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Original Research

A Study of Alkali-Activated Coatings Durability Assessment in Different Environments

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Abstract

Geopolymer concrete is an environment-friendly concrete that uses waste by-products from industries such as ground granulated blast furnace slag (GBFS) and fly ash as a substitution for cement in concrete. The African Buffalo Optimization (ABO) algorithm is utilized to select the proper mix. From the results of ABO, the paste and mortar type coating is prepared; the prepared mortar and paste type coating's compressive strength and setting time are measured. According to the outcomes, the alkali-activated material coatings based on fly ash and natural pozzolan (volcanic ash) with 1% and 5% acrylic emulsion P-2 and X-2 were selected and the M-2 mix is selected for paste-type coating. After the measurements, the concrete surface is coated with prepared mix coatings. The properties of geopolymer concrete with coatings such as compressive strength, adhesion strength, drying shrinkage, shear bond strength, chloride permeability, and capillary absorption of water were determined. From the results, the selected mix based on ABO gives higher strength and the durability was also high. It provides better strength, reduced shrinkage, water absorption, and chloride ion penetration than other techniques based on various polymeric additive coatings.

Keywords: fly ash, natural pozzolan, alkali-activated coating, geo polymer concrete, mechanical properties, durability

Introduction

In construction, the common and most used material is concrete. Nowadays, in structure design, durability was one of the vital characteristics [1]. The behavior of concrete in aggressive environments is determined by its durability and also it determines the resistance against chemical attack, weathering actions and other deterioration processes [2]. The durable concrete requires retaining its quality, functionality and shapes over its lifetime [3]. Attacks on concrete were made against cement paste, reinforcing steel, or aggregates depending on the environment [4]. The concretes were mainly damaged because of chloride ions/CO_2 (carbon dioxide) present in the environment [5]. A preventive coating is one of the technologies that are applied in concrete restoration and protection [6]. The coatings are categorized into inorganic and organic coatings; the objective of these coatings is to restrict the spread and entry of aggressive agents [7].

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For commercial purposes, the commonly used coating is organic coatings; it develops a physical barrier and prevents entry of aggressive agents [8].

The organic coating includes acrylic, polyester, vinyl, epoxy, polyurethane, and resin coatings [9]. From the hydrophobic polysiloxanes and silane products, the hydrophobic impregnation coating was created; which are also used in this coating [10]. However, it has the inability to emit the vapour pressure accumulation which shows delamination on concrete [11]. Compared to inorganic coating, the life cycle of organic coating is quite limited [12]. The most used organic and inorganic coating is shown in Fig. 1. Cementitious coatings are mostly used in inorganic coatings and it includes epoxy, acrylic and polyurethane [13]. Compared to polymer coatings, the UV resistance is high; it has excellent properties and is expensive [14]. The alkali-activated material (AAMs) is known as geopolymers and it is studied as inherent coatings on concrete, repair materials and metals in recent years [15]. The attractiveness of AAMs was based on the excellent properties in aggressive agent presence: temperature stability is high, low permeability, fire resistance and high resistance [16].

In engineering, AAMs has been developed for various applications; the most commonly studied application was binder material as an alternative to OPC (ordinary Portland cement) [17]. The maintenance and repairing of concrete structures in different environments are important topics in the field of civil engineering [18]. The chloride ions diffusion in concrete destroys the reinforcing steel passive layer and it starts the corrosion process [19]. This process results that, cause cracks on the concrete which leads to structure failure [20]. To reduce the cracks and structure failure, many methods were developed such as alkali-activated and cement-based coating, alkali-activated slag paste etc. But still, there is no significant solution for concrete failure and deterioration. Thus, the current research aimed to develop an alkali-activated coating on concrete with high durability. The concretes were deteriorated due to chloride ions. The chloride ion and CO_2 present in the environment create cracks and reduce the durability of concrete. The alkali-activated materials reduce the deterioration of concrete and steel corrosion. These issues have motivated this research towards concrete with geopolymer coatings in different environments. Some recent works of literature related to the geopolymer coatings are described below:

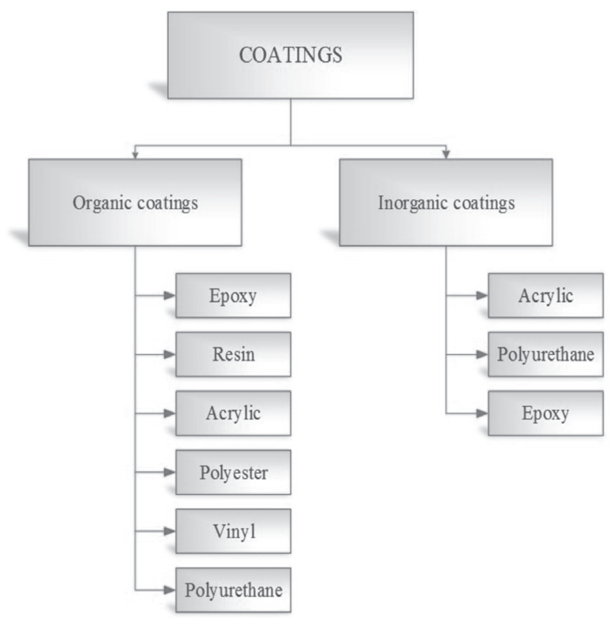

Fig. 1. Organic and inorganic coatings.

In concrete structures, to prevent the concrete from the intrusion of corrosive ion coatings was used as a practical solution. Lashkari et al. [21] have evaluated the effectiveness of utilizing geopolymer and cement-based coatings created using materials from the waste by-products. In alkali-activated mortars, the mixtures of sodium silicate, and potassium hydroxide (KOH) and sodium hydroxide (NaOH) were utilized. The durability analysis and mechanical properties were conducted for specimens. The results showed that cement mortars and geopolymer were increases the bonding and compressive strengths. However, the geopolymer mortar absorbs a high range of water.

