geopolymer concrete for manufacturing railway sleepers and concrete columns [8, 9]. A portion of this unwanted waste is often used on-site as filling material for the quarry pits. This waste can be effectively used as a construction material to preserve the environment and natural resources [10]. The QRD has been used as a partial replacement

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for sand in GPC and mortars. The consumption of QRD in concrete is recommended mainly in regions where the sand is not available in abundant quantity. The suitability of QRD to be used as a sand replacement material shows superior mechanical properties of concrete, such as compressive, tensile, and flexural strengths [11, 12]. The complete replacement of sand with QRD gave superior compressive strength properties. The QRD, having a surface area of 6000 cm^2/g, can be utilized as a precursor to making alkali-activated binders [13]. Several industrial by-products are extensively utilized to replace the Portland cement, partially or fully, to diminish the discharge of greenhouse gases associated with the cement manufacture [14, 15]. Commonly used by-products are fly ash condensed silica fume, blast furnace slag, ferrochrome slag, copper slag, steel scrap, jarosite stone wastes, copper tailings, brick waste, tire ash, etc., and some of the farming residues like palm oil fuel ash, bagasse ash, corn cob ash, elephant grass ash, wood waste ash, coconut shell and fibers, rice husk ash, tobacco waste, etc. have been established as supplements or replenishments to cement and aggregates [16, 17]. In addition to this issue, the waste generated by industries necessitates a large area for disposal [18]. Due to this disposal, it severely impacts the environment as well as human beings. An eco-friendly, sustainable, and structurally sound GeoC matrix can be developed from numerous industrial, municipal, and agricultural wastes. To eradicate the above-said problems, the use of alternate binding materials for ordinary Portland cement has been encouraged.

If this type of alternate binder is produced by using industrial by-products, it will nullify the effects on the environment and also cause health issues due to their dumping. To wipe out these hurdles, a three-dimensional polymeric binder network was developed by Davidovits in 1978, termed Geopolymer (Davidovits, 1979) [19]. These geopolymer binders are formed mainly by mixing the source material, which should be rich in silica and alumina, with an alkaline solution. Various governments and construction industries promote sustainable construction materials. through environmental protection initiatives. Similarly, using fibers is one such step for enhancing the properties and behavior of concrete. Fiber-reinforced concrete is a composite material incorporating mixtures of cement or a geopolymer concrete matrix reinforced with discontinuous, randomly oriented, and uniformly distributed discrete fibers. The optimal concentration of circular or flat fibers namely steel, glass, or synthetic which can improve the structural integrity of the concrete composite.

By considering the merits and demerits of natural and synthetic fibers, recent geopolymer research has focused on the hybridization of synthetic and natural fiber reinforcement in geopolymer composite construction [20]. On the whole, it was inferred that each natural fiber has its own unique application in the hybridized fiber-reinforced geopolymer construction [21, 22]. Nevertheless, the usage of the steel fiber and nanosilica combination obviously enhanced the flexural performance and bond strength of the self-compacting GPC samples for 50% GGBFS and GPC-based 50% fly ash (FA).

Geopolymers have drawn interest from the civil engineering community since the 1990s because of their potential and minimal carbon footprint [23]. Geopolymers formed from such alkaline-activated forms have been shown to be ideal building materials. Numerous researchers have used pozzolanic precursors and potassium hydroxide-activating liquids to produce alkaline systems [24, 25]. The inclusion of fibers improves the ductile nature of GPC. Current trends and progress concerning eco-friendly geopolymer concrete. The work concludes that GPC features prominently as an eco-friendly material in construction activities. The attractive features, as mentioned in the work, are its superior mechanical characteristics and durable attributes. Furthermore, research has identified geopolymer concrete as an adequate option for OPC concrete. In recent years, enormous research has been undertaken on geopolymer composites with many suitable cementitious materials and different by-products such as fine and coarse aggregates [26]. Geopolymer composites have emerged as an environmentally friendly alternative to OPC composites. In the deterioration of concrete structures, water plays the most important role [27]. Water permeates the pores of the concrete and carries with it substances that can cause concrete deterioration or, in the case of chloride ions, steel reinforcement corrosion. It has been suggested that the quality of concrete should be measured not only by its strength but also by its durability characteristics [28, 29].

The performance of concrete is greatly affected by its exposure to aggressive environments, or more precisely, its transport properties [30]. The ingress of moisture and the transport properties of these materials have become the underlying source for many engineering problems, such as corrosion of reinforcing steel and damage due to freeze-thaw cycling or wetting and drying cycles [31]. Therefore, the industrial use of waste in the production of activated alkali materials will not only have economic and environmental benefits associated with not using Portland cement but will also solve the problems associated with the removal of large amounts of waste, such as ash from coal-fired thermoelectric plants and slag from metal production, which could otherwise endanger the environment [32, 33]. The reduction percentage in water absorption and compressive strength loss was found to be better in geopolymer concrete than in conventional concrete. Geocrete demonstrated better resistance to aggressive environments compared to normal concrete due to its less porous structures. Moreover, it was found that the strength of alkali-activated concrete improved in a chloride environment, unlike OPC-based concrete. It is extremely resistant to acid, alkaline silica, and fire. Geopolymers have an inorganic structure and cannot be burned as easily as organic polymers [34]. Besides, geopolymers are non-toxic and smoke-free, and their processing temperature is lower than that of other ceramic composites. Geopolymers can be used as environmentally friendly building materials, which can achieve the purpose of sustainable development. Using different types of slag to produce alkali-activated geopolymer biners is important not only for saving metal resources but also for protecting the environment [35]. The degree of durability of the concrete required depends mainly on the environment of their exposure. The ingredients of concrete, the manufacturing process, and their interaction with the exposed environmental elements determine the durability of any concrete [36]. The steel fiber ratios of 0.3% and 0.6% were used, and the combined effect of steel fiber and recycled coarse aggregate on the geopolymer composites behavior regarding strength properties, sulfate resistance, elevated temperature resistance, abrasion resistance, and freezing-thawing resistance was addressed. The effects of different types of fibers on the enhanced performance of geopolymers and of cellulose fiber fabrics on the properties of cementitious composites and geopolymers were studied.

