Study on Key Factors of Mix Design and Properties of SelfConsolidating Geo-polymer Concrete Using Artificial NeuralNetwork–AReview

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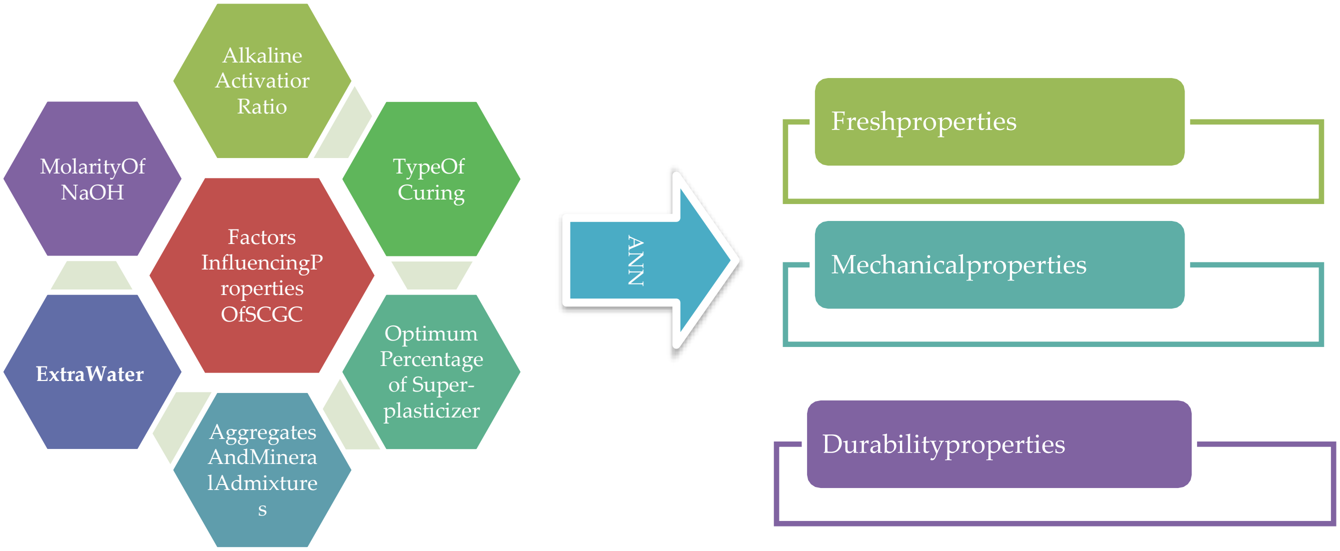
Abstract

Toovercomethechallengeofcompactionofgeopolymerconcretecausedbyitshighviscousnature,Self-consolidating Geopolymer Concrete (SCGC) has developed those flows and compacts by its own weight, avoidingthe requirement for additional compaction. The base materials used in SCGC are wastes like pulverized fuel ash,Ground Granulated Blast Furnace Slag (GGBFS), micro silica, limestone fines, rice husk ash, etc. produced fromvariousindustries,whichreactswithanalkalineactivatorsolution.Thisarticlereviewsvariousfactorsandconditionsthat affect the properties of SCGC that are based on different combinations of material bases. To determine variableslike the ideal temperature, percentage of super plasticizers, extra water, aggregate size, molarity of NaOH, ratio ofalkalineactivator,andquantityofbindermaterialstobeworked,athoroughanalysisofthemechanicalanddurabilitycharacteristics of SCGC is conducted. The results obtained from these experiments conducted to find out themechanical and durability characteristics are compared as to establish inferences and effectively comprehend thebehaviourofconcrete.Inadditiontotheassessmentbasedonexperiments,thepossibilityofusinganartificialneuralnetwork inordertoarriveatthe design mix andpredictthepropertiesofSCGCisalsodiscussed in thispaper.