The cement productions affect the environment which prompted the research through concrete development by 100% replacement of alkali solutions. Khan and Sarker [22] have investigated the properties of GGBFS mortar and alkali-activated using glass cullet waste. By increasing the porosity, sorptivity, chloride permeability and drying shrinkage were reduced. The result shows that the substitution of natural sand by waste glass offers more comparable properties. In addition, the concrete at elevated temperature losses its compressive strengths due to an increase in temperature.

Shariati et al. [23] have evaluated the effects of silica utilization and alkali activator on microstructural characteristics and durability of alkali-activated GGBFS pastes. The electrical resistivity, as well as final and initial absorption of water, was measured. As a result of comparison with unconditioned specimens, the compressive strength was increased by about 5-8%. Furthermore, after large exposure, the compressive strength of concrete was reduced drastically.

The structural performance of reinforced concrete was affected due to the high chloride environment and it was a major cause of reinforcing steel corrosion. Concrete can be protected by coating the surface to prevent aggressive substances from penetrating and reducing the lifespan of the material. Aguirre-Guerrero and de Gutierrez [24] have evaluated the inorganic coating's effectiveness on the concrete surface. The reinforcing steel corrosion resistance and concrete properties were evaluated. The result demonstrated that the alkali-activated material reduces the rate of corrosion. However, a more porous microstructure affects the structures potential capacity.

Zhang et al. [25] have studied the alkali-activated PVA fibre reinforced concretes self-healing properties. To identify, quantify and visualize the healing compounds nature many tests were conducted such as water sorptivity, optical microscopy etc. By increasing the calcium ions concentration and pH were improves the self-healing of cracks in AAS composites. Subsequently, the calcium carbonate present in concrete creates cracks on the surface.

The key contribution of the research is summarized as follows,

- The binary and hybrid materials were prepared to obtain alkali-activated coatings i.e. the natural pozzolan and GBFS (Granulated blast furnace slag) for binary materials and fly ash and OPC for hybrid material.
- The selected materials were mixed in defined mixture proportions of materials and the prepared geopolymer concretes are placed on cubes, cylinder and prism specimens.
- After placing the concrete, it was cured for 7 and 28 days to determine the geopolymer concrete optimum mix; the tests were conducted to evaluate the mechanical properties of geopolymer concrete are flexural, split tensile and compressive strength.
- After the testing of geopolymer concrete, it is coated with mixed paste coating and mortar coating with acrylic emulsion addition and the proportions of emulsions were optimized by the ABO algorithm from selected proportions.
- Then the coated concrete was cured for 7 and 28 days to test the mechanical properties of concrete with coatings like adhesion strength, compressive strength and shear bonding strength; and, the concrete was cured for 28 and 90 days to test chloride permeability, drying shrinkage and capillary water absorption in a different environment to determine the concrete durability compared with other geopolymer concrete.

Experimental Procedures

The materials which are utilized in this study and the mixed proportion are described in detail in this section. Furthermore, the alkali-activated coatings on the concrete surfaces and the chemical composition of materials are also explained.

Materials

The alkali-activated coating materials were identified using two different types of mortar coatings and one different type of paste coating. In this study, type 2 Portland cement is used and the chemical compositions of used materials are represented in Table 1. The reason to select type 2 Portland cement is because of its less thermal hydration and reasonable sulfate resistance. The chemical compositions of selected materials are evaluated by X-ray diffraction (XRD). Furthermore, the GBFS was used and it is commonly known to be slag, which was categorized as 80grade in the specifications of strength as per ASTM C989 [26]. The alkaline solutions were prepared by addition of NaOH (with the molarity of 8.75×10^{-3}mol), water glass (sodium silicate) and tap water (which is used for both mixing the polymer and preparation of NaOH solutions). For hybrid material, the mixture contained 10% OPC and 90% fly ash, while the binary material mixture contained 30% GBFS and 70% natural pozzolan. The ratio of sand to precursor was 2:1 by weight.

Table 1. Chemical composition of materials.

Sl. no	Composition	Materials (oxides weight percentage)			
		Ordinary Portland cement	Natural pozzolan	Fly ash	Ground granulated blast furnace slag
1	Al_2O_3	4.45	15.63	25.08	12.14
2	CaO	57.75	5.20	2.87	44.7
3	MgO	1.62	2.50	1.21	4.23
4	SO_3	2.34	-	1.16	0.84
5	SiO_2	19.24	61.79	58.23	32.25
6	Fe_2O_3	4.37	7.42	4.56	1.10
7	Na_2O	-	4.17	0.41	0.87
8	K_2O	-	1.60	0.87	-
9	Loss on ignition	9.79	0.47	1.59	1.98
10	Others	-	1.38	1.67	2.53
11	Molar ratio (SiO_2/Al_2O_3)	-	6.79	4.19	4.09

In the activator solution, additionally, an acrylic emulsion was used as an additive. The paste and mortar coatings mix proportions are tabled in Table 2; from the mix proportions, the coatings were prepared. The paste type and mortar type is noted as follows: Alkali-activated paste and mortar coating was represented as APCP and AAMC respectively; both are dependent on natural pozzolan were made by the polymeric acrylic emulsion addition in various percentages with respect to natural pozzolan and GBFS (natural pozzolan + GBFS). The hybrid mix paste (Fly ash + OPC) led to large shrinkage, so mortar type was used i.e. mortar coating based on fly ash with polymeric acrylic emulsion addition is denoted as AAFA. For paste coating based on natural pozzolan and GBFS, the molar ratios of SiO_2/Al_2O_3 and Na_2O/SiO_2 are 7.3 and 0.185, respectively; for mortar based on natural pozzolan and GBFS, they are 7.3 and 0.135; and for mortar based on fly ash and OPC, they are 5.5 and 0.200, respectively.

