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RESEARCH ARTICLE

SYNERGISTIC RECYCLING OF DETERIORATED LATERITE SOIL AND FLY ASH ASGEOPOLYMERPRECURSORS:UPSCALINGFROMBINDERSTOSUSTAINABLEBRICKS

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Abstract

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Globallysustainabilityisthemajorchallengeforamaterialconstructionindustryin termsofmeetingecofriendlydemands.Similarly relevant provocation is expected in anthropogenic activitieslike waste management in thermal power plants. In this study, in thelight of industrial conversation appeal, two wastes, namely laterite soiland fly ash, generated through intensive and prolonged weathering ofthe underlying parent rock and operation of thermal power plant, wereused in a synergistic way in the preparation of sustainable geopolymerbinders. In order to assure a productive balance between the variousperiodicalevolutionofbuildingmaterialsdemandandwastesproduction, sustainable bricks have been regarded as optimum potentialapproach. In this regard, mix proportions and curing conditions wereinitiallyoptimized.Particularly,geopolymerisationkineticswereevaluated by varying the molarities of sodium hydroxide (NaOH) andsodiumsilicate(Na2SiO3)asfunctionofcuringperiod.Themechanical, durability and microstructural characterization of binderswere assessed to identify the influence of curing conditions (Elevatedtemperature) and mix proportions on the engineering performance and,afterwards,the productwasupscaled toatypical building brick.

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Introduction:-

Cementisthecommonlyusedbindingmaterialintheconstructionindustry.TheOrdinary PortlandCementconsumes limestone and clay as raw materials in the production process. For every ton of cement production, itreleases a ton of CO_2 into the environment (Xie & Ozbakkaloglu, 2015).The excessive use of cement composites inconstruction activitieshasbeen criticizedduetomassivecarbondioxideproductionanddepletion of naturalresources. An increase in cement utilization is a concern for the environment and human health (Kupaei et al., 2013;Xie & Ozbakkaloglu, 2015). One of the alternative solutions for the above concern is using the alkali as a bindingmaterial (Geopolymer), which has gained popularity in the recent literature (Khalil et al., 2020; Kupaei et al., 2013;Preethi&VenkataramaReddy,2020).

During burnt bricks' production, 24 million tons of coal is usually consumed, apart from 10 million tons of biomass,whichcausesaairpollution(Eliche-Quesadaetal.,2021).Theenormousamountoffertiletopsoilisconsumedby

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claybricksowingtothefastdepletionofthesoil.Hence,thealternativetothesebricksisGeopolymerbricks,which have recently gained popularity. These advantages make Geo polymer a promising alternative to traditionalOPCincivilinfrastructureconstruction.

The polymer-based composite concept was invented in 1950 by Chelokovski and later named as geopolymer by aFrench professor Davidovits in 1978. Geopolymer binding properties are formed by the reaction of any hydroxidewith silicate, and alumina forms an alumino silicate gel which possess binding property (Mathew & Issac, 2020;Mustafa et al., 2011). NaOH hydroxide is the most commonly used hydroxide solution compared to other hydroxidesolutions like potassium hydroxide, magnesium hydroxide etc., because of its availability and NaOH possess agreaterabilitytorelease silicate and aluminomonomersand possessgoodstrength(Atabeyetal.,2020).

Previous studies have shown that the alkali solution lesser than 6M solution doesn't perform well (Wong et al.,2020). It was also observed that an increase in the fly ash percentage by more than 10% reduces the strength of thegeopolymer composite (Udawattha et al., 2018; Wong et al., 2020). Ambient curing and oven curing can both beadopted effectively in the curing of geopolymer composites; 60^0C oven curing for 24 hours in an oven is consideredan optimum temperature of curing(Mo et al., 2014; Saravanan et al., 2019; Xie & Ozbakkaloglu, 2015). But further,manyresearchershaveshown60^0Cto80^0C(Fořtetal.,2019)andfurtherupto100^0Cbysomeresearchers(Atabeyet al., 2020). NaOH to Na_2SiO_3 ratio plays a vital role in the preparation of geopolymer composites, 1:2.5 NaOH toNa_2SiO_3ratiogave the bettercompressive strength ingeopolymercomposites(Mathew&Issac,2020).

