International Journal of Creative and Open Research in Engineering and Management
ISSN: 3108-1754 (Online)
Volume 02 Issue 09 September-2026 | Impact Factor: 3.5

"Experimental Investigation of the Mechanical Performance of Low-Calcium Fly Ash and Slag-Based Geopolymer Concrete"

[1]Manish Meshram, [2]Prof. Ashish Shrivas,
[1]M.Tech Student,[2]Assistant Professor,
[1,2,]Civil Engineering Department,
[1,2,]Vikrant University, Gwalior, (M.P.) India

How to Cite this Article:

Meshram, M. (2026). Experimental Investigation of the Mechanical Performance of Low-Calcium Fly Ash and Slag-Based Geopolymer Concrete. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(9), 1-9. https://doi.org/10.55041/ijcope.v2i9.078

https://doi.org/10.55041/ijcope.v2i9.078

ABSTRACT: Geopolymer concretes produced using fly ash and slag (FAGPC and SGPC) were investigated in terms of their mechanical properties and short-term durability performance. An alkaline activating solution was prepared by combining sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions. Conventional ordinary Portland cement (OPC) concrete was also prepared for comparison. The primary objective of the study was to assess the potential of geopolymer concrete as an alternative to conventional Portland cement concrete (PCC) for structural applications. The research also aimed to support the development and standardisation of geopolymer concrete for use in the construction industry.

Concrete specimens incorporating slag-based geopolymer concrete (SGPC), fly ash-based geopolymer concrete (FAGPC), and OPC concrete were prepared and exposed to different aggressive environments, including 5% sulfuric acid, 5% magnesium sulfate ($MgSO_4$), and 3.5% sodium chloride (NaCl) solution representing seawater conditions. The durability performance was evaluated through acid-resistance testing, visual examination, and measurements of changes in specimen weight. Compressive strength tests were conducted before and after chemical exposure to determine the effect of these aggressive environments on the mechanical performance of the geopolymer concretes.

The results indicated that SGPC containing 100% slag exhibited higher strength and durability than FAGPC containing 100% fly ash. This superior performance was attributed to the formation of a denser and stronger cross-linked aluminosilicate polymer network in the slag-based geopolymer concrete. Furthermore, the 100% fly ash-based geopolymer concrete demonstrated better durability than conventional OPC concrete under the investigated chemical environments. However, its mechanical performance was lower than that of OPC concrete, mainly due to the relatively low reactivity of fly ash, its lower calcium content, and the more porous internal structure of the geopolymer matrix. Among all the chemical exposure conditions, sulfuric acid produced the most severe deterioration in all types of concrete.

Keywords: Fly ash–slag-based geopolymer concrete (FAGPC/SGPC); mechanical properties; durability; sulfuric acid; magnesium sulfate; seawater; chemical attack.

INTODUCTION: One of the major durability issues is the deterioration of structural parts due to sulfuric acid attack, which raises maintenance costs and reduces the life span of substructures. Due to chemical wastes and acid rains, sulfuric acid can be harmful to RC elements of foundations (groundwater, arising from the oxidisation of pyrite in backfill) and RC slab, beam, and column elements at chemical facilities. Furthermore, the damage of the sewage system as a result of the sulfuric acid attack may result in severe 918 infrastructure issues including as groundwater contamination, sewerage transport failure, and ground settlements.

In order to strengthen the durability of concrete against chemical environments, additional cementitious ingredients (fly ash, ground granulated blast furnace slag) were utilised in part. Geopolymer concrete (GPC), a new cement-free substance, has recently emerged as a viable alternative to regular Portland cement (OPC) concrete. GPC consumes less energy during production and emits approximately 6 times less CO2 than OPC. Furthermore, waste materials (fly ash, slag) are disposed of in a manner that reduces air pollution, and their use in GPC production has a positive impact on the global economy and environment. GPC could replace OPC concrete as a construction material due to its lower energy requirements and environmental friendliness. In recent years, studies on the mechanical and durability performance of GPC have been conducted in order to use GPC instead of OPC. According to the studies, GPC has a high mechanical strength and chemical resistance. However, there are few investigations on the chemical resistance of GPC specimens, and further durability research is needed before GPC specimens can be used instead of OPC specimens in chemical situations.