Keywords: *Artificial Neural Network; Design mix; Durability properties; Mechanical properties; Self ConsolidatingGeopolymerconcrete*



1. Introduction

Inmanyfields,Indiaisstillinthedevelopmentstage.India'sinfrastructureisexpandingquicklyacrossalloftheseindustriestomeetthedemandsofothersectors.Cementconcreteusagehassurgedasaresultofthebuildingindustry'srapid expansion in response to the demand for urban growth. Many groups concerned with environmental conservationhavefrequentlyopposedtheusageofcementasabindingmaterialinconcretemixturesformanyyears.Thisisrelatedtotherecentfocusonglobalwarmingandtheconsiderabledepletionof non-renewableresourcesaddedinthemakingofOrdinaryPortlandCement.Themanufactureofcementsetsfreesomeharmfulgaseslikecarbondioxide(CO2)thatcancontributetotripleplanetarycrisis:pollution,biodiversityloss,andclimatechange[1].Oneofthemainindustriesemitting CO2 is the steel and concrete sector, which is determined to reduce CO_2 emissions by 2030. According tostatistics, a person consumes 1 cubic meter of concrete annually, making it the most widely utilized substance. By2030, 4800 million metric tonnes of cement may be produced worldwide, with India producing 290 million metrictonnes of cement in 2018 [2]. Concrete is an essential component of infrastructure construction, and due to its manyuses, it is second only to water in terms of usage worldwide. During the manufacture of cement, one ton of CO_2 isdischarged into the environment, making up 5% of all CO_2 emissions worldwide. It is stated that approximately 1.35billion metric tonnes of greenhouse gas emissions are produced each year on account of cement manufacturingworldwide. The CO_2emissions from cement production are anticipated to virtually double from current levels by 2020.Therefore, using an alternative binding material that can lessen land pollution, air pollution, and the deterioration ofpreciousnaturalresourcesisvitalforasustainableenvironment[3].Therearemanywasteproductsfromindustryandagriculture that are easily accessible in India and throughout the world. These wastes include Fly Ash (FA), MetaKaolinite, Ground Granulated Blast Furnace Slag (GGBFS), Rice Hull Ash (RHA), and Micro Silica. When disposedofontheground,thesepollutantscauselandcontamination.Thesewastematerialshavepozzolanicqualitiesandhave been added to cement for ages to improve the workability, mechanical strength, and durability of concrete. This hasprompted researcherstolookfor more environmentally friendlyalternativesto OPC.

One such area of research involves the use of geopolymers, which are created when different materials, includingnaturalpozzolanasandwastesfromvariousindustries,suchasflyash,GGBS,ricehullash,sugarcanebagasse,react. Using binders that have been alkali activated, such as lead smelter slag, powdered GGBS, and palm oil fuel ash, amaterial called geopolymer concrete has been created. By using these wastes as cementitious materials, significantproblems about the storage and discarding of waste from the mining and processing industries can be addressed bygeopolymers[4].Priortotheirwidespreaduseincommercialapplications,itisnecessarytohaveagoodgraspofthisnew type of binder's durability properties. Up till now, only few studies have examined the selective sulphuration oflead smelter slag. Numerous research has examined the corrosion, sulphate attack, and acid attack action that inducesdeterioration of fly ash geopolymer concrete. Vibration is necessary for optimal compactability while compactingregular geopolymer concrete. Concrete vibrations encourage noise pollution. The alternative is self-compactingconcrete (SCC), which fills the formwork with its self-weight and does not require any way of compacting. SCCprovides easy filling of concrete in tight spaces, greater compaction, reduced maintenance, reasonable constructionrates,higherconcretequality,cheaperoverallbuildingcostsandgoodbondstrengthwithreinforcement.Thebenefitsof geopolymer technology and the growing preference for SCC in the building sector powers the production of novelconcrete which combines the interests of both the concretes. Portland cement is not used in the manufacturing ofSCGC, nor is any type of compaction necessary. The properties of SCGC have not been extensively researched. Asamorphous materials by nature, fly ash, GGBFS, and silica fumes are activated by alkaline solutions namely sodiumhydroxideandsodiumsilicatetoproduce geopolymergel,whichisthenusedtomakeconcreteknownasgeopolymerconcrete. SCGC was produced by a series of studies utilizing fly ash as the base material and altering the sodiumhydroxide molarity, ratio of alkaline solutions, curing temperature, curing time, dosage of the superplasticizer, andamount of the alkaline activator during oven-curing. According to one publication, compressive strength on the 56-day of GGBFS-based SCGC at room temperature was 40 MPa, compared to just 16 MPa for FA-based SCGC.ResearcherswhoreplacedFAwithGGBFSbetween10and100%foundthattemperaturecuringwaseliminatedwhilecompressivestrengthincreased[5].UtilizingGGBFSshortensthetimeneededforcorrectplacementandcompactionof geopolymer paste by hastening the material's setting process. Furthermore, increased slag content results indecreasedconcreteslumpandmortarflow.Microsilica,flyash,andGGBSarefrequentlyincludedforthecreationofhigh-strength, high-performance concretedue ofitsgreatengineeringcharacteristics.