Laterite is the materials widely available in the tropic and sub-tropic regions of Africa, Australia, India, South EastAsia and South America. Laterite is directly cut into the shapes of bricks and is also used for road works, and it'sused for both structural and nonstructural construction works (Mathew & Issac, 2020). Since it's naturally availableand rich in iron content, after the deterioration of the soil, it loses its binding property, which is not even good foragricultural activities. This deteriorated soil can be used to prepare composites using alkali binders(AYANDA et al.,2011;Jainetal.,2011;Olowuetal.,2014).

In this study, deteriorated laterite soil locally availablein Bidar, Karnataka, stone dust, andfly ash was utilizedalong with alkali solution as a binder to prepare the laterite bricks. The mix design of the preparation of laterite-based geopolymer bricks is optimized by considering the variable ratios of laterite soil to stone dust with a fixedpercentage of fly ash. The alkali solution is optimizedby varying themolarity and alkali to silicate ratio withvarying curing temperatures. From all the optimized ratios, bricks are prepared and evaluated for the physical anddurable parameters,alongwiththestudyofthe structuralintegrityoftherequiredsamples.

Materials:-

LateriteSoil

Laterite soil was procured from the Bidar district,Karnataka state, which is rich in ferrous content and heavymaterial. The laterite soil was characterized, and the results are tabulated in Table. 1. The elemental composition oflaterite soil was determinedby X-ray diffraction (XRD)analysis.Silica (Si)and alumina (Al)are themajorcomponents present in these materials as shown in Figure1. The scanning electron microscope (SEM) images showsthe pictures oflateritesoil.

Table1:- PropertiesofLateriteSoil.

Parameter	**Values**
Specificgravity	2.64
pH	7.82
EC(μS/cm)	102
SiO_2(%)	56.4
Al_2O_3(%)	7.74
CaO (%)	1.4
MgO (%)	0.13
Fe_2O_3(%)	34.43
LiquidLimit(%)	21.12
DryDensity	1.99gm/cc

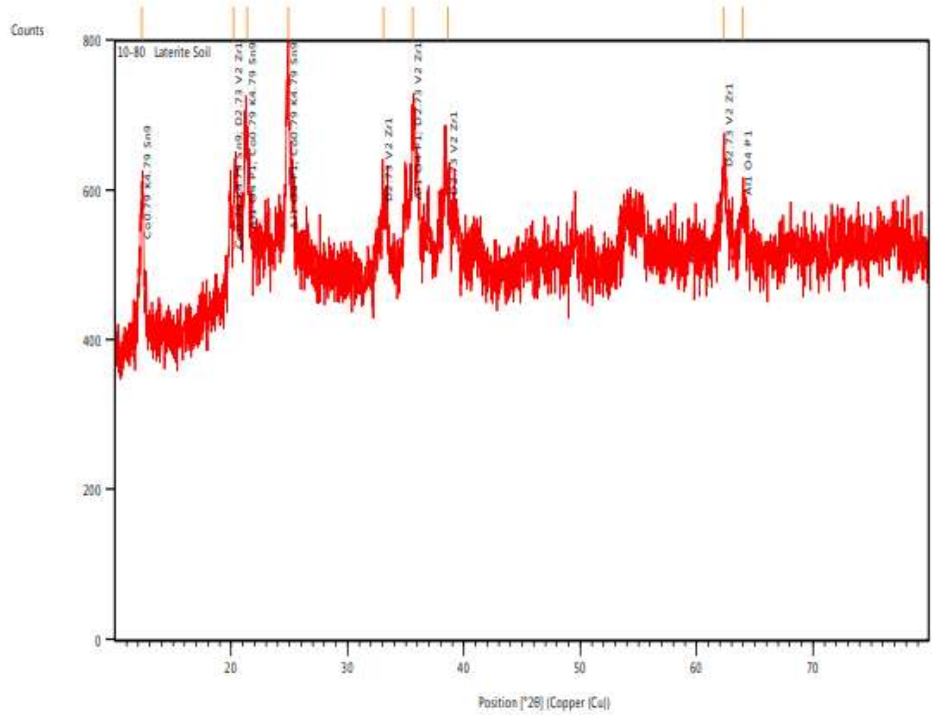


Figure1:-XRD patternofLateriteSoil.