In this study, the geopolymer concrete is prepared with GBFS, fly ash, alkaline liquids, fine and coarse aggregates. Class F fly ash conforming to ASTM C618 [27] is used and it has low calcium content. The GBFS properties were conformed to ASTM C 989-2018 and the activators such as NaOH and Na_2SiO_3 were used and locally available river sand and 20 mm size crushed granite stone was utilized as fine and coarse aggregate respectively.

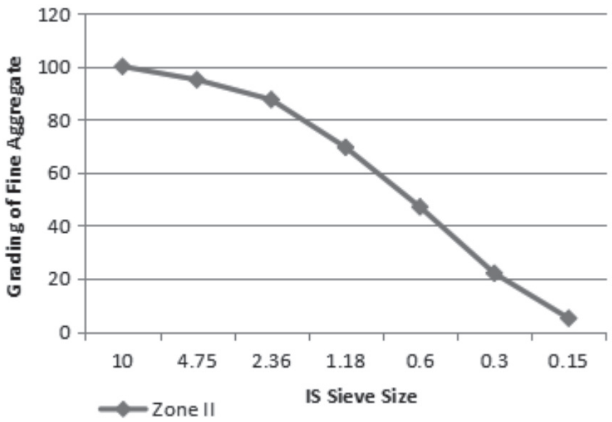

Fig. 2. Zone II - Grading Curve.

The river sand (fineness modulus of 3.2 and specific gravity of 2.7) was conforming to specifications of IS 383:2016 [28] and grading curve is plotted as shown in Fig. 2. The geopolymer concretes mix proportions are shown in Table 3. The molar ratio of SiO_2/Na_2O is 0.5 [39] which was present in the Na_2SiO_3 liquid.

Table 2. Mix proportions of paste and mortar coating.

Sample	Mix. no	Mix (%)	Precursors (kg)				Sand (kg)	Alkaline solution (kg) (NaOH + tap water + waterglass)	Acrylic emulsion (g)	Acrylic emulsion/ precusor (%)	(Liquid/ solid) ratio
			Fly ash	OPC	Natural pozzolan	GBFS					
AAPC	M-1	0	-	-	0.7	0.3	-	0.626	0	0	0.27
	M-2	5	-	-	0.7	0.3	-	0.626	50	5	0.27
	M-3	10	-	-	0.7	0.3	-	0.626	100	10	0.27
AAMC	P-1	0	-	-	0.7	0.3	2	0.713	0	0	0.38
	P-2	5	-	-	0.7	0.3	2	0.722	50	5	0.39
	P-3	10	-	-	0.7	0.3	2	0.741	100	10	0.40
AAFA	X-1	0	0.9	0.1	-	-	2	0.935	0	0	0.43
	X-2	1	0.9	0.1	-	-	2	0.935	10	1	0.43

Table 3. Geopolymer concrete mix proportions (kg/m³).

Mix. no	Mix (%)	Aggregates		Binders		Solution	
		Fine	Coarse	Fly ash	GBFS	Na_2SiO_3	NaOH
C-1	90% Fly ash 10% GBFS	610.2	1220.35	366.1	40.68	116.22	46.48
C-2	80% Fly ash 20% GBFS	610.2	1220.35	325.42	81.36	116.22	46.48
C-3	70% Fly ash 30% GBFS	610.2	1220.35	284.74	122.03	116.22	46.48

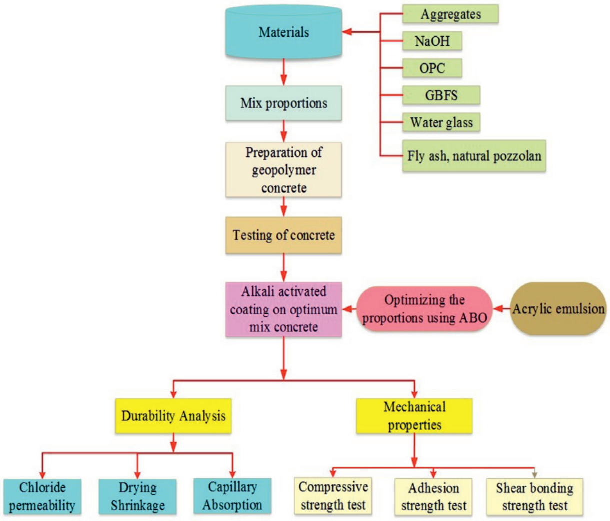

Fig. 3. Proposed methodology.

Proposed Methodology

Concrete protection via protective coating is in high demand in the building industry. In this study, the concrete surface has an alkali-activated coating applied to it to stop the concrete from degrading. Concrete deterioration is minimized by the mixing of alkali-activated components. The coating proportions are then optimized using the ABO method.

A single application is sufficient to prevent cracks and concrete deterioration thanks to optimized coating proportions. The proposed approach is shown in Fig. 3. Finally, the resilience and mechanical qualities of the covered geopolymer concrete were assessed in various settings.

Preparation of Geopolymer Concrete

In a concrete pan, the materials like fly ash, aggregates, and GBFS with designed mix proportions were mixed for 2 minutes. After mixing, the alkaline solution was added to the dry mix and it is mixed for another 3 minutes in the pan mixer. In a mould, the freshly mixed concretes were poured and vibrated. The prepared concrete samples are shown in Fig 4. After 24 hour, from the moulds, the concrete specimens were removed and at room temperature, the concrete is allowed curing for up to a specified period.

Testing of Geopolymer Concrete

The prepared Geopolymer concrete with different proportions is tested as shown in Fig. 5 and it shows high strength. The split tensile, flexural and compressive strength of Geopolymer concrete was evaluated at 7 and 28 days respectively. Mainly, Geopolymer concretes compressive strength is dependent on the chemical and physical interaction between concrete mixtures

Fig. 4. Casting of Geo polymer Concrete.

Fig. 5. Testing of Geo polymer Concrete.

Table 4. Test result of geopolymer concrete.