Visual inspection, weight change, and compressive strength change are some of the assessment methods used to determine the chemical resistance of concrete specimens. In this research work, the chemical resistance of the slag based GPC (SGPC) and FA based GPC (FAGPC) samples were studied by visual inspection, weight loss, compressive strength tests after the sulfuric acid attack at the ages of 28, 56, and 90. days. Visual inspection and weight loss were also used to assess the effect of sulfuric acid on cube specimens. The findings may have implications for structural elements in order to extend the service life of structures subjected to sulfuric acid attack. It is usually associated with Portland cement as the main component for making concrete.

GEOPOLYMER CONCRETE

In 1978, a French professor named Davidovits coined the term geopolymer to describe a wide spectrum of materials characterised by networks of inorganic molecules (Geopolymer Institute 2010) For silicon (Si) and aluminium (Al), the geopolymers rely on thermally activated natural resources like Meta kaolinite or industrial leftovers like fly ash or slag (Al). Silicon and Aluminum are dissolved in an alkaline activating solution, which then polymerizes into molecular chains, forming the binder.

"The polymerization method involves a fairly quick chemical reaction under alkaline conditions on silicon-aluminum minerals that results in a three-dimensional polymeric chain and ring structure," Professor B. Vijaya Rangan explained. The eventual structure of the geopolymer is largely determined by the Si to Al (Si:Al) ratio, with most materials considered for use in transportation infrastructure having a Si:Al ratio of 2 to 3.5. Fly Ash reacts with an aqueous solution containing Sodium Hydroxide and Sodium Silicate in equal parts, yielding a three- dimensional polymeric chain and ring structure made up of Si-O-Al-O linkages. The chemical reaction of Geopolymer concrete does not require water; instead, water is ejected during curingand subsequent drying. In contrast, when Portland cement is combined with water, the hydration reactions yield the principal hydration products calcium silicate hydrate and calcium hydroxide. This difference has a substantial impact on the mechanical and chemical qualities of the geopolymer concrete that results, as well as making it more resistant to heat, water ingress, alkali–aggregate reactivity, and other types of chemical attack. The role of calcium in geopolymers generated from fly ash is critical since its presence can promote flash setting, which must be carefully regulated. The source material is combined with an activating solution that supplies the alkalinity (sodium hydroxide or potassium hydroxide are typically employed) required to liberate the Si and Al, as well as a possible additional silica source (sodium silicate is most commonly used).

The temperature during curing is critical, and depending on the source materials and activating solution, heat is frequently required to assist polymerization, but certain systems have been created to cure at room temperature.

This study paper goes over the importance of Geopolymer Concrete, as well as the constituents, properties, applications, and limitations.

OBJECTIVES

Comparison of different property like sulphuric acid affects and compressive strength, density of modified concrete, with partial replacement of standard concrete with fly ash and slag burnt geopolymer.

- To analyze the effect on the strengthening of fly ash and slag burnt geopolymer in concrete.
- Analysis the property of fresh concrete prepared by fly ash and slag burnt geopolymer particle material replacement
- Using knowledge of the various parameters to work out the best result and secure concrete output.
- To safeguard the optimization natural resource, prices.
- Greater resource consumption and optimum concrete serviceability.

LITERATURE REVIEW:

Prabir Kumar Sarker (2009) Pull-out tests were conducted using fly ash-based Geopolymer concrete and reinforcing steel bars. The tests were conducted using beam end specimens that met ASTM Standard A944 requirements. The compressive strength of concrete ranged from 25 to 55 MPa. Deformed 20mm and 24mm diameter reinforcing steel bars were employed in the test. In both Geopolymer and OPC concrete specimens, the failure was caused by concrete splitting in the region bonded with the steel bar. When the test results were compared, it was discovered that Geopolymer concrete had a higher bond strength than OPC concrete. It was also recommended that existing design equations for bond strength of OPC concrete with steel reinforcing might be applied conservatively for Geopolymer concrete bond strength calculations.