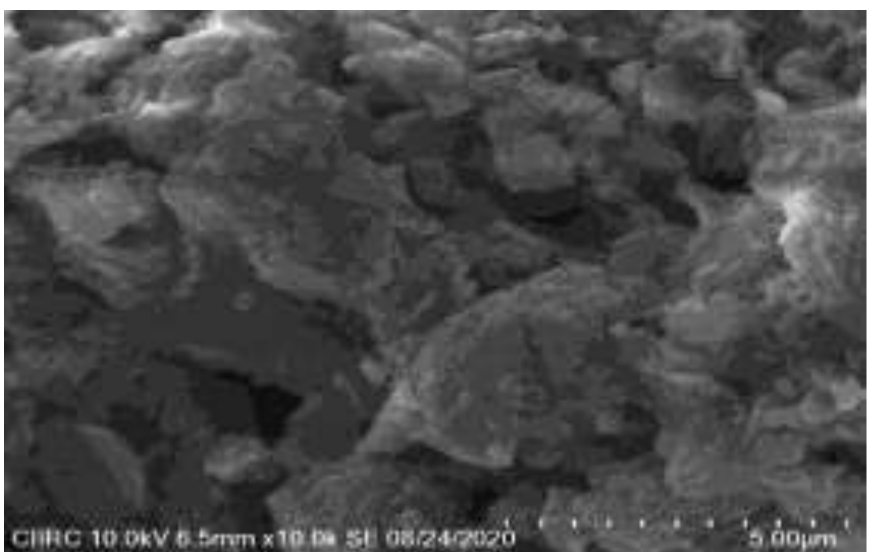


Figure2:- SEMofLateriteSoil.

FlyAsh

Class-F Fly-ash was obtained from Raichur thermal power plant. Karnataka, which was characterized and the resultsaretabulatedinTable2.

Table2:- PropertiesofClass-Flyash.

Parameter	**Values**
Specificgravity	2.15
pH	8.4
EC(µS/cm)	225
SiO_2(%)	55
Al_2O_3(%)	24

CaO (%)	0.98
MgO (%)	0.47
K_2O(%)	1.75
Fe_2O_3(%)	7.8
TiO_2(%)	1.45
Lossonignition(%)	5.25

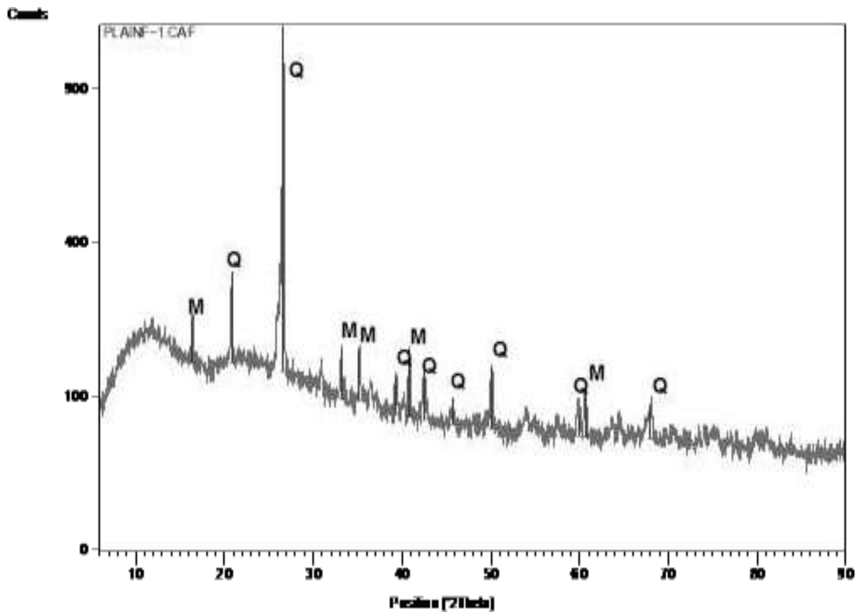


Figure3:-XRD patternofFlyAsh-ClassF.