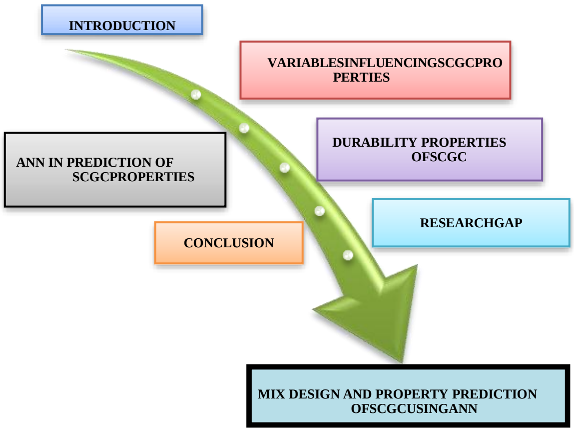


Fig.1.OverviewofContentsofthepaper

2. ArtificialNeuralNetwork inPredictionofSCGCProperties

Thereisnocommonlyapprovedmethodfordeterminingtheproportionstobemixedinconcrete,despitepreviousstudies on the performance and design mix variables of self-consolidating geopolymer concrete. **Lim C.H. et al.**investigated how to optimize the design mix of cement concrete using various algorithms and artificial intelligencetools[6].**TopcuI.B.andco.**havefoundthat,whenappliedtoalkali-activatedconcrete,theartificialneuralnetworks(ANN) method revealed that compressive strength can be estimated with the least amount of error compared to theexperimental data [7]. As defined by **Yaprak H. et al., an** ANN is a tool for training statistical data modeling bychangingtheweightsontheavailabledatainordertomodeladifficultconnectionbetweentheinputsandthedesiredresult [8]. **Lahoti and co.** used ANN to find the strength of alkali-activated metakaolin based concrete and looked atthe consequence of some important ratios: Silicon/Aluminum molar, water/solid, Aluminum/Sodium molar, andwater/sodiumoxidemolarity[9].Inanotherstudy,**Nazari,A.,andco-authors**examinedandpredictedthemechanicalstrengthofgeopolymerconcretesthatdependsoncuringtime,Calciumoxide content,SodiumHydroxideconcentration, and the water/sodium oxide molar ratio study. These models included ANNs having different countsofneuronsinthecovertlayers[10].**Bondar,D.**researchedhowscientistsusedavarietyoffunctionsforthedifferentlayers to try and optimize them. Ling and others demonstrated a strong correlation linking the experimental mechanicalpropertiesandsettingtimeresultsofhigh-calciumflyashbasedgeopolymerconcreteandtheANNmodelpredictions[11].

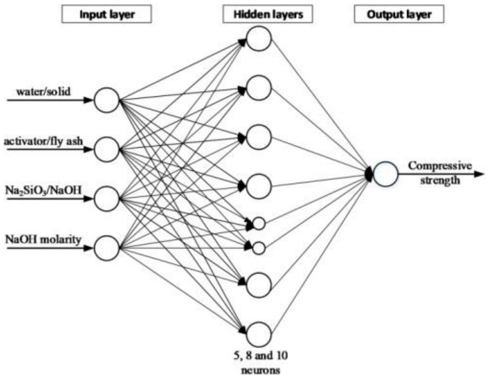


Fig.2.SchematicmodelofthepredictionprocessthroughANN[28]

3. VariablesInfluencingthePropertiesofSCGC

There are some factors that influence the properties and behavior, like workability, compressive strength, ITZformationatthemicrostructurallevel,etc.,ofself-consolidatinggeopolymerconcrete thatneedtobestudiedindetailin order toarrive at a bettermixdesign.