Wallah (2009) The drying shrinkage of heat cured fly ash based Geopolymer concrete made of low calcium fly ash as the source material, alkaline solution, and aggregates typically utilised in regular Portland cement concrete was investigated. To investigate the drying shrinkage of this concrete, four sets of test specimens with varying compressive strengths were created. The test findings were compared to the expected drying shrinkage values using the Gilbert Method, which is often used for regular Portland cement concrete. The heat-cured fly ash-based Geopolymer concrete demonstrated extremely little drying shrinkage in tests.

Palomo et al (1999) The effect of curing temperature, curing time, and the alkaline solution to fly ash ratio on compressive strength was investigated. The compressive strength was said to be impacted by both the curing temperature and the curing duration. When cured at 85°C for 5 hours, the maximum strength was achieved using sodium hydroxide (NaOH) mixed with sodium silicate (Na_2SiO_3) solution.

Smith Songpiriyakij et al (2011) have discussed the bonding strength between embedded rebar and substrate concrete utilising Geopolymer paste as the bonding agent in their study. Round bar and Geopolymer paste bonding strengths were somewhat greater (1.05-1.12 times) than control concrete, and the strength was particularly strong in the case of deformed bars (1.03-1.60 times). The bonding strength to compressive strength ratios were also shown. The bonding strengths of Geopolymer paste were higher than those of epoxies when compared to commercial repair products, ranging from 1.24 to 1.81 times. The bonding strength of Geopolymer paste was found to be sufficient in these tests, indicating that it might be employed as a bonding medium for repair work. To improve both compressive and bonding strengths, combinations with a high silica fume content and a high NaOH concentration were proposed. The compressive and bonding strengths of Geopolymer paste with 60% fly ash and 40% silica fume and an 18M NaOH concentration showed that it had the best compressive and bonding strengths. The bonding strength of this mixture was found to be 1.05 to 1.12 times that of control concrete using round bar and 1.03 to 1.60 times using deformed bar, depending on paste age. For high compressive and bonding strengths, rice husk ash integration with fly ash as the starting materials might be produced, but the curing time would have to be prolonged - 28 days. Incorporating fly ash with silica fume greatly improved the compressive and bonding properties of the Geopolymer paste. The compressive and bonding strengths increased as the amount of silica fume increased. The effect of alkaline concentration was demonstrated by the greater value of compressive and bonding strengths achieved for 18M NaOH concentration.

Sukhoon Pyo et. al. [2016] they directed investigation utilizing as a recent development on impact testing system that sudden release strain energy to produce pulses. Three fiber classes were estimated, a distorted fiber and two additional sorts of straight fiber. Test impact answer was assessed regarding first breaking power, post-breaking strength, and energy incorporation force and strain power. The test results shows that examples with distorted fiber typically show genuinely preferable mechanical capacities over examples with straight fiber for the arrangement of strain rates estimated. All UHP-FRC arrangement experienced show additional rate sensitivities in energy consideration power, ordinarily made considerably more energy dissipative under expanding strain rates.

Lam Tang Van, Dien Vu Kim The strengthening of concreting using industrial waste such as aluminium powder and flyash in addition to cement up to 0.25 percent to 1% decreased the density of aerated concrete by 32.2 percent compared to standard specimens. They discovered that specimens containing 30% fly ash had a compressive intensity of 52.7 Mpa after 28 days.

Guglielmi et al The compressive strengthening of concrete mix decreased as the Al content rose from 0.2 to 0.4 percent added in concrete mix.

