Mechanical Properties and Microstructural Characteristics of Concrete containing Geopolymer Aggregate

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ABSTRACT

GGBS use has been studied extensively. It focused on replacing cement with GGBS, but producing artificial aggregates with GGBS helps use slag in concrete. This large-scale use reduces environmental pollution and depletes natural resources. This paper discusses geopolymer aggregate manufacturing. The study shows that geopolymer aggregate can be used as aggregate replacement material in concrete. Strength and density of concrete made with geopolymer aggregate and natural gravel were also studied. It confirming geopolymer aggregate increase mechanical properties of conventional concrete. Geopolymer artificial aggregate concrete had a dry density of 1,787 kg/m^3 and stronger compressive, tensile, and flexural strength than natural aggregate by 16%, 11%, and 21% respectively. GPA concrete was stronger than regular aggregate concrete. Rough GPA surface and fracture planes produced during aggregate production improve cement-paste-aggregate bonding in GPA concrete.

Keywords: *Geopolymer aggregate*, artificial aggregate, light weight concrete, microstructure

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1. General

Most adaptable man-made building material in the world, concrete is widely employed in all kinds of construction projects. Concrete strength, durability and other properties depend on its materials, mix, compaction and curing. Development of concrete technology has made it possible to build strong, long-lasting, and uniform concrete while utilising resources that are readily available locally. Use of additional cementing materials, mineral admixtures, or component substitution has been one of main thrust areas of study in concrete. When used to partially replace cement and aggregates, industrial wastes with pozzolanic characteristics that develop cementitious capabilities increase strength, durability, and environmental protection. In majority of country, people are becoming more and more concerned about effects that mining for river sand and crushed stone aggregate has on environment. Researchers thus strongly advise producing lightweight concrete using alternative aggregates.

Concrete self-weight is a drawback and its density of 2200-2600 kg/m^3. This material's weight makes it uneconomical. Self-weight of structural and non-structural parts must be lowered to meet application requirements. This economical design results in lightweight concrete (Ramamurthy et al 2008). Lightweight concrete's low heat conductivity improves with density (Ramazan Demirboga et al 2003). Lightweight concrete has decreased bulk, acceptable strength, improved thermal and acoustic insulation, and lower energy requirements during construction. Lightweight concrete can't always replace heavier concrete in terms of strength, but it has some advantages, including reduced dead loads, cost-effective structures, improved seismic resistance, high sound absorption, high thermal insulation, and good fire resistance (Tommy et. al. 2004). Lightweight concrete is made by changing the material composition or manufacturing process. Lightweight aggregates are used to make concrete.

1.1 Artificial aggregate

Use of aggregate in quarries has potential to have a major effect on ground water. These quarries can modify groundwater distribution and water table, which can have an effect on local water usage, consistency and surface water due to changes in water courses.

Looking alternative aggregate sources is really a significant challenge for aggregate and building industries. Any steps are taken to solve disadvantages of natural aggregates, such as taking from areas with sufficient aggregate deposits and creating artificial aggregate. Artificial aggregate produced without any standard guidelines, allowing for a wide range of mixed varieties. Because of the abundance of mixed combinations, researchers worked to find best proportions for producing artificial aggregates.

Ordinary Portland Cement impacts the environment by releasing a lot of carbon dioxide into the atmosphere and by using up a lot of natural resources. However, the majority of the research shows that fly ash-based geopolymer aggregate takes longer time to build up when it is cured at room temperature. Because of this, using fly ash-based geopolymer aggregate concrete as a speedier alternative to regular Portland cement concrete is highly unfeasible. Ground granulated blast furnace slag will be used in a unique manufacturing process to create geopolymer coarse aggregate (GPA). In this investigation, GPA concrete has been added to Ordinary Portland Cement concrete in an effort to improve its qualities. Geopolymer stones made from cementitious materials, commercially available sodium hydroxide (12 M) and sodium silicate solution were used to prepare GPA. Optimize mix design and process conditions of GPA concrete. Dry materials were mixed in a mortar mixer and alkaline solution added continuously until a uniform mix was obtained. Manufactured geopolymer stones are crushed at 3 days after casting and sieved into different sizes under condition of oven curing

In this research, properties of ordinary portland cement concrete were improved by complete replacement of geopolymer aggregate instead of natural aggregate. A comprehensive experimental research was conducted to explore a feasible manufacturing process for geopolymer aggregate (GPA) processing, as well as primary mechanical properties and microstructure characteristics of Geopolymer aggregate concrete. Aim of this research was to make geopolymer coarse aggregate from slag, a waste from iron and steel processing produced by quenching molten iron blast furnace slag. As a result, findings of research to determine use of GPA in conventional concrete and efficiency.