3.1. MolarityofNaOHand RatioofAlkalineSolutions

A mixture of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) has been a common pair of alkalineactivatorstobeaddedtothebindermaterials.Themanufactureofhigh-strengthgeopolymersissignificantlychangedby the molarity of the NaOH solution. It should be noticed that compressive strength rises as NaOH molarity raises.The ratio of fly ash to alkaline solutions and the relationship between Sodium silicate and Sodium hydroxide areadditionalfacetsthat influence the geopolymerstrength.

B.R.ArunandothersresearchedthemechanicalcharacteristicsandflowabilityofflyashandmetakaolinSCGCatvarious NaOHmolaritiesbychangingtheflyashtometakaolinmassfractionby0,10,20,and30%bymassforallmolarities,including8, 10,and12M,whilekeepingthebindercontentconstant.Workabilityparametersandvariousstrength tests such as compression, split tensile, and flexural strengths were found to increase with rising molaritieswhiledecreasingwhenmetakaolinwasincorporatedwithflyashcontent[12].**GuohaoFangandothers**usedalkali-activated fly ash slag (AAFS) concrete cured at controlled temperature in a study that was similar to the one that wasdoneinthepreviouspaper.TheyfoundthatanidealmixtureofAAFSconcretewithaslagpercentageof20–30%,analkaline activator to binder ratio of 0.4, a NaOH concentration of 10 M, and a Na_2SiO_3ratio of 1.5–2.5 met theperformanceparametersofworkability, setting time,and compressive strength[13].

Guneet Sainia and others studied GGBS to try to create alkali-activated SCGC by inducing 2% nano silica byweight into six mix designs with binder contents of 450 - 500 kg/m3, respectively, and varying molarities of 10, 12,and 16 M of alkaline solution. The performance and properties of geopolymer concrete are significant impacted bythe ratios of sodium silicate to sodium hydroxide (SS/SH), alkaline activator liquid to binder (AAL/B), and water tobinder (W/B), all of which were set at 2.5, 0.45, and 0.27, respectively, in a GPC mix design. At 90 days, they foundthat the sample of 16 M alkaline solution, with a binder content of 500 kg/m3, had the highest compressive, flexural,and splittensile strengths—81.33 MPa,7.875MPa, and6.398MPa,respectively[14].

3.2. CuringTemperatureofConcrete

Inmostcementitioussystems,mechanicalstrengthdevelopmentisalsosignificantlyinfluencedbycuringconditions.Accordingtoanumberofstudies,thespecimen'smechanicalstrengthcanchangewhileitiscuredatroomtemperature,ambienttemperature,orheat.**YaminiJ.Patelandothers**testedhowthemechanicalpropertiesofSCGCblendedwithGGBSandRiceHuskAsh(RHA)changedwhenRHAwasreplacedatdifferentpercentages(five, fifteen,andtwenty-fivepercent)andatdifferenttemperatures.At70 temperatureofcuringandambienttypeof curing,theidealreplacementrateforRHAwithGGBFSis5%and15%,respectively.Whencomparedtocuringat roomtemperature,thestrengthisgreaterat70 .Thedensemicrostructureof5%RHAatroomtemperatureand15% RHAat70 °Cproducesastrongermaterial,accordingtoSEMimaging[4].

Sherin Khadeeja Rahman and the others described how they used a single alkali activator as a building blocktocreateaunique,ambient-curedSCGC.Theworkability,mechanical,andmicrostructuralcharacteristicsoftheeightdistinct concrete mixtures were investigated. After 28 days, they reached the ideal combination along with a unitweight of 2200 kg/m3 and an average compressive strength of 40 MPa using a binder of 960 kg/m3 and sodiummetasilicate alkali of 96 kg/m3. A few more studies investigated the qualities of SCGC by ambient curing thespecimens until the right days for assessing the concrete's increased compressive strength and microstructure. Thespecimenswere firstcuredinahot air ovenat60 °Cor70°Cfora periodof 24hours [3].