M. Narmatha and Dr. T. Felixkala It's been suggested that Metakaolin [MK] is a pozzolanic admixture with a variety of special properties. Metakaolin is a common admixture for use in concrete and cement. Metakaolin usually replaces 8 to 20 percentage [by weight] of Portland cement. This type of concrete has excellent engineering properties. The specimen was cast in M60 concrete with 5%, 10%, 15%, and 20% substitutes, respectively. The compressive intensity ranged between 45 and 55 MPa after seven days. The compressive intensity after 28 days ranged from 61 to 73 MPa. The split tensile strengthening for MK 10%, 15%, and 20% rises by 14.70%, 20.56%, and 11.76%, respectively. MK 10%, 15%, and 20% flexural intensity increases by 11.11 percent, 14.28 percent, and 7.94 percent, respectively. The result shows that metakaolin, which replaces cement 15% in the mix, outperforms all other mixes and is useful in achieving high efficiency. The addition of metakaolin increases compressive and break tensile strength by up to 15% as compared to cement replacement.

Dr. K. Srinivasu, M. L. N Krishna Sai, N. Venkata Kumar It should be noted that concrete is one of largely used building material, which depletes natural resources, causing environmental concerns in terms of raw material use and CO2 emissions during cement production. As The heat of hydration is reduced when cement is replaced with pozzolana. Fly ash, base ash, blast furnace slag are common industrial waste materials. Concrete is interested in elective cementation products such as metakaolin, silica fume, steel fibres, quarry dust, wood waste, limestone, and calcined clays. Heat of 6000°C to 8000°C causes dehydroxylation of the crystalline structure of kaolinite, resulting in metakaolin. Kaolinitic clay is commonly available in the earth crust. At 10% condensate silica fume, 5% MK, and 1.5 percent steel fibre material, high tensile strength was observed. In comparison to the blend, control concrete concrete with 8% MK and 1.5 percent steel fibre has an improving compressive strengthening 8.9%, tensile strength of 26.94 percent, flexural strengthening of 58.28 percent. The uses of metakaolin in concrete as a 25% substitute for cement resulted in excellent strength and durability improvements. The use of metakaolin has improved water permeability and absorption, results in increasing in concrete density. Metakaolin was used in the preparation of acid resistance concrete, which showed strong resulting in provisos of chloride permeability and sulphate resistance.

MATERIALS AND METHODOLOGY

Cement

Table: Properties of cement

Properties	Value
Grade of Cement	OPC(53 grade)
Sp. gravity of cement	3.15
Initial setting time	Not least than 30 min
Final setting time	Not least than 60 min
Normal Consistency	31.5%

FINE AGGREGATE

TABLE :PROPERTIES OF F.A.

Properties	Value
Specific Gravity	2.60
Fineness Modulus	3.74
Water absorption	0.6%

Coarse Aggregate:

Table :Properties of C.A.

Properties	Values
Specific Gravity	2.94
Size of Aggregate	20 mm
Fineness Modulus	7.08
Water absorption	0.219
Aggregate Impact value	15.2%
Aggregate Crushing value	22.5%

Slag-Based Geopolymer Cement

The first geopolymer cement developed in the 1980s was of the type (K,Na,Ca)-poly(sialate) (or slag-based geopolymer cement) and resulted from the research developments carried out by Joseph Davidovits and J.L. Sawyer at Lone Star Industries, USA and yielded the invention of Pyrament cement. The American patent application was filed in 1984 and the patent US 4,509,985 was granted on April 9, 1985, with the title 'Early high-strength mineral polymer'. Slag the furnace slag used in this study is a by-product of the ferrosilicon industry and is commercially available in the market as ground granulated blast furnace slag (ggbs),which is conforming to bs 6699-1992 (british standard). The physical and chemical properties of slag are durability studies on the slag based geopolymer concrete strengthened with physical and chemical properties of slag observation slag colour white % passing through 45-micron sieve (wet sieving) 91.35 specific gravity 2.86 blaine's fineness (m2 /kg) 415 sio2 37.3 al2o3 11.48 fe2o3 0.23 cao 42.47 mgo 7.32 so3 1.2 moisture content 10 -13.