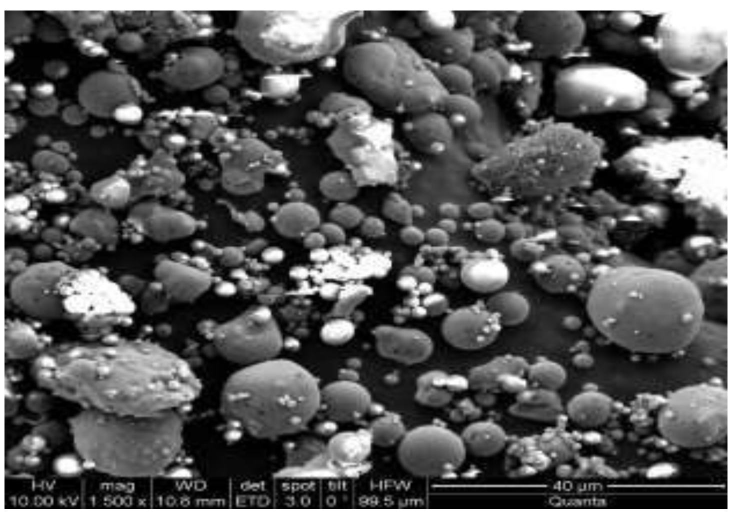


Figure4:-SEM patternofFlyAsh-Class F.

A. Stone Dust

Stone dust was procured from a locally available quarry, and it's a finely crushed material having properties similartosandhavingaspecificgravityof2.67.

GeopolymerSolution

Geopolymer is a basic inorganic solution formed by a mixture of hydroxide, silicate with any pozzolanic materiallike fly ash, GGBS, silica fume which contains alumina forms a alumino silicate gel which acts as a binding agent inanygeopolymercomposites

B. Sodiumhydroxide(NaOH)
Itsbasicalkalisolutionhasamolarmass39.997gms/mol,andit'saninorganiccompound,alsoknownascausticsoda,thatwas procuredintheformofcrystalline.

C. Sodiumsilicate (Na2SiO3)
It'sasilicatesolutionprocuredintheformofliquid whichisheavyandalsoknownaswaterglass

D. Potablewater(H_2O)
The potable drinking water available in the locality is used for the preparation of dilution of sodium hydroxide to therequired solution

Methodology:-

2 Procurementofallthematerials(Lateritesoil, Fly ash, StoneDust,NaOHandNa_2SiO_3)
3 Characterizationofthematerialsfortheir properties
4 Preparationofvariousdrymixesoflaterite soiltostone dustbykeeping theflyashpercentage constant
5 Preparingthehydroxide solutionofvaryingmolarityfrom8Mto 14Mwithavariationof2molarity
6 BykeepingtheNaOHtoNa_2SiO_3ratioof1:2.5constant,forthevariousmixratiosandvaryingmolarity,thebrick specimens areprepared andcuredatanelevatedtemperatureof60^{0}C inanovenfor24hours
7 These specimensaretestedforphysicaland durable tests
8 Fromthetest results,optimumratioandoptimum molaritywereobtained
9 By keeping the above optimum ratios constant, the specimens are prepared for the various ratiosof NaOH to$Na_2SiO_3$with a variation of 0.5, andthese specimens are cured at an elevated temperature of 60^{0}Cin an ovenfor24hours
10 These specimensare testedforphysicaland durable tests
11 From all the optimum values obtained from the above results, the specimens are prepared and cured in an ovenfor varying temperatures from 60^{0}C to 120^{0}C with temperature variation of 10^{0}C andspecimens are tested forphysicalanddurabletests
12 From all the tests, optimum mix ratio, molarity, NaOH toNa_2SiO_3 ratioand oven curing temperature isobtainedforthepreparationoflaterite-based geopolymerbricksis obtained

MixRatios
Table3:- Variousmixratios.

Mix	**LateriteSoil**	**StoneDust**	**FlyAsh**
Mix-1	100	0	0
Mix-2	90	0	10
Mix-3	80	10	10
Mix-4	70	20	10
Mix-5	60	30	10
Mix-6	50	40	10
Mix-7	40	50	10

Theabovemixratioinpercentagebyweightisadoptedforvaryingmixratiooptimization

E. AlkaliActivatorRatio
Table 4:-VariousratiosofNaOHtoNa_2SiO_3.

Ratio	**NaOH**	**Na_2SiO_3**
Ratio-1	1	1
Ratio-2	1	1.5
Ratio-3	1	2
Ratio-4	1	2.5

F. Preparationofbrickspecimens
Thelaterite soil, stone dust and fly ash are dry mixed for the various mix ratiosand geopolymer of requiredmolaritiesand ratios isaddedin the range of16 to 18% with total weightuntil achieve good workabilityandthis mixisfilledin3 layers withproper tamping until the voids are cleared in thebrick mold of size(230mmx110mmx80mm) adleftfor a day to achieve green strength and demoluded after 24 hours and cured inoven.

Figure5:-Brick Specimens.