2. MATERIALS AND ITS PROPERTIES

2.1. Fly ash

The huge amount of industrial waste by product from thermal power plants are utilized only up to 50% of the production. At the same time, the disposal of industrial wastes such as fly ash, ground granulated blast furnace slag, mine waste, red mud, etc. has become a greater issue since it requires large areas of useful land for disposal and also indulge huge impact on the environment. Fly ash is the single-largest material required for the production of fly ash based Geopolymer concrete. It is also estimated that about 1.9 billion metric tons of fly ash would be required even if it is required to replace 100% OPC. Hence there is a substantial amount of fly ash supply across the globe, its utilization to develop a fly ash based GPC seems to be the most sustainable approach. The mix was prepared using low-calcium-based fly ash with reference to IS code 3812-1(2003). Table 1 specifies the characteristics of fly ash. The fly ash was obtained from the Mettur thermal power station.

2.2. Quarry Rock Dust (QRD)

QRD exists in the form of limestone, silica, and dolomite powders. It can be defined as the residue or waste material formed during the quarrying or crushing of large parent mass rocks to produce aggregates. Table 2 represents chemical properties of quarry rock dust. The quarrying operations account for more than 15% of the waste dust in the total aggregate production. Quarry dust is a byproduct of quarrying, crushing, and sieving activities resulting in the production of about 10–15% non-valued waste in the stone quarries, which are invariably named quarry dust (QD), quarry waste (QW), quarry sand (QS), rock powder dust (RPD), crushed sand (CS), crushed rock powder (CRP), or artificial sand (AS). Utilization of quarry dust reduces the burden of dumping dust on earth, causing pollution.

2.3. Construction and demolition waste

In recent decades, huge amount of Construction and Demolition (C&D) waste are produced due to urbanization. The wastes from demolished concrete cause environmental issues when disposed in landfills. However, these demolished concrete wastes can be recycled as construction material. The recycling C&D waste has positive effects on both the environmental and economic aspects. But the key pro of geopolymer concrete utility is that it recycles concrete waste and demolition waste and transforms them into coarse aggregate, which provides both environmental and economic benefits.

Table 1: Physical and chemical parameters of fly ash.

PROPERTIES	OBSERVED VALUES
Fineness (%)	8
Particular surface area (m^2/g)	36.1
Particle size (mm)	<0.0075
Specific gravity	3.15
Initial setting time (mins)	130

Table 2: Chemical properties of quarry rock dust.

PROPERTIES	OBSERVED VALUES
Particular surface area (m^2/g)	135–145
Particle size (nm)	30–45
SiO_2	62.48
Al_2O_3	18.72
Fe_2O_3	6.54
CaO	4.83
MgO	2.56
Na_2O	Nil
K_2O	3.18
TiO_2	1.21
Mn_2O_3	Nil
SO_3	Nil
Loss of ignition (%)	0.48
Bulking of sand (%)	22
Specific gravity	2.64
Fineness modulus	2.87
Type/zone	Medium sand/zone II

2.4. Metal swarf

Processing of steel and iron industries produce huge tonnes of solid waste. Among which milling scale represents approximately 2% of the steel produced. The finer mill scale is heavily contaminated with oils and ends up in landfills. The Environmental Protection Agency has designated this residue as hazardous waste. Some waste from steelmaking and metallurgy has found broad usage in the construction industry, such as granulated slag from pig iron manufacturing, which is nowadays commonly used as aggregate in concrete. Steel slag containing active cementing materials, such as fly ash, could also aid in the hydration process. Recent studies reveal that steel slag improve the mechanical properties of hardened concrete when used as a coarse aggregate. It also found that partial or complete substitute of steel slag for natural aggregate in cement-based materials achieve good physical properties and durability. On the other hand, test results of steel slag aggregate reduce workability and dimensional stability in concrete.

2.5. Lignocellulosic fibre

Manufactured fibers are long-lasting, have poor insulation capacity, nonbiodegradable, and create microplastic pollution, ends with entirely non-eco-friendly. Hence, using natural fibers is a step moving towards more sustainable approach. The utility of natural fibers are diversified. They are used in building materials, chemicals, cosmetics, medicines, insulation, particle boards, animal feed, and human food. Natural fibers are divided into three types as plant-based, which includes bagasse, sisal, hemp, coconut, jute. Animal-based which includes wool, silk, hair and mineral-derived in the form of basalt, wollastonite, asbestos.