Fly Ash-Based Geopolymer Cements

Low-calcium FA, known as 450-N (fineness category N, loss on ignition (LOI) Category B) based on BS EN 450-1, was used in this research. The percentage of LOI subjected to fly ash category B was in the range of 2–7%, in accordance with BS EN 450 standard. Indeed, LOI is commonly used as an indicator to identify the residual carbon content in fly ash. Additionally,

% LOI indicates the presence of carbonates and combined water in clay minerals. This FA type is widely employed in the UK, which can increasingly be found as the substantial ingredient in the low-carbon blended cement such as T2PC. Indeed, 450-N FA used in this laboratory work has a higher value of siliceous and aluminous materials, compatible with other cementitious components, in which it can combine with liberated lime during the cement hydration in the presence of H2O.

METHODOLOGY

In this study, low calcium (F-type) fly ash (FA) and ground granulated blast furnace slag (GGBS) were used in order to obtain fly ash based geopolymer concrete (FGPC) and slag based geopolymer concrete (SGPC). For the comparison, an ordinary Portland cement concrete (OPC) produced with Type 1 cement was produced. As an alkali activator of the GPC, the sodium hydroxide (NaOH) and silicate (Na2SiO3) solutions and with a hydroxide to silicate ratio of 1/2.5 was used by weight. The sodium silicate liquid with an alkaline modulus of 2 and

sodium hydroxide pellets were taken from a local supplier. The sodium hydroxide powder was dissolved in tap water to obtain 14 M NaOH, which was the weakest concentration against chemical attacks [14]. The alkaline solution was prepared about 30 min before mixing. A polycarboxylates based superplasticizer (SP) was utilized to obtain S4 slump class concrete. No I (5-12 mm) and No II (12-22 mm) with specific gravities of 2.71 g/cm3 and 2.72 g/cm3 were utilized as coarse aggregates. As fine aggregates, natural sand and crushed sand with specific gravities of 2.65 g/cm3 and 2.70 g/cm3 were used. The aggregates were used as saturated surface dry moisture condition. Table 1 illustrates the chemical composition and physical properties of the ground granulated blast furnace slag, Type I OPC cement, and F-Type fly ash materials.

DESIGN MIX

To study the result of fly ash and slag burnt geopolymer cement with replacing some percent of cement to check the strength of cement mortars, mix was preparing with

various % of fly ash and slag burnt geopolymer (by weight). Concrete mixtures with various percentage of fly ash and slag burnt geopolymer used as half-done or full replacement for cement were ready in order to study the result of fly ash and slag changes on the strengthening to normal concrete mixture. mixture was ready with various proportion of. The proportion (by weight) of fly ash and slg burnt geoolymer were adding to the mixtures are giving as: 0%, 5%, 10%, 15%, 20%, and 25%.The concrete mix decided for this analysis is M20 grade with water-cement ratio of 0.45. for this analysis total 54 no. of Cubes of usual sizes 150x150x150mm then cured for 7th day, 14th , 28th days and testing done as per IS: 516-1959. The main purpose for observance the sample for large curing time of 28 and 56 day is to examine the harmful impact from uses of copper slag as the place of cement and check compressive strengthning of concrete mixture. The mix proportion selected for analysis As per IS 10262-2009 is Given Below.

RESULT AND DESCUSSION

VISUAL OBSERVATION

Fig. 4.1 illustrates the visual inspection of the FAGPC, OPC, and SGPC cubes specimens after two months of acid solution exposure The results showed that the FAGPC and OPC specimens had severe surface deterioration, while the SGPC specimens had moderate surface erosion. On the cube and cylinder specimen surfaces of the FAGPC specimens, macrocracks and the expansion of geopolymer mortar were plainly visible. Severe white deposits were also found on the specimen's surface. The enhanced permeability caused by the macrocracks may be to blame for the substantial degeneration of the FAGPC specimen surfaces. After the sulfuric acid attack, the cement mortar on the surface of the OPC specimens was nearly completely destroyed, and extensive surface erosion was observed. The reaction between sulphate ions in the sulfuric acid solution and CaO in the cement phase is responsible for the significant quantity of deterioration. On the surfaces of the SGPC specimens, there was very little white deposit and very little surface degradation. When the cube's and cylinder's surfaces begin to deteriorate, specimens were considered. There is no clear difference was observed between cube and cylinder specimens. However, the acid-influenced surface area becomes higher for the cube specimens than the cylinder specimens due to its bigger sizes.