Lightweight concrete made with natural or artificial lightweight aggregates is affordable in many places. It can be used to make internal and external walls, roof deck inner leaves and floors with varying particle sizes and strength. This research investigates slag made lightweight geopolymer aggregate concrete. Material and building applications will benefit from experience.

1.2 Need For the Present Study

In general, the steel industry generates a lot of solid waste as it goes through its many operations. These solid wastes include a variety of useful products that, if cheaply recovered, can be utilised again. The ultimate goal of enhancing the operational effectiveness and economics of the steel industry is why the steel industry throughout the world has already implemented a number of creative solutions and continues to do so in order to utilise these wastes to 100% of their potential. These actions give a significant amount in addition to lowering the cost of trash disposal and environmental degradation. Furthermore, technology for producing value-added goods on a sustainable basis are required. About 30% of GGBS is used in limited applications such as fills and embankments, backfills, pavement bases, subbase courses and in applications requiring intermediate technical skill such as blended cement, concrete pipes, precast/prestressed product materials, light-weight concrete bricks and blocks, autoclaved aerated concrete and light-weight aggregate (Baykal and Doven 2000). The aggregates in concrete are essential components that enhance the concrete's bulk form. Massive amounts of aggregates are used, which destroys slopes and causes geological and environmental imbalances. In the majority of the country, people are becoming more and more concerned about the effects that mining for river sand and crushed stone aggregate has on the environment. The negative effects of aggregate extraction include risks to the environment from pollution, noise, dust, and blasting vibrations, as well as loss of trees and degradation of the natural ecosystem. Unplanned rock extraction causes landslides on fragile and steep hill slopes. (2004) Behera et al. A alternative aggregate which is both economically feasible and appropriate for the building industry is needed, as environmental contamination and overuse of natural aggregates are becoming major concerns. A promising new source of structural aggregate material is slag aggregate. The best way to dispose of slag is to use it as aggregate in concrete, which also addresses the issue of environmental contamination. In view of the above, an effort has been made in the current study to build a concrete with slag aggregates completely replacing fine and coarse aggregates. This meets the requirement for substitute aggregates in concrete and reduces environmental contamination brought on by slag disposal.

1.3 Objectives of Present Study

In this work, geopolymer aggregate concrete strength and microstructure were evaluated.

(i) To evaluate properties of geopolymer aggregate concrete.

(ii) To study strength characteristics of geopolymer aggregate concrete

(iii) To investigate microstructure characteristics of geopolymer aggregate concrete.

2. Materials Properties and Methods used.

2.1 Materials

Cement, fine aggregate, coarse aggregate and geopolymer aggregate were used in the present work. Methodology adopted for formation of geopolymer aggregates is also presented in this section.

2.1.1 Cement

Ordinary portland cement of 43 grade confirming to IS: 8112-1989 used in present experimental investigation. Specific gravity of cement is used as 3.15. Cement properties are tested as per Indian Standards.

2.1.2 Fine Aggregate

Natural river sand with fraction passing through 4.75 mm sieve and retained on 600µ sieve used and tested in accordance with IS:2386. Physical properties are presented in table 2.1. River sand confirms to grading zone II confirms to IS: 383-1970. Grading curve of conventional fine aggregate is shown in Figure 2.1.