2.6. Alkaline activators

The commonly used alkaline activators in the geopolymerization process are sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3), and potassium hydroxide (KOH) and potassium silicate (K_2SO_3). The chemical reactions of the geopolymer matrix depend on the molarity of NaOH and Na_2SiO_3 present in the alkaline activator solution. The Na_2SiO_3 solution exhibits higher activation potential compared to other alkaline activators such as NaOH, KOH, and calcium hydroxide. Na_2SiO_3 contains dissolved silicon particles, which easily react during the geopolymerization process. Numerous research studies investigated the influence of the molarity of NaOH, Na_2SiO_3/NaOH ratios, and alkaline activator to fly ash (AA/FA) ratios on the compressive and flexural strength of GPC. Also called as stimulator solution, with the combination of NaOH and Na_2 SiO_3. Sodium hydroxide in pellet form is purchased from local vendors. Commercially available sodium silicate solution with a silicate modulus of 2.0 and bulk density of 1390 kg/m^3.

Table 3: Characteristics of Recycled Coarse Aggregate (RCA).

PROPERTIES OBSERVED VALUES	
Specific gravity	2.76
Fineness modulus	6.32
Water absorption (%)	0.6
Crushing strength (MPa)	2.4
Grading zone	II
Maximum size of aggregates	10–4.75 mm

Table 4: Characteristics of lignocellulosic fiber.

PROPERTIES OBSERVED VALUES	
Standard compliance	ASTMC-1116
Shape	Monofilament
Standard length	12 mm
Specific gravity	0.91
Melting point	162 ˚C and above
Water absorption	Nil
Alkali sesistance	99% Strength retained
Tensile strength	3500–7700 kg/m^3
Young’s modulus	35 $\times 10^3$ kg/cm^2
Diameter	18 micron, nominal

Table 5: Characteristics of metal swarf.

PROPERTIES	
Specific gravity	3.3
Maximum size (mm)	2.10
Fineness modulus	6.84
Water absorption (%)	3
Bulk density (kg/m^3)	3.45
Aggregate impact value (%)	3.12

2.7. Recycled Coarse Aggregate (RCA)

The aggregates used in concrete are recycled coarse aggregates and metal swarf. RCA is obtained from construction-demolished waste. The obtained aggregates are cleaned, washed, and prepared to be mixed into the specimens. Metal swarfs are obtained from steel manufacturing industries. Table 3 depicts characteristics of Recycled Coarse Aggregate (RCA).

As per procedures outlined in the Indian Standard (IS) code, the properties such as dispersion of particle sizes, aggregate density, fineness modulus, and water absorption are evaluated. Table 4 shows the characteristics of lignocellulosic fiber and Table 5 displays the characteristics of metal swarf respectively.

3. MIX PROPORTIONS

Since there is no proper mix design standard code provision for geopolymer concrete, two parameters, one is synthesis parameters and the other one is process parameters are followed to evaluate mix design procedure of GPC. Synthesis parameters influence the ratio of source material to alkaline solution, the ratio of NaOH to Na_2SiO_3, and the molarity of NaOH. Processing parameters includes the type of curing, curing period, rest period, temperature of curing, curing regime, and extra water content added to the concrete. Low-calcium (ASTM Class F) fly ash-based geopolymer is used as the source material. Class F fly ash tends to have a low setting time and also reduces the microcrack during the process of hardening.

Table 6: Mix proportion.

	G1	G2	G3	G4	G5	G6	G7	G8	G9
Fly ash (kg/m^3)	550	550	550	550	550	550	550	550	550
Quarry rock dust (kg/m^3)	590	590	590	590	590	590	590	590	590
Recycled Coarse Aggregate (kg/m^3)	460	460	460	460	460	460	460	460	460
Metal swarf	520	520	520	520	520	520	520	520	520
Lignocellulosic fiber (coir fiber) (kg/m^3)	0.061	0.122	0.184	0.245	0.307	0.368	0.429	0.491	0.552
Sodium hydroxide (kg/m^3)	45	45	45	45	45	45	45	45	45
Sodium silicate (kg/m^3)	240	240	240	240	240	240	240	240	240
Superplasticizer (%)	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
Extra water (%)	55	55	55	55	55	55	55	55	55
Rest period (days)	2	–	–	–	–	–	–	–	–

Totally nine different specimens of M30 grade were cast for testing. Quarry rock dust was added as fine aggregate in all specimens. Recycled coarse aggregate and metal swarfs were incorporated in the ratio 50:50. Table 6 represents the mix proportion of geopolymer concrete. One percentage of polyethylene-based superplasticizer was added to all specimens. Lignocellulosic fiber (coir fiber) was added in different percentages, such as 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, and 0.80%, respectively. The addition of metal swarf as coarse aggregate increases the strength of concrete. Excessive addition of fibers reduces the workability, results in non-cohesion of the concrete mix, and induces cracking in the specimens.

3.1. Preparation of test specimens

The concrete mixes were blended in a drum mixer in line with IS 516-1959. The standard test method conducted in accordance with IS 1199-1959 was used to analyze the concrete samples and the workability of fresh concrete. Fly ash and quarry rock dust were mixed, and then coarse aggregate was blended with the dry mixture. During the final minute of mixing, the alkaline solution was added into the concrete. To achieve good workability, 1% of superplasticizer was added with 10% of extra water to the mix. Alkaline solution was prepared one day earlier before concreting due to reduce heat of hydration. Workability tests were conducted in slump cone to determine the cohesiveness and ease of concrete to work in place, followed as per IS Code IS 7320-1974. The mixed concrete was cast into cube molds measuring 150mm × 150mm × 150mm. The specimens were left for two-days rest period. After two-days rest period, the specimens were demolded from the cubes. And no rest period was required for the specimens cast with coir fibers. Then the specimens were kept at ambient temperature for curing, following IS 516-1959.