Mix. no		Compressive strength (MPa)		Split tensile strength (MPa)		Flexural strength (MPa)	
	Days	7	28	7	28	7	28
C-1		45.25	56.54	2.24	3.42	3.45	5.52
C-2		52.52	68.74	2.46	3.56	3.52	5.75
C-3		41.63	58.39	1.82	3.24	3.38	5.34

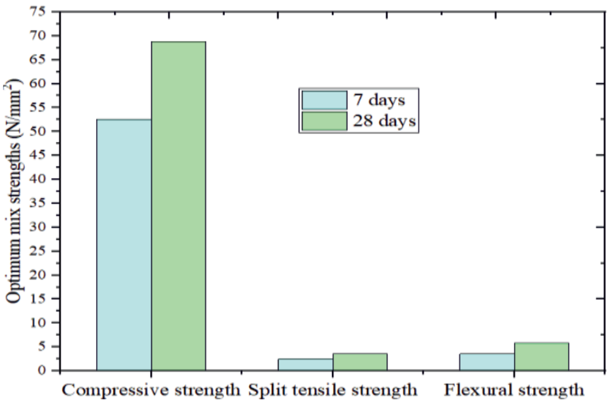

Fig. 6. Strengths of Optimum mix geopolymer concrete.

and alkaline solution. The cube of size 150x150x150 mm, cylinder of size 150 mm dia x 300 mm height and prism of size 100x100x50 mm were used [41].

From the test result of geopolymer concrete, the proper mix proportion for alkali-activated coating is selected. The geopolymer concrete's strength test results with the different mixes are represented in Table 4.

It was evaluated that the fly ash and GBFS plays a vital part in strength improvement; after 24 hour the geopolymer concrete strength has been found to be more than 25 MPa. The optimum mix strength result is demonstrated in Fig. 6. From the results, the C-2 mix is the optimum mix of geopolymer concrete; it has high strength compared to other mixes.

African Buffalo Optimization (ABO) Algorithm

In this work, the ABO [29] calculation is used to determine the optimum mix of alkali-activated paste and mortar coating in the selected mix by machine learning. This process depends upon the selection of alkali-activated materials and it makes an alert about

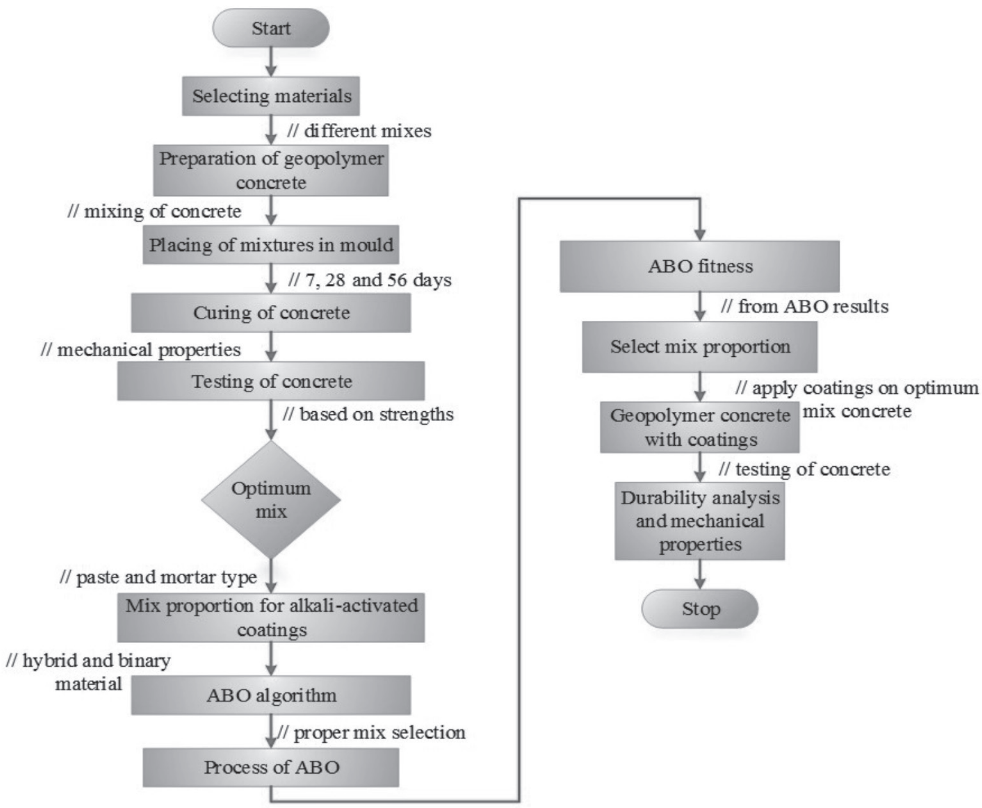

Fig. 7. Flow diagram of ABO algorithm in the selection of coating proportion.

the failure of mix proportions. The fitness function of the ABO algorithm is calculated by Eq. (1),

$$q_{.\mu}+1=q_{.\mu}+m_1a_1(s_{t\max.\mu}-\delta_\kappa)+m_2a_2(s_{r\max.\mu}-\delta_\kappa) \quad (1)$$

Where, m_1a_1 and m_2a_2 are the learning factors of buffalo, $q_{.\mu}$ and δ_κ denotes the exploration and exploitation moves of buffalo (μ, κ = 0,5, ..., N), $s_{t\ \max.\mu}$ represents the best fitness value and $s_{r\ \max.\mu}$ denotes the individuals best proportion. The process of the proposed method is detailed in algorithm 1.

The complete flow diagram for the process of the ABO algorithm in a selection of alkali-activated coating proportions is represented in Fig. 7.

The effectiveness of geopolymer concrete with coatings was evaluated with regards to compressive strength, shear bonding strength, adhesion strength, drying shrinkage, capillary absorption and chloride permeability. The concrete with suitable coatings was prevented from cracks and deterioration. The ABO algorithm is utilized to determine the suitable proportion for concrete coatings.