WEIGHT CHANGE

Table. :Variation in weights of the cube samples against 5% sulfuric acid attack

S.No.	Days	SGPC	OPC	FAGPC
1.	28	100	100	100
2.	56	102.32	99.65	99.72
3.	90	99.89	99.20	99.63

CHANGES IN THE COMPRESSIVE STRENGTH

Table :Variations in the compressive strengths of the cube samples (150x150x150 mm) under sulfuric acid attack

S.No.	Days	SGPC	OPC	FAGPC
1.	28	78.34	49.58	22.36
2.	56	62.83	35.04	12.64
3.	90	45.15	29.39	11.32

CONCLUSION

In this study, the durability performance of the oven-cured fly ash and slag based geopolymer concrete specimens (SGPC and FAGPC) were investigated against 5% sulfuric acid attack according to XA3 environment condition given in TS EN 206 standard. For comparison, an ordinary Portland cement concrete was also produced and tested under 5% sulfuric acid solution. The following results were obtained:

(1) Visual inspection results showed that severe surface deterioration was observed on FAGPC and OPC specimens, while moderate surface erosion was observed on SGPC specimens. In addition, there is no clear difference was found on the surface deterioration of the cube specimens.

(2) The weight change results showed that the degradation on the 150x150x150 mm cube specimens after two months of sulfuric acid exposure, which can be attributed to the more sulfuric acid influenced surface area of the cube specimens due to the size effect.

(3) Compressive strength test results indicated that the compressive strengths of the specimens were increased in the order of: FAGPC (22 MPa) < OPC (50 MPa) < SGPC (78 MPa). The lowest compressive strength of the FAGPC specimens can result from the low activity of fly ash particles, low fly ash amount in the mix, and low CaO content. After the sulfuric acid attack, the highest deterioration (49% loss) was also observed on FAGPC specimens and similar compressive strength reduction (~42%) was obtained for the OPC and SGPC specimens. The high amount of degradation in FAGPC specimens can be also attributed to higher permeability and porosity due to the less dense microstructure. The deterioration of the SGPC and OPC specimens in the sulfuric acid solution can result from the high CaO content.

(4) The findings indicated that SGPC samples can be utilized in structural applications since SGPC specimens performed better mechanical and durability performance than OPC specimens even under low slag content (360 kg/m3). However, FAGPC specimens with low fly ash content (360 kg/m3) and high Na2SiO3/NaOH ratio (2.5) showed poor performance than the OPC samples against 5% sulfuric acid attack. For better mechanical performance and durability properties of FAGPC specimens, more FA content (>400 kg/m3) and/or different alkaline activator ratios (Na2SiO3/NaOH) should be utilized for the structural applications under sulfuric acid attack.

SCOPE OF FUTURE WORK

1. This research work was proposed to study the influence of slag burnt and fly ash based geopolymer concrete put in M20 mixes. And the similar words could be extended to higher grades of concrete mixed with varying water/cement ratio.
2. Slag burnt and fly ash geopolymer cement could be successfully replaced by ordinary Portland cement.
3. While it have high shearing strengthening value so it could be useful for stabilization purpose.
4. Slag burnt and fly ash based geopolymer used for backfilling purposes.