4. EXPERIMENTAL RESULTS AND DISCUSSION

The densities were calculated for all trails with respect to ASTM C 29/C29 M-17a, IS: 2386 (Part 3) – 1963. Specimens were tested for their compressive strength at 3 days, 7 days, and 28 days. Table 7 displays the slump value for concrete specimens. The test was carried out as per IS Code IS 516-1959. The flexure strength was determined at 3 days, 7 days, and 28 days as per IS 516-1959. In each case of this study results, Table 8 represents the densities of geopolymer mix. The values represent the average of the three trials. Figure 1 depicts the densities and slump values of concrete mixes The water absorption capacity of concrete specimens were carried out as per the codal provision prescribed in IS 1124-1974.

4.1. Compressive strength test

Universal test machine that conformed to the IS 516-1959 standard was used to crush all specimens at a rate of roughly 0.25 MPa/s while under load control. Figure 2 represents the strength of compressive strength at 3, 7, and 28 days. The results of the test are presented in Table 9. The test results reveal that an increase in the percentage of coir fiber increases the strength up to 0.4%, beyond that percentage of increase, the strength gets reduced. A high percentage increase in fiber percentage reduces the workability of the concrete. Also, the addition of RCA and metal swarf in the ratio of 50:50 increases the strength of concrete. The strength of geopolymer concrete without adding fibers shows less strength compared to a mix with fiber content. Figure 3 shows the variation in compressive strength.

Table7: Results of slump test.

SPECIMEN	G1	G2	G3	G4	G5	G6	G7	G8	G9
Slump value (mm)	120	100	95	80	75	60	45	40	35

Table 8: Densities of geopolymer mix.

	G1	G2	G3	G4	G5	G6	G7	G8	G9
Densities (kg/m^3)	2360	2378	2384	2399	2412	2424	2439	2444	2456

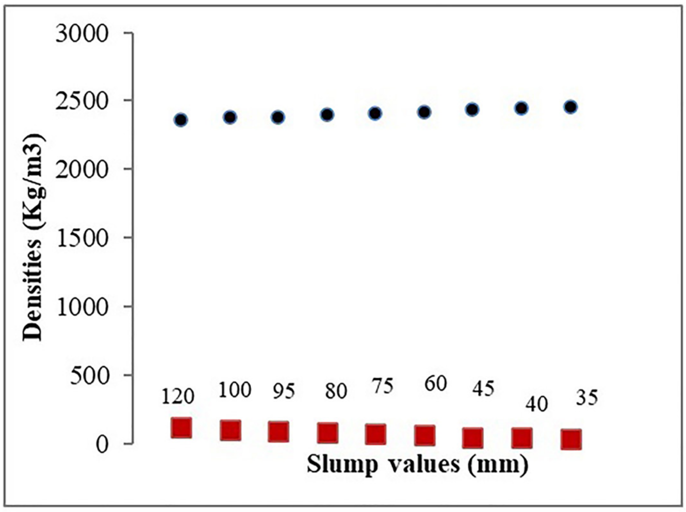

Figure 1: Densities and slump values of concrete mixes.

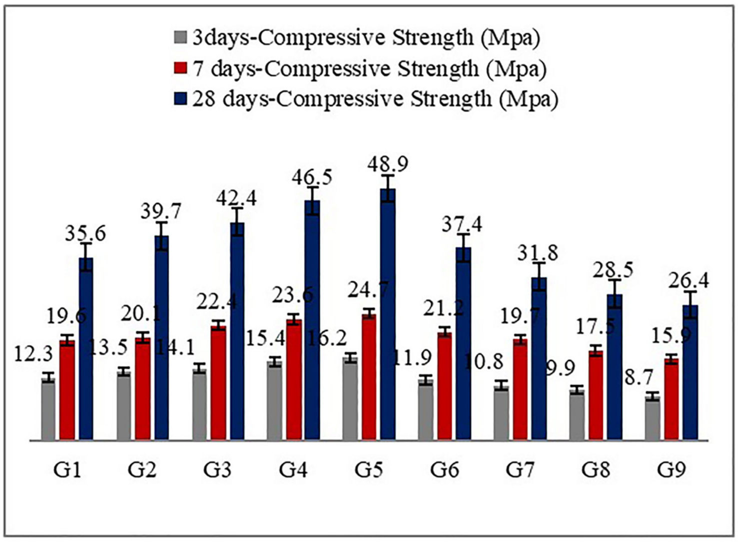

Figure 2: Compressive strength of geopolymer mixes.

Metal swarf incorporated into the concrete as coarse aggregate with 50% increases the strength of geopolymer concrete. It balanced the strength of the concrete even if the concrete was blended with 50% recycled coarse aggregate. Hence, it's a better choice to choose 50:50 proportion of RCA and metal swarf as replacement for coarse aggregate in GPC. Also, the incorporation of QRD as fine aggregate increases the strength of concrete. Silica and alumina are the major sources that enhance the polymerization process in geopolymer concrete.

Table 9: Compressive strength.