Alkali Activated Material Coating on Concrete

The suitable mix proportion of concrete coating is selected from ABO calculations. The proper mix proportion of alkali-activated paste and mortar type coatings is tabulated in Table 5. Based on the proportions, the alkali-activated paste and mortar coating with binary and hybrid material is prepared. The concrete surface should be clean and polished before coating.

Initially, precursor materials dry homogenization was carried out; after this, the activated solution was incorporated and mixed with precursor materials for 4min by a speed of 136 r.p.m in Hobart N50mixer. In mortars, the sand is added next and it was mixed for 1min. Once the coating is mixed, then by spatula the coatings were spread evenly on the surface of the concrete. After dried of the first coat, the next coat was applied i.e. second coat; approximately 5 hour needed for drying the first coat. The thickness of the coating on concrete was determined by the Elcometer 500 coating thickness gauge of concrete on each specimen.

Algorithm: 1 ABO algorithm and geopolymer concrete with alkali-activated coating

Start
{
Material selection()
Geopolymer concrete preparation ***// different mixes***
Mixing of materials
Placing of concrete mixtures in moulds
Concrete curing ***// 7,28 and 56 days***
Testing of concrete
// split tensile strength, compression strength, flexural strength
Optimum mix selection ***// from results of strength***
Mix proportion selection()
Alkali-activated paste and mortar type coatings
// based on a binary and hybrid mix
Develop ABO algorithm
// determine the optimum mix of paste and mortar coating
Process of ABO()
Consider the prepared mix proportion as P
int P=M-1, P-1, X-1 etc. ***// here M-1, P-1, X-1 are the selected mix proportion***

Compute $q_{.\grave{\imath}}+1$ *using eqn. (1)*
// appropriate mix proportion for coating

For all P= $q_{.\grave{\imath}}+1$
// optimize the proportions
Here $q_{.\grave{\imath}}+1$ *is the fitness process of ABO*
Geopolymer concrete with Coating ***// from selected proportion by ABO fitness***
Testing of concrete after coating
// Mechanical properties and durability analysis
}
Stop

Table 5. Selected mix proportions for coating.

Sample		AAPC	AAMC	AAFA
Mix. no		M-2	P-2	X-2
Mix (%)		5	5	1
Precursors (kg)	Fly ash	-	-	0.9
	OPC	-	-	0.1
	Natural pozzolan	0.7	0.7	-
	GBFS	0.3	0.3	-
Sand (kg)		-	2	2
Alkaline solution (kg)		0.626	0.722	0.935
Acrylic emulsion (g)		50	50	10
Acrylic emulsion/precursor (%)		5	5	1
Liquid/Solid ratio		0.27	0.39	0.43

Tests of Coating Materials

To measure the compressive strength of alkali-activated material coatings [40], 70.6 mm cubic mould conforming to IS: 10080-1982 [30] were prepared and tested for 7 and 28 days at a 27ºC temperature and 65% relative humidity. The capillary water absorption test was carried out on concrete specimens with 60 mm height and 76.2mm diameter. In concrete, the coating was applied on one side and after applying coating on the concrete surface, the test was carried out for 7 days. The cylindrical concrete disks of 76.2 mm dia and 50 mm height were used for evaluating chloride permeability and the procedure is indicated in ASTM C1202 [31].

The pull-off test is conducted to determine the adhesion strength of the alkali-activated material coatings by 8-shaped specimens. The mortar was prepared in half of the 8-shape mould and in the remaining half of the 8-shape mould coating was poured; cured for 28 and 7 days respectively. By axial tensile testing, the measurements were taken. The Vicat test as per ASTM C191 [32] was conducted to determine the coatings setting time. The test result of alkali-activated material coating is illustrated in Table 6.

Results

The best C-2 mix geopolymer concrete with alkali-activated material coatings underwent durability tests and mechanical performance testing at various curing times. The mix proportioning of the coatings is elaborated in MATLAB R2018b, which is running on the Windows 7 platform and was chosen from the ABO calculation findings. Concrete with coatings is mechanically and durably analyzed in various situations.

Case Study

In this research, the optimum geopolymer concrete mix C-2 were made by fly ash, GBFS, coarse and fine aggregate with a solution i.e. sodium silicate and sodium hydroxide. The fly ash and GBFS content was added as 80% and 20% respectively. From the selected mix, the geopolymer concrete is prepared. In geopolymer concrete, the selected mortar and paste-like coating were applied on geopolymer concrete substrate with selected mix proportions. By applying these coats, the durability of concrete is high and it prevents cracks.

Table 6. Test result of alkali-activated materials coating.

Mix. no	Compressive strength (MPa)			Setting time (min)	
	Days	7	28	Initial	Final
M-2		27.25	33.74	310	420
P-2		12.5	20.42	122	150
X-2		11.74	23.92	254	310

Natural Environment

In the natural environment, the atmospheric condition is selected for preparing geopolymer concrete and alkali-activated material coatings. The geopolymer concrete with coatings mechanical properties and durability were determined in natural conditions.

The concrete cube is cured for 7 and 28 days at 40ºC and 75% relative humidity for determining the compressive strength. The coated concrete was cured on different days for various tests.

The mechanical properties of coated concrete in atmospheric conditions are represented in Table 7 and coated concretes durability result is represented in Table 8.

Built Environment

The optimum mix of geopolymer concrete was cured at different days under room temperature of 27ºC with a relative humidity of 65%. In a built environment, the laboratory is selected for the preparation and curing of coatings and concrete mixtures.

The laboratory test results were chosen as an effective value for comparison purposes. To determine the strength and endurance of various coatings, mechanical and durability tests were carried out. The geopolymer concrete with alkali-activated material coatings improves the strength and increases the concrete durability. The mechanical and durability test results were illustrated in Table 8 and 9 respectively.