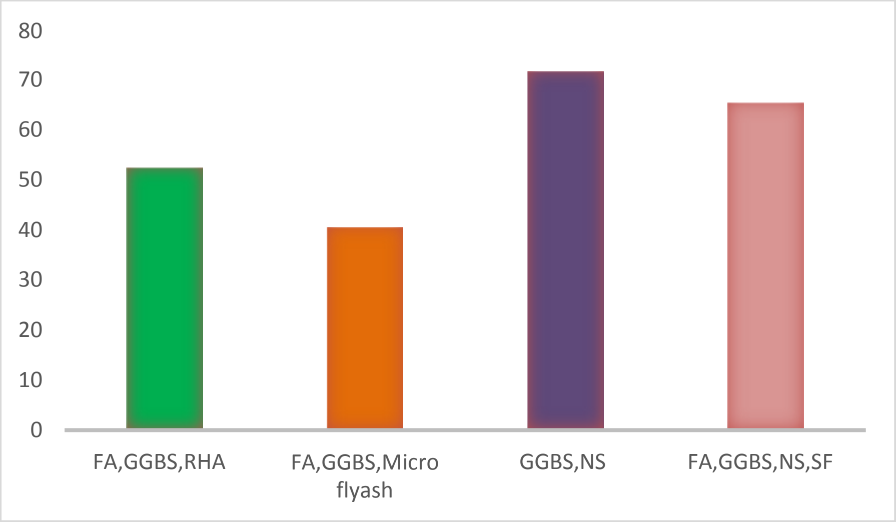


Fig.3.Hardenedpropertiesof SCGCwithheatcuringforvariouscombinationsofmaterials

3.3. Super-plasticizersandExtraWater

Shin Hau Bong and others reported on the impacts of several water reducers and retarders on the characteristicsof freshly formed and hardened geopolymers made with a mixture of fly ash, slag, and solid activators. Anhydroussodium metasilicate powder value of 0.9 and GD Grade sodium silicate powder value of 2.0 were the two differentgradesofsodiumsilicatethatmadeupthesolidactivators.Twonaphthalene-basedsuperplasticizer(designatedasN1and N2), different retarders, and some modified polycarboxylate-based super-plasticizers (designated as PC1, PC2,and PC3) were all tested. All the admixtures of GD-grade sodium silicate with solid activator not only reduced thecompressivestrengthbuthadnobeneficialimpactonworkabilityorsettingtimeeither.Anhydroussodiummetasilicate powder (PC1) and sucrose were found to be the better superplasticizers as well as retarders. Theyincreased workability by up to 72% and set time by up to 111%, respectively, but had a weak effect on compressivestrength.The"combined"admixturesalsoimprovedthemixture'sflowabilityupto39%andsettingtimeupto141%,althoughtheysomewhatdecreaseditscompressivestrength(16%)[15].

Samuel Demie and others studied the microstructure and compressive strength of an interfacial transition zone(ITZ) made of SCGC based on fly ash. Additionally, correlations between the ITZ's microstructure and the surge incompressivestrengthwereexamined.Therequisiteworkabilityqualitiesweresuppliedbymixeswithsuperplasticizerdosages of 6% and 7%, which were also within the SCC range of EFNARC standards. Different SP dosages—3%,4%, 5%, 6%, and 7%—were used to prepare concrete examples, which were then cured for 48 hours at 70 °C. Whentested at 28 days with a 6% SP dosage, SCGC's compressive strength may reach 51.52 MPa. The concrete specimenwith 7% Sp had the maximum compressive strength at all ages, and by just improving the ITZ of SCGC, themicrostructureattributeswerealsoenhanced.ThevaryingITZthicknessbroughtonbythevariousSPdosageshadanimpactonthemicrostructuralalterationsandthemechanicalstrengthoftheconcrete.AriseinSPusageenhancesthecompressivestrengthofSCGC,whereasadeclineinITZthicknessstrengthenedthemicrostructure[16].Somearticlespublished the findings of an experiment to determine how much extra water and superplasticizer affect the strengthandflowabilityofflyash-basedSCGC.Ninedifferentcombinationswithsuperplasticizerlevelsrangingfrom3to7%andadditionalwatercontentsbetween10%and20%oftheflyashbulkwerecreatedandtested.Itwasfoundthattheworkability was improved by adding more additional water and superplasticizer. However, adding more water than15% caused bleeding, segregation, and lowered the concrete's compressive strength. When the additional watercontentinself-compactinggeopolymerconcretetopped12%bymassofflyash,itscompressivestrengthconsiderablyfell [16].