G. TestsonSpecimens

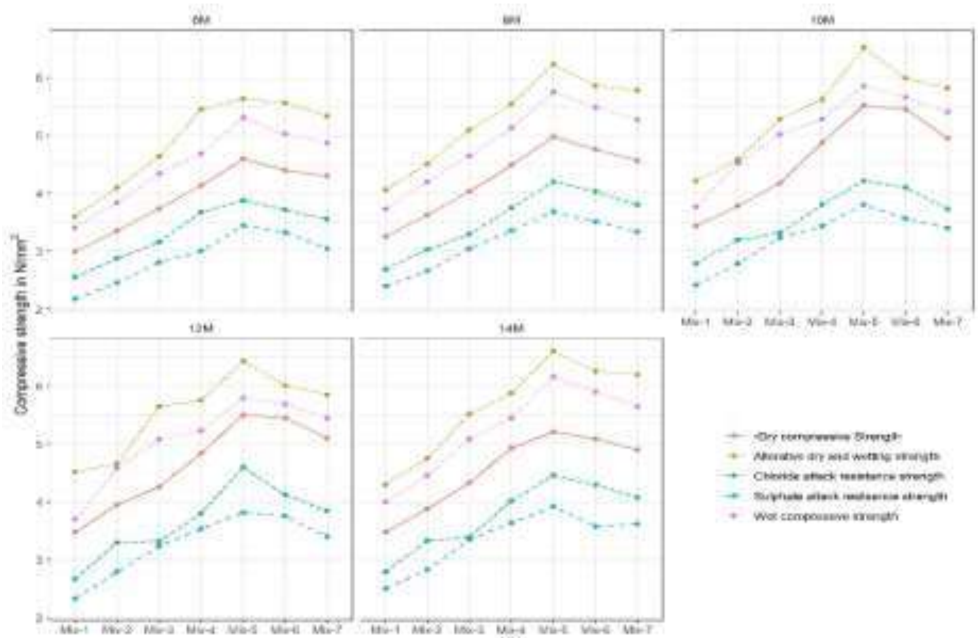
Thebrickspecimensaretestedincompressivetestingmachineattherateofloading4kN/minforthefollowingparameters.

1. DrycompressiveStrength
2. Wet compressivestrength
3. Alterative dryand wetting strength
4. Sulphateattackresistancestrength
5. Chlorideattackresistancestrength

ResultsandDiscussions:-

Theresultsofbrickspecimensofvariousmixratiospreparedbyvariousmolarityof NaOHbykeepingthealkaliactivatorratio1:2.5cure dinovenfor24hoursat60^{0}C are showningraph.1

Here it's observed that compressive strength increased along with increase in the molarity of the hydroxide solutionbutsignificantlyincreasedfrom6to 8MofNaOHand verymarginalincreaseinthefurtherincreaseofthemolarityand 8M canbeoptimizedfromthese observations.



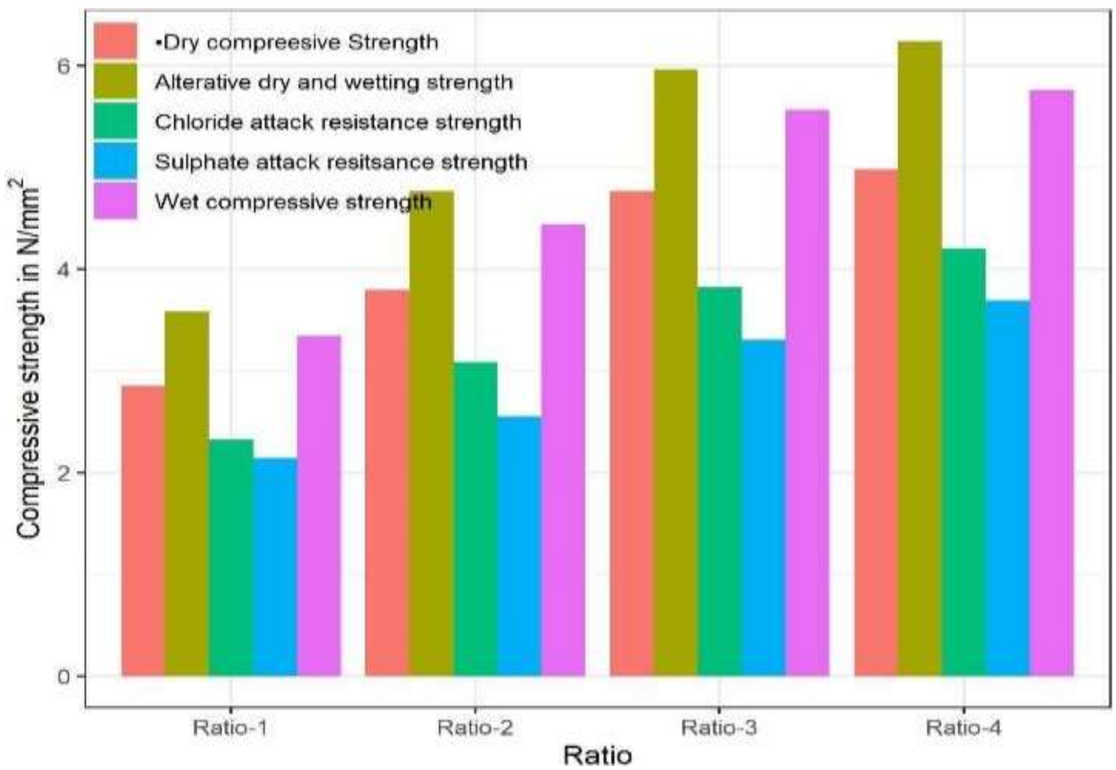
Graph.1:-Compressivestrengthresultsofvariousmixratios.