Discussion of Results

The optimum mix of C-2 with selected M-2, P-2, and X-2 alkali-activated material coatings on concrete substrate gives more strength to the structure. To check the durability of coatings on concrete, chloride permeability, capillary water absorption and drying shrinkage were carried out; and, to find the concretes mechanical properties with coatings like compressive, adhesion and shear bonding strength were conducted. The performance of the current work is compared with other existing works such as alkali-activated and cement-based coating mortars in the marine environment, reinforced concrete with alkali-activated protective coatings and concrete with surface pretreated coarse aggregate [33]. The effectiveness of the proposed method is analyzed by comparing it with other works.

Compressive Strength

The optimum mix of geopolymer concrete was cured at different days under room temperature of 27ºC with a relative humidity of 65%. In a built environment, the laboratory is selected for the preparation and curing of coatings and concrete mixtures. The optimum mix of geopolymer concrete is prepared with a selected proportion and it is coated with a selected different mix. To evaluate the geopolymer concretes strength with coatings, a compressive strength test was conducted. From the results, the concretes compressive strength with coatings was high compared to other methods.

Table 7. Mechanical properties test result of coated concrete under natural environment.

Mix. no	Curing period (days)	Compressive strength (MPa)	Adhesion strength (MPa)	Shear bonding strength (MPa)
M-2	7	54.67	0.92	3.25
	28	69.82	1.0	3.85
P-2	7	56.72	1.1	4.1
	28	71.26	1.24	4.4
X-2	7	54.32	0.9	3.12
	28	68.46	1.05	3.64

Table 8. Durability test result of coated concrete under natural environment.

Mix. no		Chloride permeability (coulombs)		Capillary water co-efficient (mm)								Drying shrinkage (x 10^{-6})	
	Days	28	90	28				90				28	90
				1 h	5 h	24 h	72 h	1 h	5 h	24 h	72 h		
M-2		640	720	0.65	0.92	1.22	1.4	0.5	0.84	1.05	1.2	141.2	321.4
P-2		1200	1450	0.54	0.87	1.02	1.24	0.49	0.96	1.15	1.3	136.5	317.6
X-2		1800	2350	0.62	0.87	1.2	1.35	0.56	0.98	1.22	1.51	245.8	399.2

The compressive strength is evaluated by Eq. (2),

$$\textit{Compressive strength} = \frac{\textit{Applied load}}{\textit{Cross-sectional area}} \quad (2)$$

The geopolymer concrete's compressive strength with selected coatings is represented in Table 9 for 7 and 28 days curing. The measured strength is contrasted with other methods to determine the proposed work effectiveness and is represented in Table 11 and Fig. 8 respectively.

By comparing with other methods, the proposed method has high compressive strength. The concrete with coatings improve the strength and concrete with high strength are suitable for construction application. The coatings with the addition of alkali-activated materials improved the strength by adding alkaline solution.

Adhesion Strength

The adhesion strength results were determined from the pull-off test; it was done after curing of 7 and 28 days. For the pull-off test, 8-shape specimens are used; by axial tensile testing, the measurements were taken. The test result of adhesion strength is represented in Table 9 for 7 and 28 days curing. The proposed works effectiveness is analyzed by comparing it with other existing methods.

The comparison of adhesion strength with other methods is illustrated in Table 12 and the adhesion strength comparison at 28 days is represented in Fig. 9. By comparing with other methods, the adhesion strength is high for the proposed method.

The average adhesion of the proposed and other methods shows that the proposed method has high strength. The mortar with high strength is applicable for all concretes and the adhesion strength is increased by adding acrylic emulsion. The presence of acrylic emulsion in paste and mortar type coatings increases the adhesion strength.

Shear Bond Strength

The shear bond strength evaluation is measured for 7 and 28 days, the coating with alkali-activated material increases the shear strength of concrete than normal OPC concrete. The result of this experiment is similar to the compressive test.

The obtained average shear bond strength is compared with other methods and it is represented

Table 9. Mechanical properties test result of coated concrete under built environment.

Mix. no	Curing period (days)	Compressive strength (MPa)	Adhesion strength (MPa)	Shear bonding strength (MPa)
M-2	7	55.94	1.12	3.42
	28	69.75	1.30	3.87
P-2	7	58.42	1.21	4.24
	28	70.54	1.45	4.6
X-2	7	60.75	0.96	3.27
	28	73.99	1.01	3.76

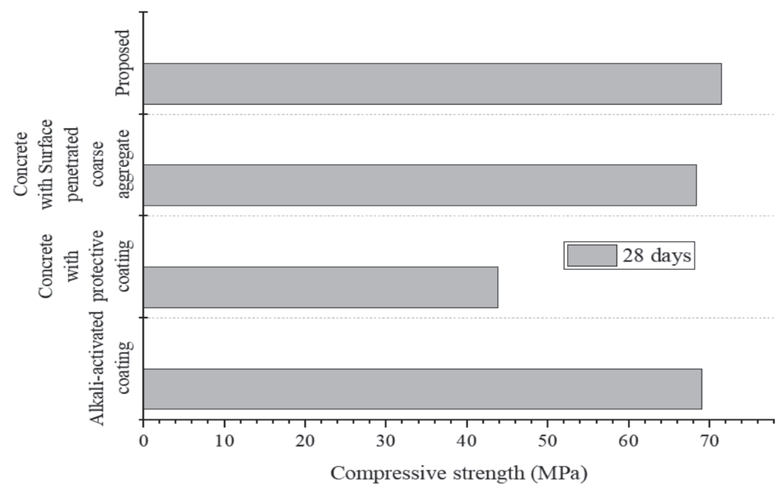

Fig. 8. Comparison of compressive strength at 28 days with existing methods.