3.4. AggregatesandMineralAdmixtures

SelçukTürkelandothersinaseriesoflaboratorytests,onbothfreshandhardenedpropertiesofSCC,theimpactsofmineral admixturesnamely—flyash(FA)andlimestonepowder(LP)—aswellastwotypesofcoarseaggregates—limestoneandolivinebasalt—wereinvestigated.ComparedtoM2'smixtureofFAandbasaltaggregate,M3'smixtureof LP and limestone aggregate had a 21 percent positive impact on slump flow. In addition, when in contrast to theother SCC combinations, the one developed with fly ash and limestone aggregates has a compressive strength at 28days that is approximately 15–27% higher, whereas basalt aggregate combinations have the lowest flexural strengthat28days.Segregationwasnotcausedbybasaltaggregatesthathaveahighrelativespecificgravity.Theaverageaircontent of SCC, which includes FA M1 and M2, is higher than that of other compounds. The ability of SCC towithstandfrostisalsoenhancedby usageofFAandraising theaircontent[17].**UysalMuctebaetal.**workedon thecharacteristicsofSCC.Portlandcement(PC)wassubstitutedwithdifferentamountsofflyash(FA),granulatedblastfurnaceslag(GBFS),limestonepowder(LP),basaltpowder(BP),andmarblepowder(MP).ThemineraladmixturesFA and GBFS greatly improved the workability and compressive strength of the SCC mixtures, based on test results.After 400 days, by substituting 25% of the PC with FA, the strength reached more than 105 MPa. Moreover, theaddition of mineral admixtures had the positive impact of reducing the strength loss brought on by attacks by sodiumand magnesium sulphate. The strongest resistance to attacks by sodium and magnesium sulphate, however, wasachieved by the mixture of 40% GBFS and 60% PC [18]. **Mehmet Gesoglu and others** evaluated 22 concretemixtures with 450 kg/m3 of total binder content and persistent water to binder ratio of 0.44. In contrast to the controlmixture, which simply comprised regular Portland cement, the rest of mixtures' binders were binary (PC and FA).Portland cement was replaced with fly ash, powdered granulated blast furnace slag, and silica fume to createcementitious blends such as PC + S, PC + SF, ternary (PC + FA + S, PC + FA + SF, and PC + FA + S + SF), andquaternary (PC + FA + S + SF). By weight of cement, the replacement levels for SF were 5%, 10%, and 15%, whilethose for FA and S were 20%, 40%, and 60%, respectively. When the durability characteristics of the concrete weretaken into consideration, their findings indicated that the ternary use of S and SF offered the supreme performance[19]**. I.M. Nikbin and others** examined 12 SCC mixes' most crucial mechanical qualities under different conditions,including ageing, coarse aggregate volume, and maximum coarse aggregate size. As the coarse aggregate sizeincreases from 9.5 mm to 19 mm, the compressive strength for w/c ratios of 0.38 and 0.53 rises by 5% and 25%,respectively, while the tensile strength falls by 14% and 6%. As the volume of coarse aggregate grows from 30% oftheaggregatevolumeto60%oftheaggregatevolume,thecompressivestrengthdoesnotriselinearly.Astheconcreteage increases from 3 to 90 days for both w/c ratios of 0.45 and 0.65, the compressive strength rises by 180%. Thetensile strength improves by 100% as the concrete age rises from 3 to 90 days for both w/c ratios of 0.45 and 0.65[20].