SPECIMEN	AVERAGE COMPRESSIVE STRENGTH (MPa)		VARIATIONS IN COMPRESSIVE STRENGTH (%)	
	7 DAYS	28 DAYS	7 DAYS	28 DAYS
G1	19.6	35.6	0	0
G2	20.1	39.7	0.11	0.02
G3	22.4	42.4	0.19	0.14
G4	23.6	46.5	0.30	0.20
G5	24.7	48.9	0.37	0.26
G6	21.2	37.4	0.05	0.08
G7	18.9	31.8	−0.1	−0.03
G8	17.5	28.5	−0.19	−0.1
G9	15.9	26.4	−0.25	−0.18

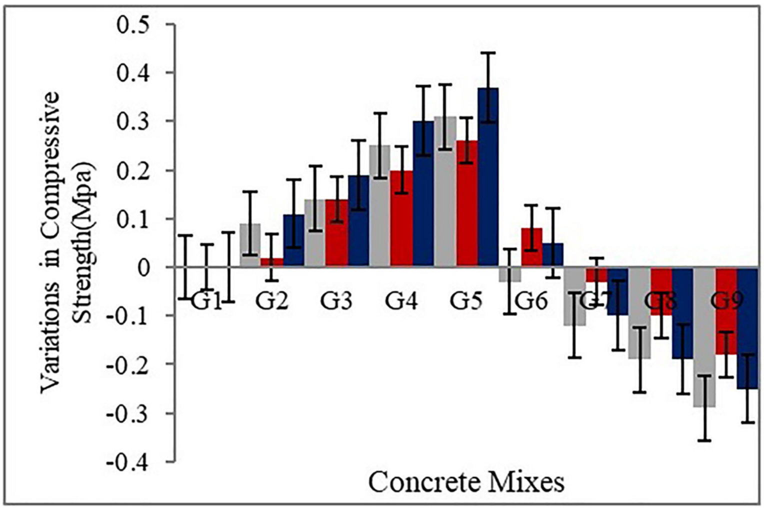

Figure 3: Variation in compressive strength.

QRD possesses 62.48% SiO_2 and Al_2O_3 with 18.72%, whereas river sand possesses SiO_2 with 89.52% and Al_2O_3 with 3.12%. Compared to river sand, QRD shows a good percentage of alumina sources. Thus, QRD enhances the polymerization process in geopolymer concrete. The addition of metal swarf and QRD results in an enhanced, rapid increase in early strength. The results reveal that the addition of lignocellulosic fiber (coir fiber) increases the compressive strength of concrete. Upto addition of coir fiber in geopolymer concrete up to 0.4% increase the strength of concrete. Beyond that percentage increase, the strength of concrete gets reduced. The addition of 0.1%, 0.2%, 0.3%, and 0.4% of coir fiber reveals an increase in compressive strength of 39.7 MPa, 42.4 MPa, 46.5 MPa, and 48.9 MPa, respectively. The addition of 0.5% of the increase in coir fiber reduces the strength of concrete, with a variation of 0.05% and 0.08% in strength at 7 days and 28 days, respectively. More than 0.5% addition, that is, when added with 0.6%, 0.7%, and 0.8%, reduces strength drastically with 0.1%, 0.19%, and 0.25% in 7 days and 0.03%, 0.1%, and 0.18% in 28 days, respectively. Without an increase in fiber, it shows a good percentage of target strength. Formation of Si-O-Al bonds and chain links are excellent, with 0.4% addition of coir fibers and inclusion of QRD and metal swarf increasing the strength, which reveals that more polymeric chains of Si-O-Al links are formed in the early stages of polymerization.

4.2. Porosity and water absorption test

The test report exhibits that concrete shows an enhanced early and rapid increase in strength up to 0.4% with the addition of fibers. The results show 13.5 MPa, 14.1 MPa, 15.4 MPa, and 16.2 MPa strength in 3 days as 0.1%, 0.2%, 0.3%, and 0.4% with inclusion of fibers, respectively, and 11.9 MPa, 10.8 MPa, 9.9 MPa, and 8.7 MPa with the addition of 0.5%, 0.6%, 0.7%, and 0.8% fibers. Initially, the test results confirm that the workability of concrete gets reduced with the addition of coir fibers into the concrete. But the concrete without fibers shows high degree of workability with 120-mm slump value. A high degree of workability was achieved in concrete with the addition of 0.1%, 0.2%, and 0.3% fibers with slump values of 100mm, 95mm, and 80mm. Whereas an increase in fibers with an increase of 0.4% and 0.5% shows a medium degree of workability. And the increase in further addition of fibers with 0.6%, 0.7%, and 0.8% shows a low level of workability with 45 mm, 40 mm, and 30 mm slump, respectively.

Polymeric chain links of Si-O-Al bonds the polymerization process gets reduced with a higher percentage of coir fibers in concrete. The addition of 1% of superplasticizer blends the concrete with good consistency. When workability is reduced, the compressive strength of concrete is reduced. The density of concrete increases with an increase in the percentage of coir fibers between 2300 and 2500 kg/m^3.Even though the density increases, it does not increase the strength of concrete. Thus, the addition of more percentages above 0.4% of fibers reduces the polymerization process and the formation of Si-O-Al bonds.

