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EMPHASISE OF STEEL REINFORCEMENT IN CONCRETE AND GEOPOLYMER COATINGS FOR CORROSION PROTECTION OF STEEL REINFORCEMENT IN CONCRETE(SRC)

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Abstract - *Generally, In construction the industries are facing a corrosion in steel. The steel in reinforced concrete has been found as the significant factor leading premature failure of concrete constructions. Durability of concrete structure is placed as main global issue in construction sector. The loss of durability and life of construction is directly depend on corrosion of steel. A lot a research as done to control corrosion in steel and to prevent, among that application of coating to steel reinforcement is an effective method of corrosion control. These two mechanisms must be controlled while coating on steel (i) Chloride Attack and (ii) Carbonation of Concrete. The coated steel is impressed in water and chlorides and its very tuff to achieve perfect epoxy coating. In the circumstance of galvanized steel reinforcement, the connection ofuncoated steel rebars with coated steel bars should be evaded to realize the long-term corrosion defense presentation of galvanized steel rebar. The epoxy coated reinforcement increases permeability between the concrete and decreases corrosion in reinforcement against which is not coated reinforcement. To improve the performance of the coating reinforcement should be focused on their basic characteristics of proper resistance to water, adhesion, chemical, abrasion, friction and cost. The present work focused on improving long-period corrosion for steel. Based on collection of literature, the geopolymer coating for steel have many advantages and having excellent controlling corrosion and fire resistance properties, Improving a good bond strength between coating of steel and concrete. By knowing advantages from literature collection, the investigation has done offering by geopolymer binder. The two main constituents of geopolymer places a role in this investigation. Such that investigation source are mainly materials and alkaline liquids. The selected source materials are; by-product materials such as fly ash, Ordinary Portland Cement(OPC), Microsilica, Rice husk ash, Kaolin, Ferrosilicon Powder, Vanadium Pentoxide and Silica fume were used as reactive material, combination of Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) as alkaline liquid used for geopolymerisation. Ten formulations were made and experimental evaluation has been carried out on all the studied coatings for its adhesive strength, flexibility, bendability, corrosion resistance, saltspray, impact test.*

Key Words: Corrosion, Geopolymer, Materials, Steel, Aluminosilicate, Adhesion test, Impact test, Flexibility test.

1. INTRODUCTION

Corrosion of steel in concrete involves a complex series of reactions, the proportions of which may vary with environmental exposure and materials characteristics. In a high-pH environment, such as concrete, hydroxide (OH^-) is abundant in solution. Hydroxide ions may react with iron at the steel surface to create ferrous hydroxide ($Fe(OH)_2$). Carbonation is a process in which carbon dioxide diffuses intothe concrete from the air. The reaction product, calcium carbonate,has a pH of about 9.5, which is below the level necessary to sustain the passive layer.

[$Ca(OH)_2 + CO_2 CaCO_3 + H_2O$] -1.1.

[Calcium silicate hydrates + $CO_2 CaCO_3$ + $SiO_2 nH_2O$ + H_2O]-1.2.

[Aluminate hydrates + $CO_2 CaCO_3$ + hydrated alumina]-1.3.

[Ferrite hydrates + $CO_2 CaCO_3$ + hydrated alumina and iron oxides]-1.4.

[Anode: 3Fe+ 8OHFe_3O_4 + 4H 2O + 8e]-1.5.

[Cathode: 8e + $4H_2O$ + $2O_2$8OH]-1.6.

1.1 Geopolymer Coatings

Geopolymer is an inorganic polymer a alkali-activated binder) has gained worldwide interest and its high anticorrosion property made with a coating material and it has the benefit of fire resistance. The reaction of solid aluminosilicate material with highly silicate solution produce a synthetic alakali aluminosilicate, thus produced material generically called "geopolymer" but in more of references that they termed as an "Inorganic polymer".The geopolymer solution can be tailored by correct mix and processing to optimise the properties such as flexibility, adhesion and to offer excellent corrosion resistance coatings with reduced cost.