From thegraph.1 it also observed thatforall the various molarities,mix 5 performed betterwhich istabulatedintable.5.

The compressive strength after alterative dry and wet has increased between 22 to 25% in comparative with drycompression strength afteroven curing because of the removal of leaching due to wetting and drying whichincreases the strength (Preethi & Venkatarama Reddy, 2020). The strength of the brick is reduced by 20 to 25%during the sulphate and chloride resistance test in comparative to dry compressive strength. From all these results 8MNaOH andmix5is consideredforthefurtherstudies.

Table 5:-CompressivestrengthinN/mm^{2}formix5.

Molarity	**Dry**	**Wet**	**Alternativedryandwet**	**SulphateResistance**	**Chlorideresistance**
6M	4.6	5.31	5.64	3.45	3.88
8M	4.98	5.76	6.23	3.69	4.2
10M	5.52	5.86	6.52	3.81	4.22
12M	5.5	5.79	6.43	3.82	4.6
14M	5.21	6.16	6.61	3.92	4.46

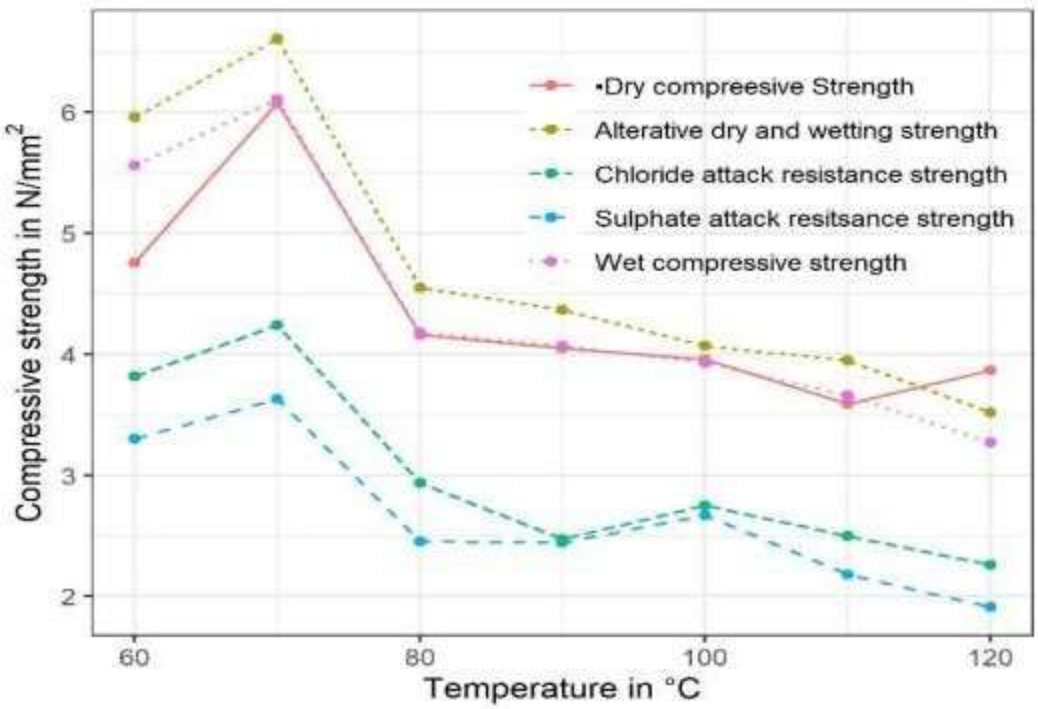


Graph.2:- Compressive strengthresultsofvariousAlkaliactivatorratio.