4.3. Porosity measurement using water-saturated method

The porosity of the concrete matrix was measured using the vacuum-water-saturated method. Dried samples were saturated and the samples were kept in the container for specific duration such as 3 hours, 6 hours, 9 hours, 12 hours, 15 hours, 18 hours, 21 hours, and 25 hours, respectively. And then, the porosity percentage of the specimens were calculated as follows:

$$n = ms - mo/p \times Vs$$

ms = Saturated mass of specimen (kg)

mo = Initial mass of specimen (kg)

p is density of water (kg/m^3) and Vs is the volume of specimen (m^3)

From the test results, it was observed that the porosity of geopolymer concrete specimens increased with an increase in the percentage of coir fiber percentage. Table 10 depicts the porosity percentage of geopolymer specimens. The porosity percentage was found to be high when added with coir fibers compared to geopolymer specimens without fibers. The porosity "n" values vary from 0.048 to 0.076. The porosity of specimens with coir fibers 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, and 0.8% varies from 0.043, 0.045, 0.054, 0.056, 0.062, 0.066, 0.073, and 0.076, respectively. The specimen without coir fiber shows porosity value as 0.048. Thus, when porosity increases, the water absorption percentage in specimens also increases. Figure 4 shows the porosity of geopolymer concrete specimens. Hence, an increase in percentage of water content increases the formation of Si-O-Al bond links and polymerization.

Also increase in the percentage of coir increases the weight of the geopolymer specimens. Also, the increase in the percentage of coir fibers increases the compressive strength of concrete up to 0.5%. The weight of the specimens ranges from 5 kg to 7 kg. Table 11 represents the water absorption percentage of geopolymer specimens with 5.63 kg, 5.71 kg, 5.79 kg, 5.84 kg, 5.97 kg, 6.17 kg, 6.28 kg, and 6.34 kg, respectively. After 24 hours of water absorption, the weight of the specimens gets increased to 5.60 kg, 5.79 kg, 5.86 kg, 5.97 kg, 6.01 kg, 6.47 kg, 6.92 kg, 7.18 kg, and 7.31 kg, respectively. Initial water absorption percentages after 3 hours

Table 10: Porosity percentage of geopolymer specimens.

POROSITY PERCENTAGE OF GEOPOLYMER SPECIMENS									$T^{1/2}$ (Mins)
G1	G2	G3	G4	G5	G6	G7	G8	G9	
0.003	0.0042	0.005	0.0062	0.0071	0.0078	0.0082	0.0092	0.0098	2
0.005	0.0078	0.009	0.0012	0.0187	0.0215	0.0345	0.0357	0.0369	3
0.014	0.0167	0.019	0.0215	0.032	0.039	0.047	0.0487	0.0516	4
0.019	0.029	0.0312	0.0387	0.0381	0.0425	0.0498	0.0518	0.0568	5
0.025	0.0353	0.0373	0.0412	0.0436	0.0456	0.052	0.0587	0.0614	6
0.031	0.0367	0.0386	0.0454	0.0469	0.0489	0.0578	0.0612	0.0638	7
0.038	0.0378	0.0388	0.0468	0.0488	0.051	0.0594	0.0647	0.0695	8
0.044	0.0393	0.0403	0.0497	0.0512	0.0568	0.0625	0.0668	0.0715	9
0.046	0.0415	0.0415	0.0512	0.0535	0.0597	0.0634	0.0698	0.0738	10
0.046	0.0426	0.0426	0.0534	0.0557	0.0612	0.0651	0.0714	0.0755	11
0.048	0.0437	0.0457	0.0545	0.0569	0.0625	0.0664	0.0732	0.0768	12

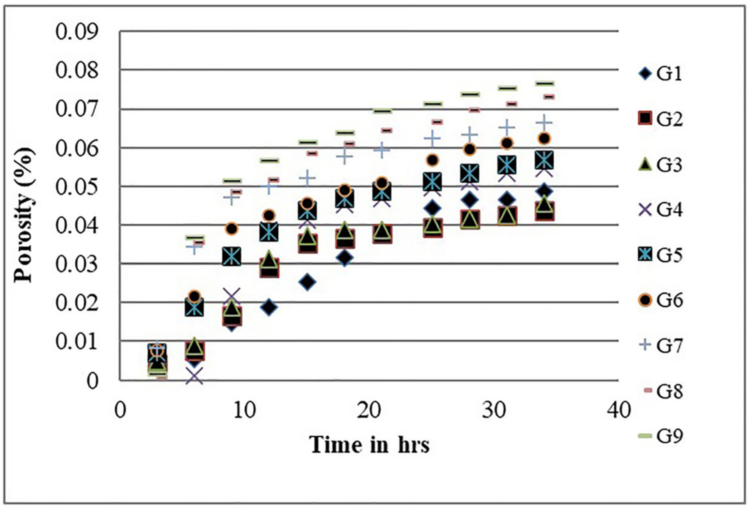

Figure 4: Porosity of geopolymer concrete specimens.

Table 11: Water absorption percentage of geopolymer specimens.