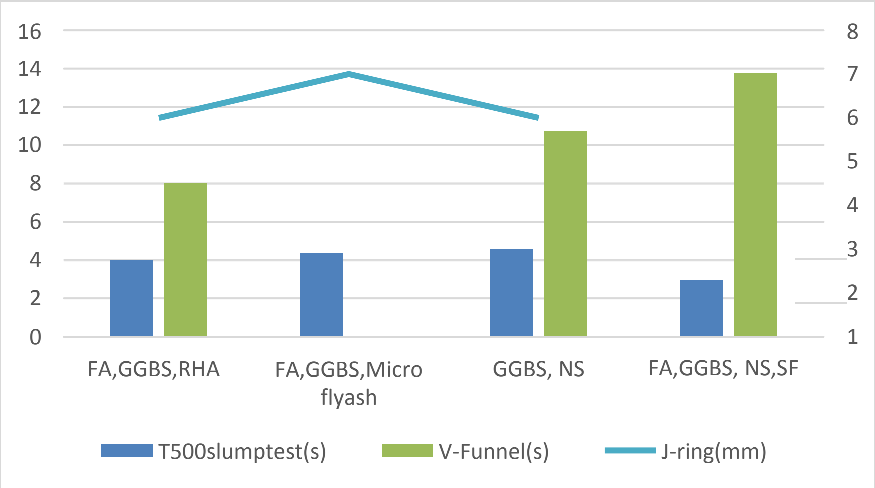


Fig.4.Comparisonofvariousflowabilitytestresults

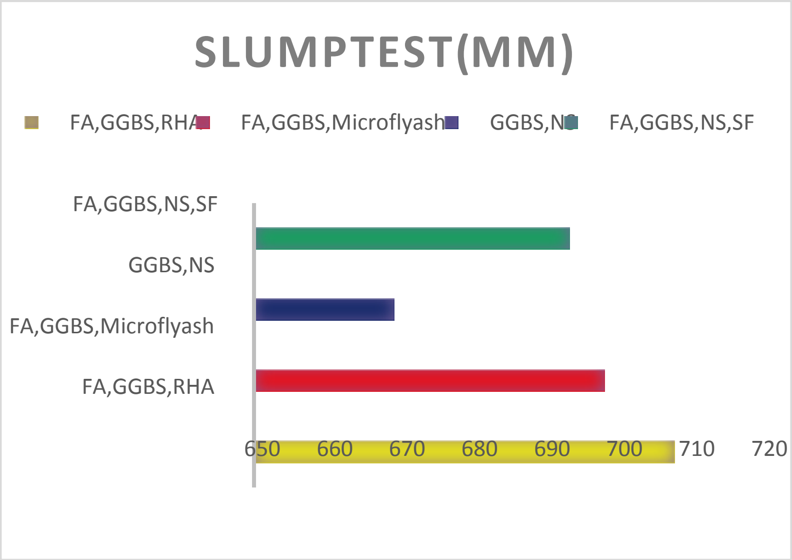


Fig. 5 Slump flow test

Dibyendu Adak and co-authors studied that in comparison to the standard geopolymer concrete with the controlconcrete,the modified geopolymerconcrete shows a notable improvement inmechanical strengthas well as durability.An8MNaOHsolutionandNa2SiO3werecombinedinaratioof11.75tocreatetheactivatorfluidforbothprocess-modifiedgeopolymerconcrete(GPCI)andtraditionalheat-curedgeopolymerconcrete(GPCII)(byweight).Resultson acid attack resistance and water absorption tests for the GPC I, II, and CC mixes after 28 days of casting. Incomparison to the GPC I, II mixes, the CC mix absorbed more water. Additionally, compared to the GPC II mix, theGPC I mix contained smaller water content. The findings of the chloride permeability test on the three mixes arereportedafterone,andthree-monthperiodofcuring.BecausetheactivatorsolutionconcentrationisthesameforGPCI, II, the RCPT values of these concrete mixtures can be looked upon for a durability study. It was discovered thatGPC I, II have different charge transfer rates [21]. **Albitar and others** examined the effectiveness of geopolymerconcretespreparedwithclass-Ffly ashoramixtureofflyash andgranulatedleadsmelterslag(GLSS).Theeffectofincorporating regular Portland cement (OPC) concrete is also examined as a benchmark for figuring out how durablegeopolymer concretes are. All samples were submerged in four chemical solutions up to nine months: 3% sulfuricacid, 5% sodium chloride, 5% sodium sulphate, and 5% magnesium sulphate. Additionally, the effects of additionalcycles, such as heating-cooling and wetting-drying, on compressive strength and mass loss were investigated. Theresults showed that the microstructure can be made better by adding graphene nanoplatelets to geopolymer binders.OPC concrete degrades more quickly than geopolymer concretes when exposed to sodium sulphate, with a reductionmagnitude of 15.4% as opposed to 13.4% and 12.3% for fly ash and GLSS geopolymer concretes, respectively. Thedetrimental effect of Sulfuric acid on OPC concrete than fly ash or GLSS geopolymer concrete, whose compressivestrengthsarereducedby10.9%and7.3%,respectively[22].