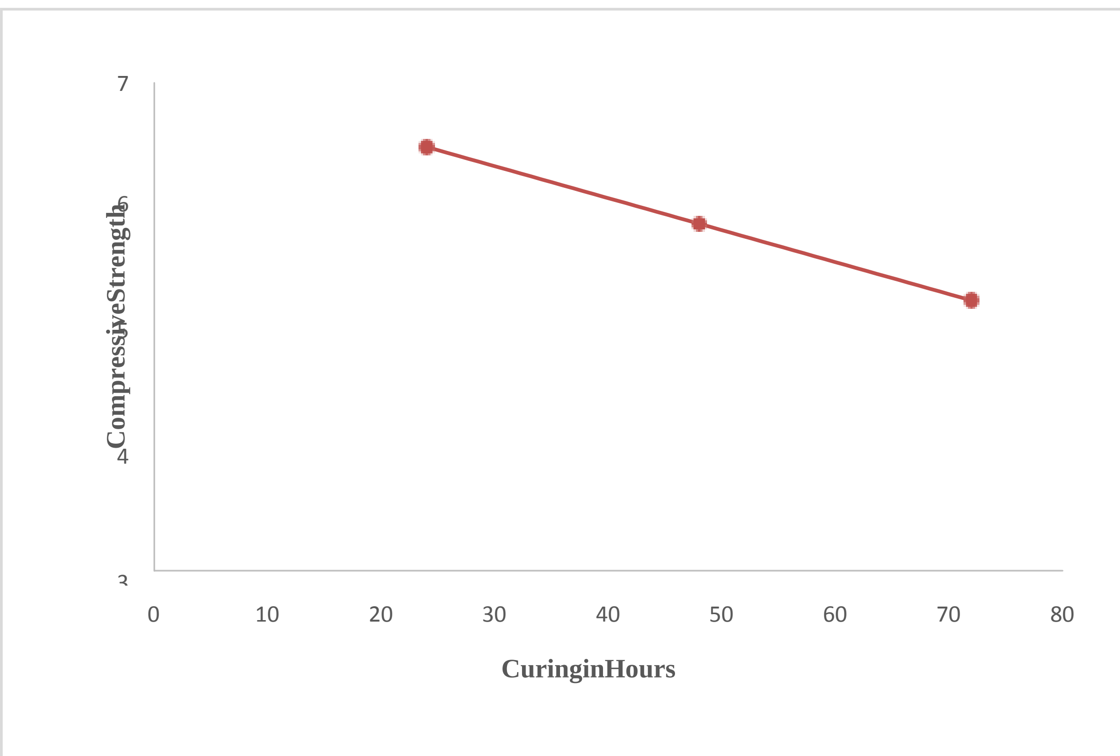
For the mix 5 by keeping the molarity of hydroxide solution 8M constant, the alkali activator ratio has been variedfrom 1:1 to 1:2.5 with 0.5 increment as represented in table.4. These specimens are cured in oven at 600C for 24hoursandtestedforvariousparametersofcompressivestrengthandresultsaretabulatedingraph.2.

Herewecanobservethatstrengthofspecimenis increasedwithincreaseinthealkaliactivatorratiofrom1:1to1:2.5but there is a very marginal increase in between the 1:2 to 1:2.5 so 1:2 is considered as optimum since all thecompressive valuesarewithininthe permissiblelimit.