Table 2.1 Physical properties of fine aggregate

Test Particulars	**Results Obtained**
Specific gravity	2.66
Bulk density (Kg/m^3)	1808
Size (mm)	Below 4.75
Fineness Modulus	2.68

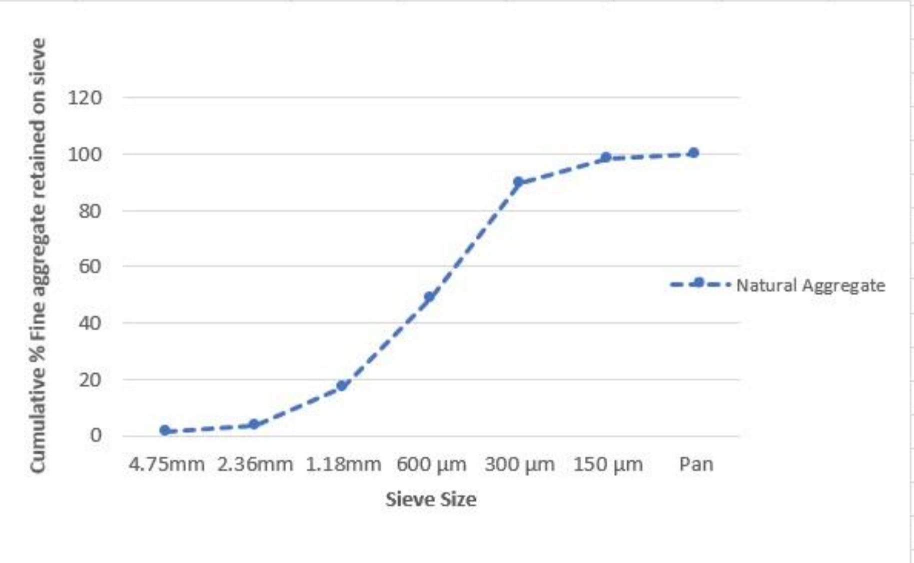

Figure 2.1 Grading curve of conventional fine aggregate

2.1.3 Coarse Aggregate

Coarse aggregate confirming to graded aggregate of size 20 mm as per IS:383-1970. The coarse aggregate and geopolymer aggregate were tested as per the procedure given in IS: 2386-1963 and physical properties are given in table 2.2. Grading curve for conventional coarse aggregate (CA) and geopolymer coarse aggregate (GPA) are shown in figure 2.2.

Table 2.2. Physical properties of geopolymer and conventional aggregate

Properties of aggregate	GPA	CA	IS Code Limit
Crushing value %	28.5	22.5	30%
Impact value %	29.62	24.5	30%
Abrasion value %	15.4	31.2	50%
Soundness %	5.6	1.4	12%
Flakiness index %	20.7	17	25%
Specific gravity	2.0	2.78	2.5 to 3.
Unit weight kg/m^3	1825	2450	1800-2700 Kg/m^3
Bulk density kg/m^3	996	1435	1200-1750 Kg/m^3
Water absorption%	0.8	0.6	2%

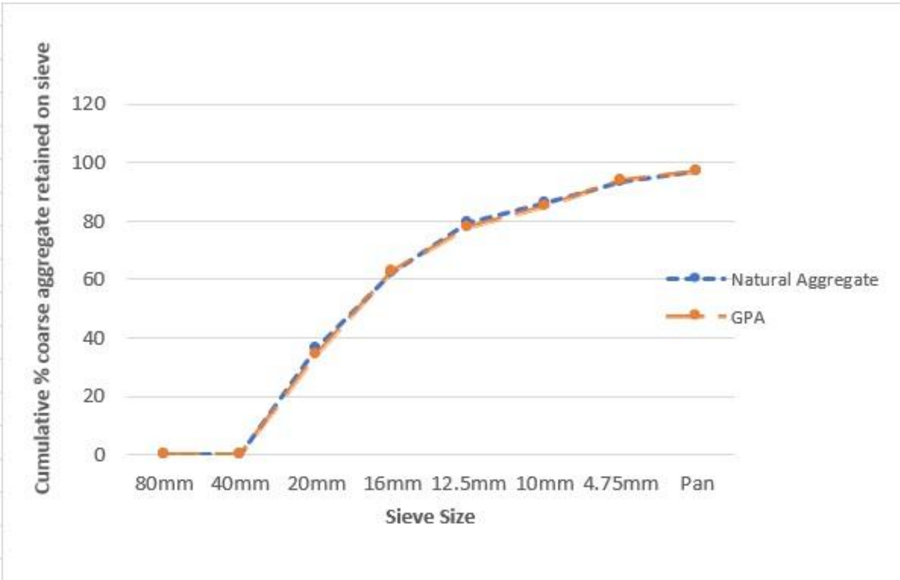

Figure 2.2 Grading Curves for Conventional Coarse Aggregate and Geopolymer Coarse Aggregate