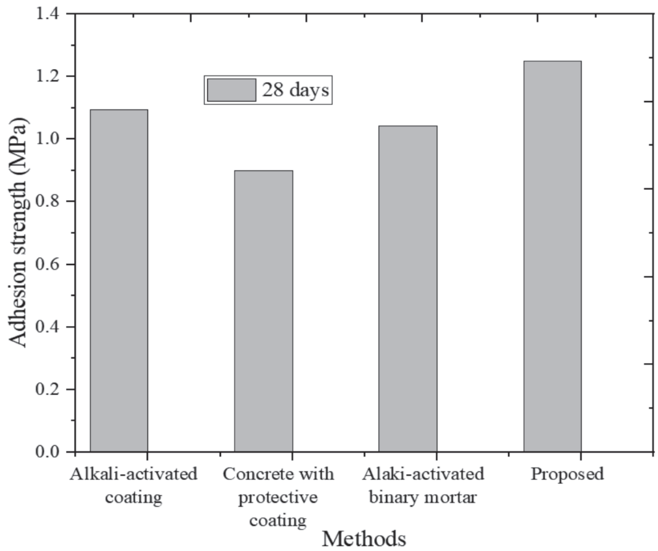

Fig. 9. Comparison of adhesion strength at 28 days with other methods.

Table 10. Durability test result of coated concrete under built environment.

Mix. no		Chloride permeability (Coulombs)		Capillary water co-efficient (mm)								Drying shrinkage (x 10^{-6})	
	Days	28	90	28				90				28	90
				1 h	5 h	24 h	72 h	1 h	5 h	24 h	72 h		
M-2		650	790	0.42	0.65	1.25	1.4	0.54	0.96	1.02	1.26	100.98	122.54
P-2		1150	1280	0.52	0.84	1.3	1.44	0.57	0.85	1.15	1.24	133.57	154.92
X-2		1500	1900	0.67	0.97	1.2	1.5	0.64	1.01	1.28	1.42	196.47	210.62

Table 11. Comparison of compressive strength.

Methods	Average Compressive strength (MPa)	
Days	7	28
Alkali-activated coating [21]	51.5	69
Concrete with protective coating [24]	30.25	43.75
Concrete with surface penetrated coarse aggregate [33]	-	68.33
Proposed	58.37	71.49

Table 12. Comparison of adhesion strength.

Methods	Average Adhesion strength (MPa)	
Days	7	28
Alkali-activated coating [21]	0.997	1.093
Concrete with protective coating [24]	-	0.9
Alkali-activated binary mortar [36]	-	1.043
Proposed	1.097	1.25

in Table 13; the shear bond strength at 28 days is compared with other methods and it is represented in Fig. 10.

From the comparison, the proposed method has high bond strength compared to others. The increase in bond strength has high durability. The concrete with applied coatings has high bond strength due to the addition of acrylic emulsion in percentages.

Drying Shrinkage

The other important characteristic of geopolymer concrete and mortar is dimensional stability. Indeed, the shrinkage can cause adhesion reduction, mortar premature peeling from concrete surface and shear stress. The geopolymer concrete with coatings has low shrinkage and is suitable for all environmental conditions. According to ASTM C596 [34], the overall steps were performed except for the room temperature control.

The obtained drying shrinkage is tabled in Table 10 and the obtained average drying shrinkage is compared with other methods; it is represented in Table 14 and Fig. 11.

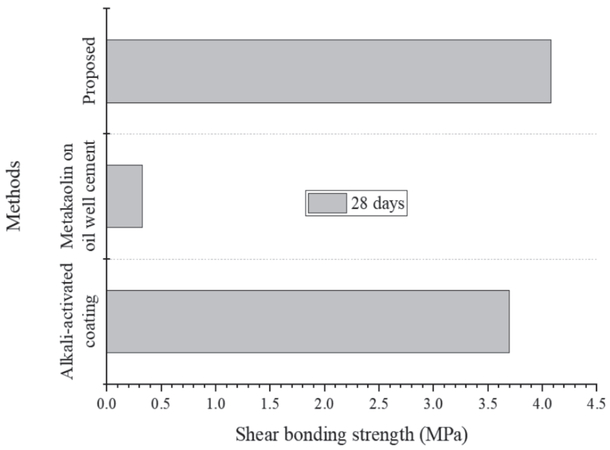

Fig. 10. Comparison of Shear bond strength at 28 days with other methods.

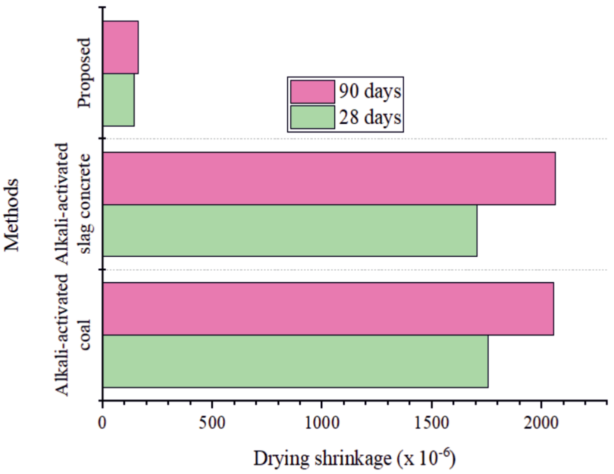

Fig. 11. Comparison of drying shrinkage.

Table 13. Comparison of shear bond strength.

Methods	Average Shear bonding strength (MPa)	
	7 days	28 days
Alkali-activated coating [21]	-	3.696
Metakaolin on oil well cement [35]	0.242	0.326
Proposed	3.643	4.077

Table 14. Comparison of drying shrinkage.

Methods	Avg. Drying shrinkage (x 10^{-6})	
	28 days	90 days
Alkali-activated coal [37]	1755	2056
Alkali-activated slag concrete [38]	1704.17	2062.5
Proposed	143.67	162.69

By comparing with other methods, the presented method has less shrinkage and is suitable for all construction applications. The geopolymer concrete with applied alkali-activated coatings has less drying shrinkage due to the addition of polymeric additives.

Capillary Water Absorption

In the inside of concrete and mortar, the water penetration into capillary spaces is an effective factor. Due to applied forces like external forces, the infiltration of water happened in the empty space of mortar and concrete. To determine the infiltration of water degree, the capillary water absorption test is conducted.