SPECIMEN ID	G1	G2	G3	G4	G5	G6	G7	G8	G9
Initial wt.	5.41	5.63	5.71	5.79	5.84	5.97	6.17	6.28	6.34
Wt. after 3 hrs	5.51	5.72	5.79	5.88	5.93	6.10	6.31	6.47	6.59
% of absorption	1.87	1.34	1.46	1.52	1.64	2.17	2.26	3.02	3.94
Wt. after 6 hrs	5.52	5.71	5.80	5.79	5.94	6.21	6.44	6.61	6.71
% of absorption	2.02	1.69	1.43	1.72	1.51	4.02	4.37	5.25	5.83
Wt. after 9 hrs	5.53	5.73	5.80	5.90	5.94	6.27	6.58	6.72	6.84
% of absorption	2.14	1.77	1.59	1.95	1.74	5.02	5.58	7.00	7.88
Wt. after 12 hrs	5.54	5.74	5.81	5.92	5.95	6.29	6.57	6.76	6.98
% of absorption	2.45	2.01	1.80	2.25	2.96	5.36	6.48	7.64	10.09
Wt. after 15 hrs	5.55	5.75	2.82	5.92	5.96	6.31	6.68	6.84	7.15
% of absorption	2.64	2.18	1.93	2.33	3.10	5.69	8.26	8.91	12.77
Wt. after 18 hrs	5.55	5.75	5.82	5.92	5.96	6.39	6.71	6.89	7.24
% of absorption	2.84	2.39	2.12	2.55	3.31	7.03	9.88	9.71	14.19
Wt. after 21 hrs	5.57	5.77	5.83	5.94	5.98	6.45	6.87	6.94	7.29
% of absorption	2.93	2.41	2.15	2.58	3.33	8.04	10.50	11.50	14.98
Wt. after 24 hrs	5.60	5.79	5.86	5.97	6.01	6.47	6.92	7.18	7.31
% of absorption	3.42	2.64	2.90	3.12	3.84	8.37	12.10	14.33	15.29

were 1.34%, 1.46%, 1.52%, 1.62%, 2.17%, 2.26%, 3.02%, and 3.94% by adding 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, and 0.8%, respectively. Figure 5 represents the weight and water absorption of GPC specimens. The results reveal that after 0.5% addition of coir fibers, the water absorption percentage increases in a higher order.

4.4. Acid attack test

To study the effects of exposure to an acidic environment, specimens were immersed in 10% sulfuric acid and 10% nitric acid, and losses were measured for an interval of 30 days, 60 days, and 90 days. The volume of acidic solution was taken as four times the volume of specimens immersed and stirred every week. Table 12 represents the weight loss of geopolymer specimens due to acid attack. The solution was refreshed at regular intervals. The effect of acid on the specimen was constantly monitored through visual inspection. Figure 6 shows the weight loss (kgs) of geopolymer concrete specimens. The loss in weight and the loss in strength were calculated during the exposure period. Al_2O_3, often known as aluminum oxide or alumina, comprises oxide ions and interacts

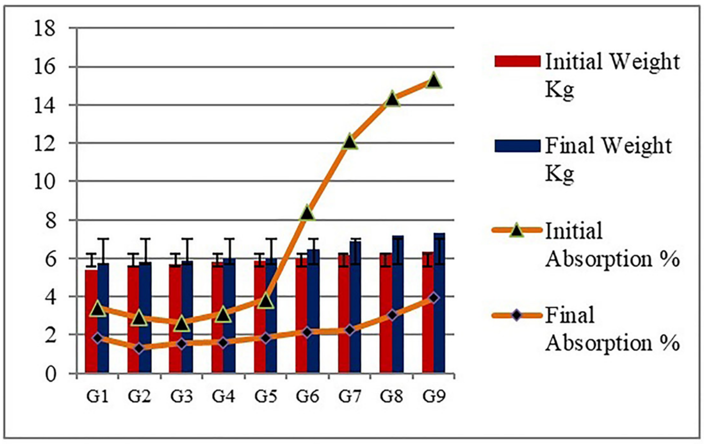

Figure 5: Weight and water absorption of GPC specimens.

Table 12: Weight loss of geopolymer specimens due to acid attack.

SPECIMEN	INITIAL WEIGHT (kg)	WEIGHT LOSS (kg)		
		30 DAYS	60 DAYS	90 DAYS
G1	5.41	5.32	5.21	5.12
G2	5.63	5.54	5.43	5.31
G3	5.71	5.64	5.55	5.45
G4	5.79	5.68	5.50	5.41
G5	5.84	5.77	5.64	5.52
G6	5.97	5.87	5.75	5.64
G7	6.17	6.01	5.94	5.87
G8	6.28	6.10	6.10	5.99
G9	6.34	6.21	6.14	6.05

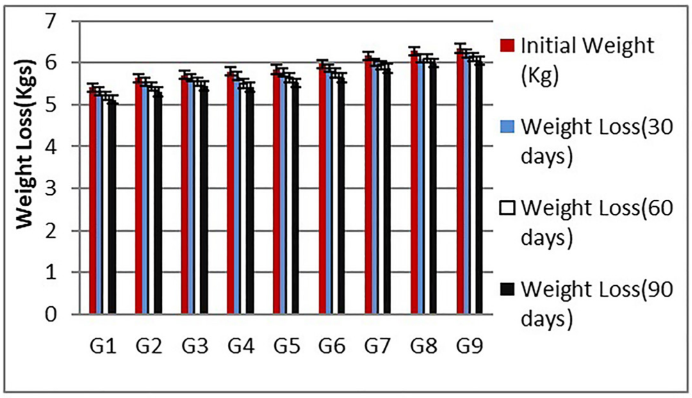

Figure 6: Weight loss (kgs) of geopolymer concrete specimens.

with acids in a manner similar to that of sodium or magnesium oxides. Aluminum oxide reacts with hot, dilute hydrochloric acid to give an aluminum chloride solution. But the alumina (Al_2O_3) is poorly dissolved in HCl. In this test, the weight and strength loss of the concrete are investigated. Hydrochloric acid (HCl) is used for the acid attack test because it not only affects the concrete's strength and endurance but also occurs naturally. The high alkalinity of Portland cement causes the corrosive assault on the concrete. Damage to the concrete starts at the surface and progresses inward. Acids attack concrete by dissolving cement mixtures. The chemical reaction yields calcium compounds that are water-soluble, which are then seeped away, leaving the aggregate.