2.1.4 Manufacturing process of geopolymer aggregate

A novel method for making geopolymer coarse aggregate from GGBS. This study incorporated geopolymer aggregate concrete to improve properties of conventional concrete. GPA was made from GGBS, 12M sodium hydroxide and sodium silicate solution. Optimize mix and process conditions. In a mortar mixer, dry materials are mixed with alkaline solution until uniform. After casting, geopolymer stones are crushed and sieved under oven curing. Figure 2.3 shows aggregate manufacturing process.

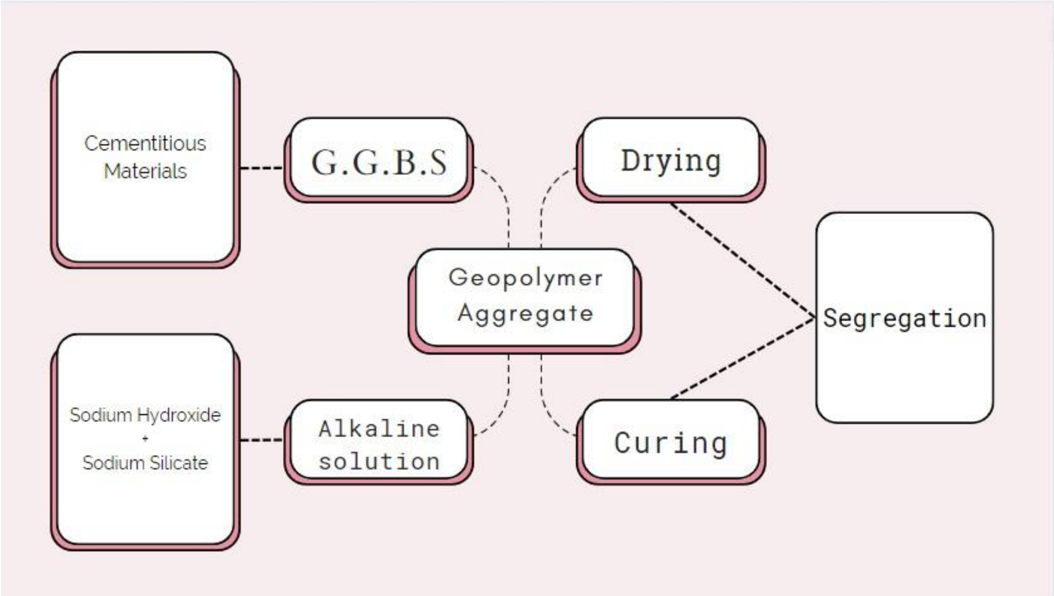

Figure 2.3 Geopolymer aggregate manufacturing process

2.2 Mix Proportioning

To prevent water from absorbing into concrete mix, coarse particles are employed in dry condition. Water-cement ratio (w/c) is determined to be 0.40, and volume of aggregates in concrete kept at 60% by volume. Water and an admixture of sulfonated naphthalene-formaldehyde condensate type are utilised. Table 2.3 lists mix design for concrete made using geopolymer coarse aggregate and natural aggregate.

Table 2.3. Concrete mix design (kg/m^3)

Concrete	Cement	Aggregate		Water	Admixture
		fine	coarse		
Conventional aggregate concrete	380	675	1450	130	1.50
Novel aggregate concrete	380	675	870	130	1.50

2.2.1 Concrete Manufacturing Process

Concrete made with capacity of 200 litre mixer. Cement, sand and coarse aggregate are mixed. Concrete mixture is mixed with water and admixture. It is glossy and well-mixed with concrete. Concrete mixture poured into 150mm x 150mm x 150mm cubes for compressive strength testing and 100mm x 100mm x 500mm prisms for flexural strength testing.