1.2 Geopolymer Processing

In general, the reactive alkali solution is prepared with sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) and the alumina silicate solid powders can be of fly ash, microsilica, kaolin, clay, high alumina clay etc. in which sufficient amount of silicate (SiO_2) and alumina (Al_2O3) must bepresent. During the reaction of alumina silicate materials with the alkali binder solution, water is gradually split out and the tetrahedral units (SiO_4 andAlO_4) alternatively linked to polymeric precursors (-SiO_4-AlO_4-(or)-SiO_4- Al_2O_4-SiO_4-(or)-SiO_4-AlO_4-SiO_4-) by sharing oxygen atoms forming amorphous geopolymeric products with three-dimensional network structure

2. Alkaline Liquids and Source Materials

In the present experimental work, there are double main elements of geopolymers, viz. The source materials for geopolymers grounded on alumino-silicate must be in a manner of rich, then the silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, micas, spinel, etc. whose empirical formula contains Si, Al, and oxygen (O). Alternatively, the by-product materials such as fly ash, Microsilica, Rice husk ash, Eluru Clay, Kaolin, Ferrosilicon Powder, and Silica fume were used as a filler material. The high-quality of the cause supplies for making geopolymers rest on factors such as reactivity availability, cost and type of submission and specific request of the end users. The alkaline liquids are from soluble alkali metals that are usually Sodium or Potassium based. Materials rich in silicon(such as fly ash or slag) and materials rich in aluminum (kaolin clay) are the primary requirement for geopolymerization to occur. The details of the sources for the raw materials and their chemical compositionsare given in Tables 1 and 2.

Table -1: Procurement detail of the Raw Materials

Name of the Material	**Procurement Details**
Fly ash	Collected from Krishna Babu Pal G Bricks, Eluru, India
Microsilica	Purchased from India Mart
Ferrosilicon	Purchased from India Mart
Eluru Clay	Procured from local chemicals suppliers.
Rice husk ash	Procured from local rice mill.
Clay	Collected from near by ponds.
Chemicals used	NaCl, NaOH, S_2Cl_2 Sb_2O_3, HCl, Na_2SiO_3 were of ARgrade. Solutions were prepared with double distilled water.
Kaolin	Purchased from India Mart
Graded fine sand	Screened river sand with fineness modulus equal to 2.58conforming to grading zone III of IS :383,1970.

Table -2: Chemical Composition of Mineral Constituents by XRF (wt%)

Material used	**SiO_2 wt%**	**Al_2O_3 wt%**	**Fe_2O_3 wt%**	**MgO wt%**	**CaO wt%**	**Density g/cm³**
OPC	21.0	6.04	3.79	2.6	63.5	3.4
Fly Ash	44.3	23.5	11.75	1.3	18.3	2.6
Micro silica	97.5	0.75	0.64	0.4	0.65	2.7
Ferrosilicon	78.2	0.46	11.40	1.1	1.21	2.2
Eluru clay	68.0	21.0	0.05	-	8.34	1.9
Rice husk Ash	94.0	0.26	0.18	0.4	0.67	2.1
Clay	65.5	15.1	11.78	0.7	1.38	1.8
Kaolin	46.5	39.5	-	-	1.55	2.6