Further by considering the mix5, 8M hydroxide solution and ratio 3 the specimens are casted and cured in oven for24hoursatvaryingelevationtemperaturefrom600C to1200C withanvariationof100Candcompressivestrength ofthespecimensaretestedforvariousparametersandobservedthatincreaseinthecompressivestrengthup to700Candfurtherstrengthisreducedwithincrease inthetemperatureasshowningraph.3



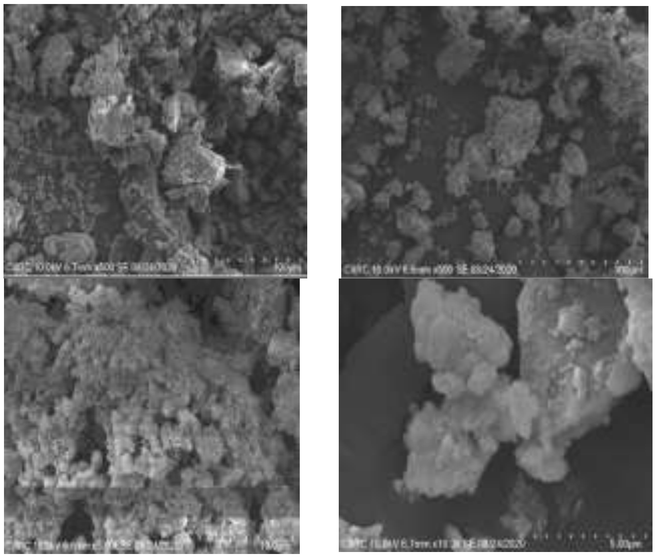
Graph.3:-Compressive strengthresultsofvarying ovencuring temperature.



Graph.4:-.Compressive strengthresultsofspecimensubjected tovaryinghoursofcuringinovenat70^{0}C.

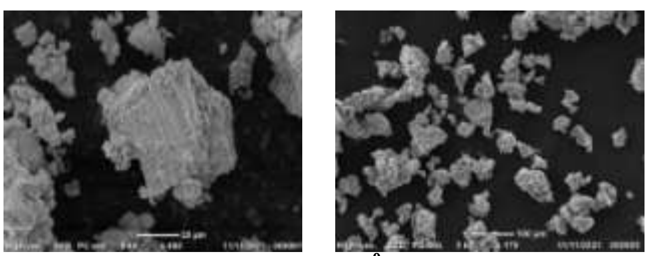
Further specimens cured in oven at 70^0C for 24, 48, 72 hours are shown the decrease in the strength with increase inthe number of days of curing in oven. SEM pictures shown in figure 6 showsagglomeration of laterite soil, stonedustandflyash.

H. Ratio-1 *Ratio-2*



Ratio-3 **Ratio-4**

I. Figure6.SEMPatternofspecimenafterfailureforvarious alkaliactivatorratio



60^0C ovenCuring **120^0CovenCuring**

J. Figure7.SEMPatternofspecimenafterfailureforvaryingcuringtemperature hoursatvaryingtemperature

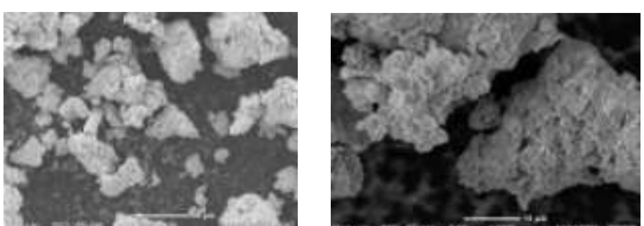


Figure8.SEMPatternof specimenafterfailureforovencuringat70^0Cfor72hours

Conclusions:-

1. Laterite soilis heavy materialwithaspecific gravityof2.64
2. Theratiomix5(60:30:10),lateritesoil, stonedustandflyashrespectivelyhasgivenbetterstrengthinallthe strengthanddurableparameters aspectwithadrycompressivestrengthof4.98Mpa.
3. Thecompressivestrengthhasbeenincreasedwithanincrementof8.26%,10.84%for8Mand10MNaOH respectivelyandfurtherindicatedflatincrement.

4. Since with 8M NaOH and Mix 5 does not yield strength lesser than 3.5Mpa in any strength parameter, these valuesareconsideredas optimum.
5. Forvarious alkali ratio, there was an increase in strength with an increment of 33%, 25.559%, 4.6% for ratio 2, ratio3andratio4respectively. ratio3isconsideredasoptimumsincethereisnoconsiderableincrementin ratio4.
6. In elevated curing, strength has been increased by 27.737% from 600C to 700C and for further increase in the temperature strength has been reduced, so700C elevated curing can be considered as optimum for lateritebased geopolymercomposites.
7. Further specimens are cured at 700C for 48 and 72 hours which decreased the strength upto 36%. Hence 24 hourscuringatelevatedtemperaturecanbe consideredasoptimum.

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