3. Results and discussions

Mechanical properties such as compressive strength, splitting tensile strength and flexural strength are presented in this section. Microstructure of geopolymer aggregate concrete has been studied.

3.1 Hardened Properties of geopolymer aggregate concrete.

3.1.1 Compressive strength results and dry density

Geopolymer aggregate concrete dry density increased from 1800 to 2250 kg/m^3 in 28 days, 56 days and 90 days, while natural aggregate concrete dry density increased from 2500 to 2650 kg/m^3. Geopolymer aggregate gained same density as natural aggregate concrete but it is 20% lighter. Neville [17] says lightweight concrete is 300 to 1850 kg/m^3. Geopolymer coarse aggregate is 38% lighter than crushed granite, but geopolymer aggregate concrete is only 20% lighter, well above the limit for lightweight concrete.

Compressive strength results at different age such as 7 days, 14 days, 28 days, 56 days and 90 days are presented in table 3.1. Figure 3.2 showed 12%, 17%, 22%, 23% and 30% increase in compressive strength at the age of 7 days, 14 days, 28 days, 56 days and 90 days showed geopolymer aggregate concrete over control aggregate concrete.

From 7 days to 90 days, compressive strength of cement concrete using geopolymer coarse aggregate is higher than regular coarse aggregate cement concrete. At 28 days, M 25 cement concrete with geopolymer coarse aggregate has a 22% better compressive strength than traditional coarse aggregate cement concrete. It has been found that both function similarly under compression. When compared to regular aggregate cement concrete, geopolymer aggregate exceeds compressive strength.

3.1.2 Splitting tensile strength and Flexural strength

The splitting tensile strength results at the different ages such as 7 days, 14 days, 28 days, 56 days and 90 days are presented in table 3.1. Figure 3.2 shows 8%, 9%, 11%, 14% and 16% increase in splitting tensile strength at the ages of 7 days, 14 days, 28 days, 56 days and 90 days shows geopolymer aggregate concrete over control aggregate concrete.

Splitting tensile strength is found higher for geopolymer aggregate cement concrete at various ages of concrete. For M 25 grade concrete, geopolymer aggregate concrete reports 11% higher splitting strength than cement concrete with conventional coarse aggregate.

Flexural strength results at different ages such as 7 days, 14 days, 28 days, 56 days and 90 days are presented in table 3.1. Figure 3.2 showed 12%, 17%, 21%, 23% and 26% increase in flexural strength at age of 7 days, 14 days, 28 days, 56 days and 90 days shows geopolymer aggregate concrete over control aggregate concrete. Geopolymer aggregate concrete yields high flexural strength at all ages when compared to control aggregate concrete.

Table 3.1 Strength of geopolymer aggregate concrete and control concrete with different ages of testing

Age of testing	**Dry density (Kg/m^3)**		**CA concrete**	**GPA concrete**	**CA concrete**	**GPA concrete**	**CA concrete**	**GPA concrete**
	CAC	**GAC**	compressive strength (MPa)		splitting tensile strength (MPa)		flexural strength (MPa)	
7 days	2510	1895	17	21	2.6	2.8	3.3	3.7

14 days	2535	1952	23	25	3.4	3.7	3.5	4.1
28 days	2580	2085	32	37	3.8	4.2	3.8	4.6
56 days	2625	2159	35	42	4.2	4.8	3.9	4.8
90 days	2682	2240	37	48	4.4	5.1	4.2	5.3