The absorption coefficient of water is compared with other methods to find the proposed method's effectiveness and it is represented in Table 15. The comparison of absorption co-efficient at 90 days is illustrated in Fig. 12.

From the comparison of absorption coefficient, the geopolymer concrete with alkali-activated coating has less water absorption. Hence the durability of concrete is high compared with other methods. The increase in the life span of concrete is the best concrete for construction.

Table 15. Comparison of absorption co-efficient.

Methods	Avg. absorption coefficient (mm)	
	28 days	90 days
Alkali-activated coating [21]	5.72	7.43
Concrete with protective coating [24]	-	6.11
Proposed	4.053	3.98

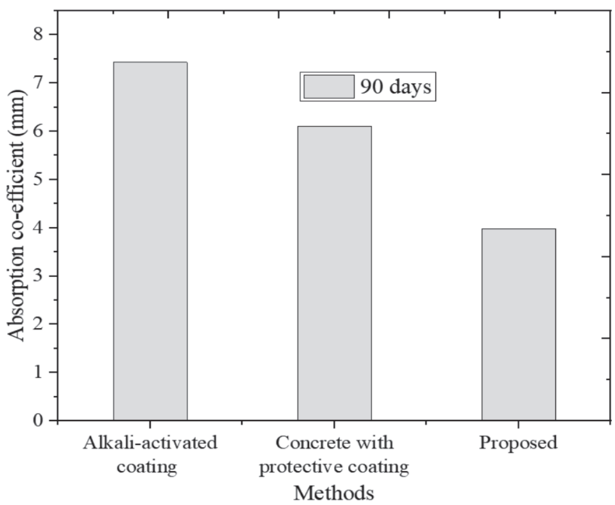

Fig. 12. Comparison of absorption co-efficient at 90 days.

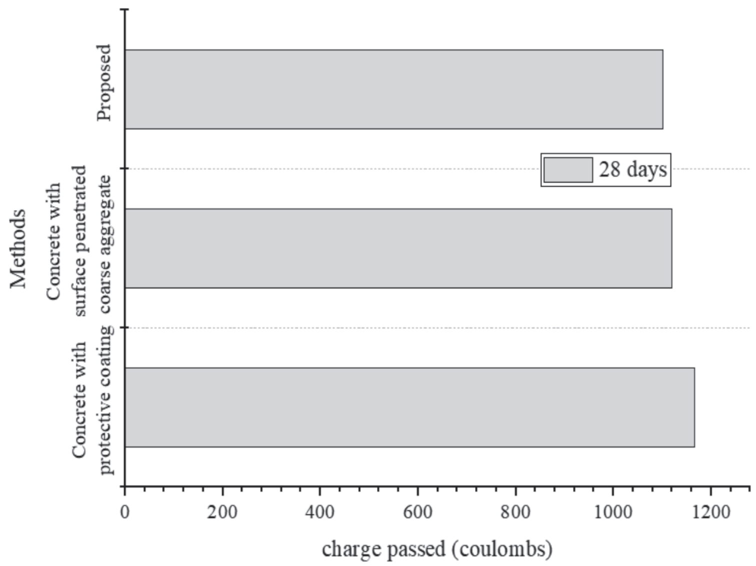

Fig. 13. Comparison of chloride permeability at 28 days.

Chloride Permeability

According to ASTM C1202, the chloride penetration test was conducted; in penetration of chloride ions, all the coated geopolymer concretes has better resistance. An addition percentage of alkali-activated materials leads to lower chloride penetration and increases porosity.

The comparison of chloride permeability is illustrated in Table 16 and the chloride permeability of concrete with coatings at 28 days is shown in Fig. 13. When compared to other methods, the chloride permeability test was conducted for only 28 days but the presented work has conducted the test for both 28 and 90 days.

The concrete with lower chloride ion penetration has high durability and less chloride penetration are also suitable in a marine environment. By the addition of acrylic emulsion in percentage, the geopolymer concrete with paste and mortar type coating has less penetration.

The overall test result shows an increase in strength by geopolymer concrete with alkali-activated paste and mortar type coatings. The alkali-activated coatings on concrete's mechanical and durability properties show better results. The alkali-activated coatings have less drying shrinkage, lower penetration of chloride ions and less water absorption. The ABO algorithm is used to select the proper paste and mortar type coatings based on natural pozzolan and fly ash. Normally, the coating with natural pozzolan has high drying shrinkage, but in this research, the coating has less shrinkage due to the addition of acrylic emulsion.

Table 16. Comparison of chloride permeability.

Methods	Avg. Chloride permeability (Coulomb)	
	28 days	90 days
Concrete with protective coating [24]	1166.67	-
Concrete with surface penetrated coarse aggregate [33]	1119.75	-
Proposed	1100	1323.3

Conclusion

This study was conducted to evaluate the optimum mix of geopolymer concrete, durability and mechanical assessment of coatings and geopolymer concrete with alkali-activated paste and mortar type coatings based on fly ash and natural pozzolan. The ABO algorithm is utilized to select the appropriate mix proportion for a coating to avoid cracks on the concrete substrate. From the results of ABO, the paste and mortar type coatings were prepared. The prepared coatings were applied on the surface of the concrete to evaluate its strength and durability. The test results showed that concrete with coatings has high strength and it can resist chloride ions. Based on the overall result, the geopolymer concrete with alkali-activated coatings has high durability. Comparing our experiment with 7 days and 28 days curing the compressive strength increase by 13.12%, Adhesion strength increases by 0.153%, shear bond strength increases by 0.434%, Drying Shrinkage increases by 19.02%. While the Absorption Coefficient decreases by 0.073% and the chloride permeability increases by 223.3%. Comparing with the existing work our experiment gives the best performance value. Furthermore, in order to achieve superior mechanical, durability, and microstructural qualities for broader applications of the sustainable loess. Study on the influence of the concentration of activators, namely, under ambient temperature curing, is also necessary in the future.

Conflict of Interest

The authors declare no conflict of interest.

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