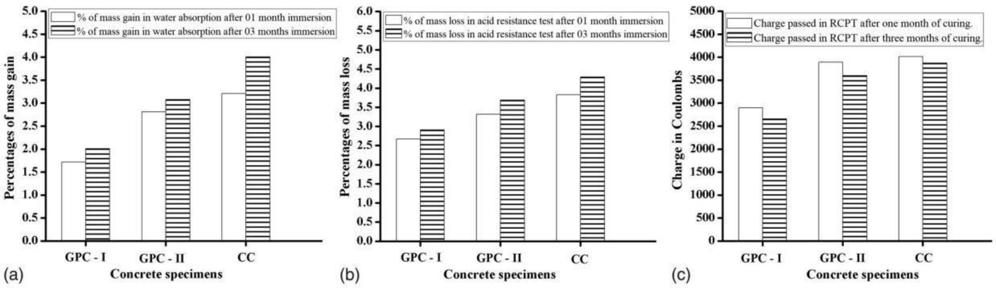


Fig.6.Graphson(a)Waterabsorption;(b)Acidattackresistance;(c)RCPTonvariousmixproportions [21]

4. Conclusion

The following inferences can be made from the examination and discussion of previous research's studies andexperiments:

- Self-compacting geopolymer concrete with fly ash as a binder can help concrete emit less CO_2than regular Portlandcementdoes.
- ThecompressivestrengthofSCGCwasimprovedwhenflyashcontentwasmixedinrangefrom400kg/m^3to500kg/m^3,particularlyassuperplasticizer dosageswere increased.
- It is evident that superplasticizers with low contents of 3, 4, and 5% lacked the capacity for the workability resultsthat fell below theSCC EFNARC limitations for filling and passing. Due to the absence of a significantcontribution fromtheSPdosage of7%,the optimal superplasticizer dosage is6%.
- Geopolymerconcrete's compressivestrengthincreasedas NaOHsolutionconcentrationincreasedfrom8Mto12 M. However, the compressive strength decreases as the concentration rises from 12 M to 14 M, with 12 Mproducing thehighestcompressive strengthacrossall testingdays.
- At70°C,alongercuringtimeof24to72hoursimprovesthegeo-polymerization,resultinginahighercompressive strengthatanearly age.
- Compared to SCC produced using ordinary Portland cement, heat-cured SCGC experiences very little dryingshrinkage.
- Withincreasingcompressivestrength,the hardenedSCGClosesitspermeabilityandabilitytoabsorbwater.
- In acid and sulphate solutions, geopolymer and OPC concretes lose weight and strength. Compared to OPCconcrete, GPCismore resistanttoacid andsulphate attacks.
- GPCthatismadebycombiningkaolinandFAhasexcellentdurabilityandcanresistchemicalattackbyupto40% more.
- GPC specimens had higher abrasion resistance than CC specimens. GPC specimens had an average wear rate thatwas27.5percentlowerthanthat of CCspecimens.
- The chloride diffusion coefficients of GPC and CC were nearly identical. When subjected to a 3% H_2SO_4 solutionforsixmonths,GPCspecimensexperiencedlessthan2%weightlossanddemonstratedverygooddefenseagainst acidand sulphateattack.

5. ResearchGap

A great number of literatures have been previously discussed about the optimum mix designs for self-compactinggeopolymer concrete with various mineral admixture combinations. Most of the research was carried out to arrive atabettercompressivestrengthoftheconcretewhileitsdurabilitypropertiesarenotinvestigatedonalargescale.Moreknowledge needs to be acquired regarding the durability characteristics and the resistance to weathering and variouschemical attacks. Researches have also been made by incorporating the use of Artificial Neural Network with trialsof different types of algorithms. There is still a gap to determine as to which algorithm gives the better and mostaccurateresultsfor thegiventype andamountofinputs.

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