*CA – Conventional Aggregate Concrete * GPA – Geopolymer Aggregate Concrete

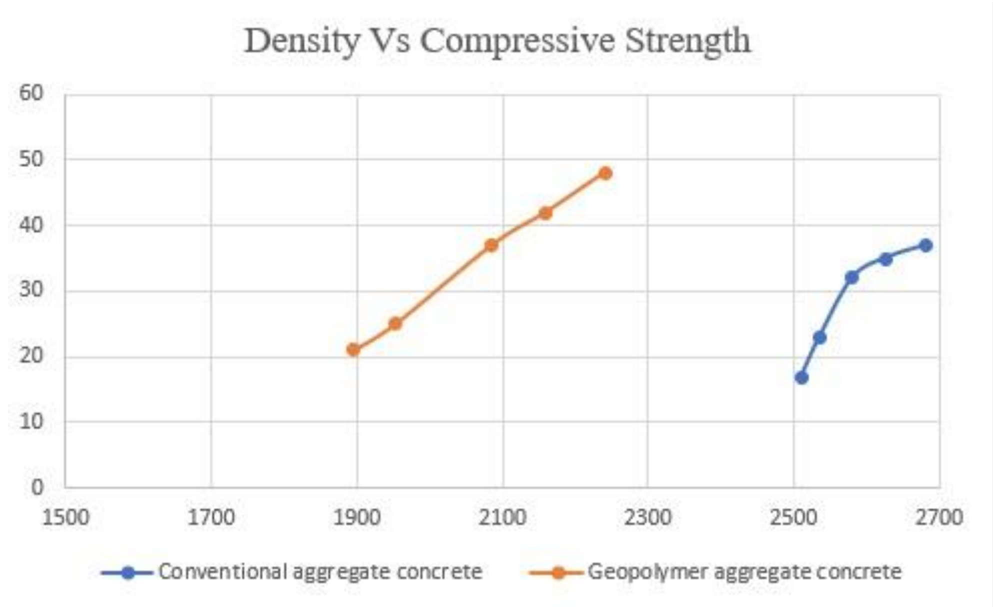

Figure 3.1 Relationship between density and compressive strength

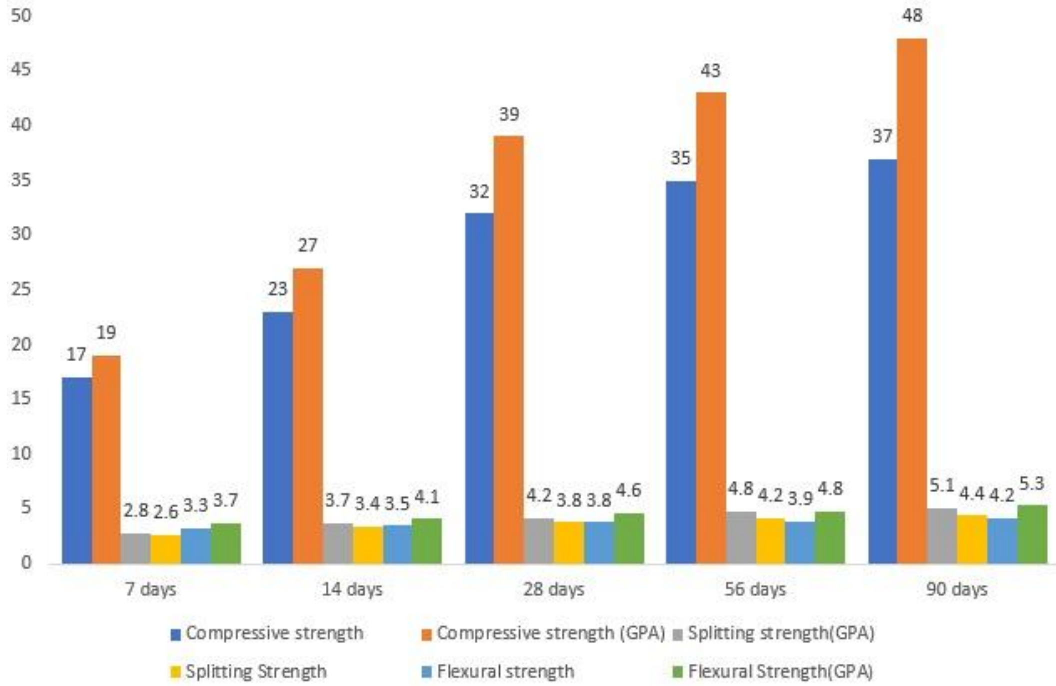

Figure 3.2 Comparison of strength of geopolymer aggregate concrete and control concrete vs. number of days