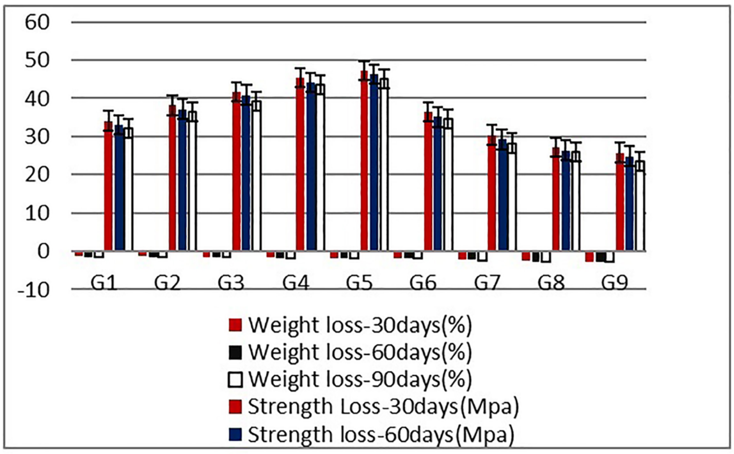

Figure 7: Weight loss (%) and strength loss (MPa) of geopolymer concrete specimens.

Table 13: Compressive strength loss of geopolymer specimens due to acid attack.

SPECIMEN	STRENGTH LOSS AT 30 DAYS (MPa)	WEIGHT LOSS AT 30 DAYS (%)	STRENGTH LOSS AT 60 DAYS (MPa)	WEIGHT LOSS AT 60 DAYS (%)	STRENGTH LOSS AT 90 DAYS (MPa)	WEIGHT LOSS AT 90 DAYS (%)
G1	34.1	1.30	33.1	1.45	32.1	1.66
G2	38.2	1.31	37.2	1.41	36.4	1.59
G3	41.7	1.42	40.9	1.52	39.2	1.64
G4	45.4	1.66	44.2	1.74	43.5	1.89
G5	47.3	1.71	46.3	1.80	45.1	1.91
G6	36.5	1.73	35.1	1.89	34.5	1.97
G7	30.4	2.01	29.2	2.17	28.2	2.59
G8	27.2	2.54	26.4	2.64	25.9	2.76
G9	25.7	2.64	24.8	2.70	23.4	2.85

For this test, we immerse the concrete cube specimens in a 7.5% concentration of HCl. The initial weights of the specimens were 5.41 kg to 6.34 kg.

When the specimens were immersed in an acid solution for 90 days, their weights were reduced from 5.12 kg to 6.05 kg. An increase in the percentage of fiber proportion does not support enhancing the weight of the specimens. Figure 7 shows the weight loss (%) & strength loss (MPa) of geopolymer concrete specimens. The weight loss percentage was almost similar in both specimens with and without the addition of fibers in acid immersion. Up to 0.5% addition of coir fiber, the strength loss of specimens was bearable, whereas beyond 0.5%, that is, 0.6%, 0.7%, and 0.8%, addition of fibers increased the percentage strength loss of specimens. Table 13 depicts the compressive strength loss of geopolymer specimens due to acid attack. The strength was reduced drastically when the specimens were immersed in an acid solution by adding more than 0.5% of coir fibers. The weight loss of specimens at 30 days in percentage varies from 1.30 to 2.64%. Weight loss at 60 days varies from 1.45% to 2.70%. And weight loss at 90 days due to immersion in an acid solution varies from 1.66% to 2.85%. Also, the incorporation of metal swarf as coarse aggregate resists the penetration of acid into the concrete and supports enhancing the strength of the concrete.

5. CONCLUSION

The strength of specimens increases with an increase in the percentage of coir fiber. When specimens were added up to 0.5% of coir fibers, the strength of concrete increased at a faster rate. Whereas the strength of specimens gets reduced when the specimens are added with0.6%, 0.7% and 0.8% of organic fibers. Addition of metal swarf as coarse aggregate in 50% proportion enhances the strength of concrete. And quarry rock dust can be replaced as fine aggregate in geopolymer concrete. Thus, more chain links in the form of Si-O-Al bonds were formed due to polymerization process. 1% addition of polypropylene based superplasticizer enhances the rate of workability in concrete. Since it requires creating the zeta potential force to increase the workability of concrete. The percentage of porosity increases with an increase in the percentage of organic fibers, from 4% to 7%. Also, the water absorption percentage was higher when a high percentage of fiber content was added to the concrete. The addition of more than 0.5% of coir fibers reveals poor workability and reduced strength with a higher water absorption percentage. Hence, the addition of more than 0.5% of coir fibers was not advisable in geopolymer concrete. Since polymerization requires a good quantity of water to form Si-O-Al bonds, the addition of fibers absorbs a larger quantity of water, which creates an insufficient quantity of water in concrete to react with the polymerization process. To develop sustainability, it was concluded that industrial waste products such as quarry rock dust and metal swarf can be used in the geopolymer concrete as fine aggregate and coarse aggregate. Already, we use fly ash instead of cement as a source material, which is a form of industrial byproduct.

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