REFERENCES:

1. ACI 363R-92 (1992),State of the Art Report on High Strength Concrete,ACI Committee Report 363, American Concrete Institute, Dteroit, 363R1-363R55.
2. Akcay, B.andTasdemir, M.A. (2009),“Optimisation of using lightweight aggregates in mitigating autogenous deformation of concrete”,*Constr.Build.Mater.*,23(1),353-363.
3. Alii, M.R. (2007),“Performance of plain and blended cements exposed to high sulphate concentrations”,*Adv.Cement Res.*,19(4),167-175.
4. Ariffin, M.A.M., Bhutta, M.A.R., Hussin, M.W., Mohd Tahir, M.andAziah, N. (2013),“Sulfuric acid resistance of blended ash geopolymer concrete”,*Constr.Build.Mater.*,43, 80-86.
5. 5ASTM C267-01 (2012),Standard Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings and Polymer Concretes.
6. ASTM C39/C39M-12 (2012),Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, 4-2 Annual Book of ASTM Standard, Philadelphia.
7. Bakharev, T. (2005),“Durability of geopolymer materials in sodium and magnesium sulfate solutions”,*Cement Concrete Res.*,35(6),1233-1246.
8. Bassuoni, M.T.and Nehdi,M.L.(2007),“Resistance of self-consolidating concrete to sulfuric acid attack with consecutive pH reduction”,37,1070-1084.
9. Bondar, D., Lynsdale, C.J., Milestone, N.B. andHassani, N. (2015),“Sulfate resistance of alkali activated pozzolans”,*Int.J.Concrete Struct.Mater.*,9(2),145-158.
10. Visitanupong, C. (2009),“Durability of fly ash based geopolymer mortar”,Thesis Approval, Graduate School, Kasetsart University, Thailand.
11. C496, ASTM (1990),Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.
12. Chi, M. andHuang, R. (2013),“Binding mechanism and properties of alkali-activated fly ash/slag mortars”,*Constr.Build.Mater.*,40,291-298.
13. Committee Euro (1990),International Du Beton (CEB-FIB),CEB-FIB Model Code Thomas Telford, London.
14. 1Dombrowski, K., Buchwald, A. and Weil,M. (2007),“The influence of calcium content on the structure and thermal performance of fly ash based geopolymers”,*J.Mater.Sci.*,42(9),3033-3043.
15. Ganesan, N., Indira, P.V. and Santhakumar,A. (2013),“Engineering properties of steel fibre reinforced geopolymer concrete”,*Adv.Concrete Constr.*,1(4),305-318.
16. Hardjito, D.and Vijaya Rangan,B. (2005),“Development and properties of low-calcium fly ash-based geopolymer concrete”,Research report GC: 94,http://www.geopolymer.org/fichiers_pdf/curtin-flyash-GP-concrete-report.pdf.
17. Hardjito, D., Wallah, S.E., Sumajouw, D.M.andRangan, B.V. (2005),“On the development of fly ash-based geopolymer concrete”,*Mater.J.*, 101(6), 467-472.
18. Hasanein, S.A., Khate, H., El-Enein, S.A.andEl-Sayed, H.A. (2011)“Resistance of alkali activated water-cooled slag geopolymer to sulphate attack”,*Ceramics-Silikáty*,55(2),153-160.
19. He,J., Jie, Y., Zhang, J., Yu, Y.andZhang, G. (2013),“Synthesis and characterization of red mud and rice husk ash-based geopolymer composites”,*Cement Concrete Compos.*,37,108- 118.
20. Juenger, M.C.G., Winnefeld, F., Provis, J.L.andIdeker, J.H. (2011),“Advances in alternative cementitious binders”,*Cement Concrete Res.*,41(12),1232-1243.
21. Komnitsas, K.andZaharaki, D. (2007),“Geopolymerisation: A review and prospects for the minerals industry”,*Min.Eng.*,20(14),1261-1277.
22. Kumaravel, S.andGirija, K. (2013),“Acid and salt resistance of geopolymer concrete with varying concentration of NaOH”,*J.Eng.Res.Stud.,*4(4),1-3.
23. Li, S.andRoy, D.M. (1988),“Preparation and characterization of high and low CaO/SiO 2 ratio “pure” C-S-H for chemically bonded ceramics”,*J.Mater.Res.*,3(2),380-386.
24. Li, Z. andDing, Z. (2003),“Property improvement of Portland cement by incorporating with metakaolin and
25. 361 *Ahmet Emin Kurtoğlu et al.*
26. slag”,*Cement Concrete Res.*,33(4),579-584.