3.2 Microstructural characteristics of geopolymer aggregate concrete

Hydration products of hydrated cement paste of geopolymer artificial aggregate mixture are formed and distributed. Examining and contrasting microstructure of GPA mix with of standard aggregate mix. Microstructure and strength parameters of all two mixtures are connected based on hydration products generated after 28 days. Based on analysis and development of hydration products in microstructure of concrete mix, cause for strength of concrete is determined. Dark shadow of control concrete as shown in figure 3.2. It is because of non homogenity and discontinuity of concrete which results in less compressive strength of concrete when compared to geopolymer aggregate concrete.

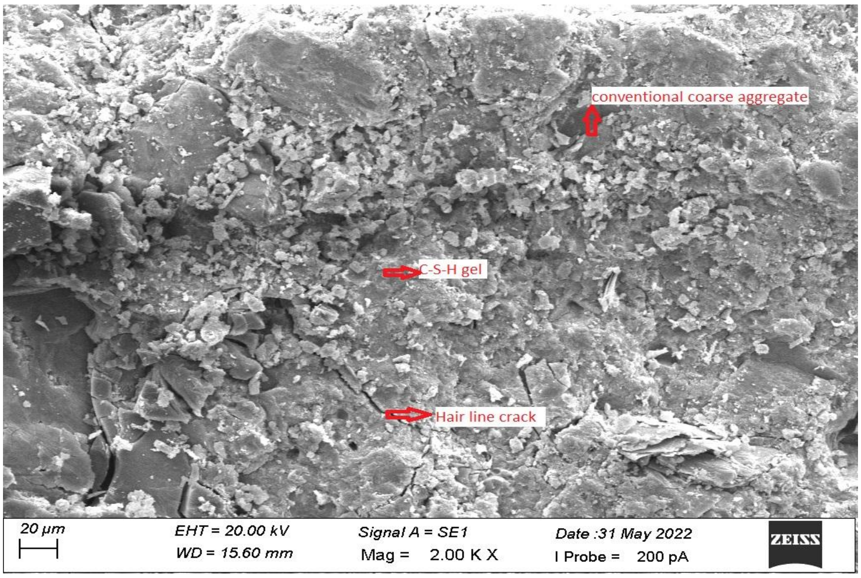

Figure 3.2. SEM micrograph of mix- 1 (conventional mix)

C-S-H gel widely distributed in mixture of hydrated cement paste which is major reason for efficient strength development of portlandite Ca(OH) and calcite ($CaCO_3$). Outer surface of hydrated cement paste which is seen in figure 3.3 SEM micrograph. One of factor contributing to mix actual strength is growth and dispersion of mineral components. No weakness in strength seen when coarse aggregate replaced with geopolymer coarse aggregate. Figure 3.3 shows internal grain are very closely packed and close particle constitute solid mass which increase compressive strength.

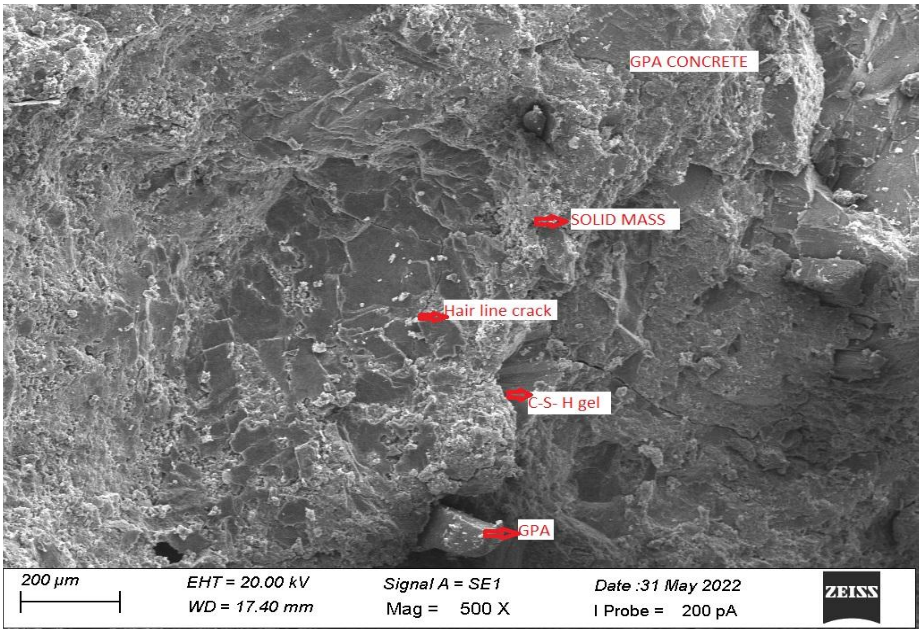

Figure 3.3. SEM micrograph of mix- 2 (geopolymer artificial aggregate mix)

Due to presence of reacted particles in mix, range of C-S-H development is significant. Microstructure of mix has highest concentration of other important mineral components are portlandite $Ca(OH)_2$ and calcite ($CaCO_3$) crystals. Primary cause of increase in strength is greater hydration of cement matrix particles as seen in figure 3.3.

In his experimental study, kayali (2008) observed enhanced adhesive and mechanical bonding in fly ash aggregate which increases fly ash aggregate concrete strength by referring microstructure. In present study, strong bond is observed in the microstructure of geopolymer aggregate concrete which increases compressive strength when compared to control concrete.

C-S-H gel is produced as result of chemical reaction between geopolymer artificial aggregate and fine aggregate and portlandite $Ca(OH)_2$. Rate of hydration in mixture is comparable to conventional aggregate mix.

Concrete microstructural behaviour affects the mix strength characteristics. The cost-effective addition of geopolymer aggregate alters behaviour of concrete microstructure and has an impact on compressive strength. The compressive strength test results show that changing the components in concrete improves the mix strength. Study of presence of mineral components and how they interact with synthetic aggregate in SEM observations provides a starting point for understanding the microstructure of concrete mix. Based on study of microstructure of two types of concrete mixes, hydration process in the mix including artificial aggregate differs from that of the other kind. Mix-2 hydration process is comparable to that of a typical concrete mix. However, C-S-H gel formation is smaller than conventional concrete mix (mix-1).

Less condensed and cracked cement-aggregate interface after 28 days due to moisture of geopolymer coarse aggregate. Increased density of ITZ attributed to geopolymer aggregate high-water absorption potential (table 1), which absorbs portion of free water and lowers original water-cement ratio in interfacial transition zone early hydration. Due to hydration, freshly formed hydrate fill in porous cement aggregate interface when curing microcracks by improving aggregate cement matrix interfacial bond.

One of the key considerations controlling compressive and flexural strength of concrete is quality and density of interfacial transition zone. Density of interfacial transition zone in geopolymer aggregate concrete increases aggregate matrix bond resulting in geopolymer aggregate concrete strength growth over time.

4. Summary and conclusion

- A comprehensive experimental research conducted to investigate viability of produced geopolymer aggregate as coarse aggregate in portland cement concrete.
- Density of geopolymer aggregate lower than conventional aggregate ranging between 1825 kg/m^3. Density of geopolymer aggregate is 34 percent lower than density of crushed granite aggregate. Density of geopolymer aggregate concrete is 18 percent lower and far beyond top density limit of lightweight concrete.
- At ages of 7 days, 14 days, 28 days, 56 days and 90 days, the compressive strength, splitting tensile strength and flexural strength of geopolymer aggregate concrete is more than control aggregate concrete. Replacement of natural aggregate content in producing geopolymer aggregate concrete shows an increasing trend of mechanical properties at various ages. Strength mainly depends on replacement of GPA because of high pozzolanic nature when mixed with cement and form densely packed C-S-H gel. Microstructure depends on composition of cement paste and light aggregate used in mix. Since geopolymer aggregate having pozzolanic reactivity, calcium hydroxide produced during hydration interacts with pozzolanic material and calcium silicate hydrate.
- Innovative and sustainable product has potential as coarse aggregate in portland cement concrete by reducing environmental impact.

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