2.1 Preparation of ten Geopolymer Coatings

Geopolymer binder properties are highly dependent upon the type, ratios and concentrations of mixing constituents. Each constituent and the variables associated with that constituent play a significant role in determining the characteristics of the final product. The resulting geopolymer solution (binder solution) was in 1:3 ratio, one part of NaOH and three parts of Na_2SiO_3(120 gm Na_2SiO_3). Mix thoroughly still the sodium silicate solution fully dissolved in NaOH solution This binder solutionwas used to prepare the final coating formulation as described in Table 2. The volume of the binder solution and reactive material indicated in the above table after trial and error has resulted the brush able coating, dried in 24hours at room temperature with acceptable adhesion. The prepared geopolymer binder was mixed with required quantity and combinations of fly ash, microsilica, OPC, Kaolin, clay, Eluru clay,ferrosilicon powder, rice husk ash and Vanadium Pentoxide (V_2O_5) in such a way that the resultant solution gives brush able consistency and offers rough surface finish in order to enhance the bonding between the coated steel and the concrete. Two coats were applied to avoid the formation of pinholes in the coatings. The formulated coatings were brushed two coats to get uniform film thickness. All the experiments were carried out at an ambient temperature of 32 ± 1º C. Then in the second day, it was kept in an oven at 50º for threehours to accelerate the cross linking and later it was allowed to cure for 5 daysin the ambient condition. The pigment and fillers were selected to react with geopolymer solution to form.

Sl.No	Coating Code	Materials used
1	GPR	Binder(25ml) + Fly ash(10g) + Iron oxide Red (2g) +Silica fume(0.2g)
2	GP1	Binder(30ml) + Fly ash (10g) + Iron oxide yellow (2g) +Silica fume(0.2g)
3	GP2	Binder (30ml) + Micro silica (10g) + Iron oxide yellow(2g) + Silica fume(0.2g)
4	GP3	Binder(30ml) + Fly ash(5g) + Micro silica(5g) + Ironoxide yellow(2g) + Silica fume(0.2g)
5	GP4	Binder(50ml) + OPC (10g) + Iron oxide yellow+ Silicafume(0.2g)
6	GP5	Binder (40ml) + OPC(5g) + Fly ash(5g) + Iron oxideyellow(2g) + Silica fume(0.2g)
7	GP6	Binder(40ml) + OPC(5g) + Micro silica(5g) + Iron oxideyellow(2g) + Silica fume(0.2g)
8	GP7	Binder (40ml) + OPC (3g) + Fly ash(4g) + Micro silica (3g) + Iron oxide yellow(2g))+ Silica fume(0.2g)
9	GP8	Binder(40ml) + OPC(5g) + Kaolin(5g) + Iron oxideyellow(2g) + Silica fume(0.2g)
10	GP9	Binder(50ml) + Fly ash (5g) + Kaolin(5g) + Iron oxideyellow(2g) + Silica fume(0.2g)

Table-2: Nomenclature for different coating systems

Fig -1: Dry mix of source materials

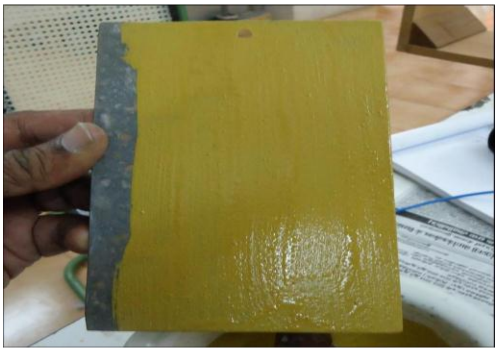

Fig -2: Coated with brush for testing

Fig -3: Coating thickness measurement

Fig-4: Elcometer 456 Coating Thickness Gauge Device

The employed Elcometer 456 Coating Thickness Gauge was shownin Figure 3 It provides reliable and accurate coating thickness measurements. The principle of electromagnetic induction is used for non- magnetic coatings on magnetic substrates such as steel.

3. RESULTS AND DISCUSSION

3.1 Coating Thickness

The thickness of coating was measured using a handy digital display thickness measuring Elcometer 456 as shown in Figure-4 Upon each coated surface, 6 measurements are averaged and the average values are reported in Table-3. This coating thickness is called dry film thickness (dft) and was given in microns. The obtained values lie in the range of 210µm to 237µm.The coatings were applied with brush. Two coats were given on pickled and cleaned surface of the mild steel panels.

Designation of Coating	Coating Thickness (urn)	Adhesion Test (by Tensometer)		Flexibility Test (ASTMD-522)	Impact Test	
		Load at Failure N	Stress at Failure N/mm^2		On coated plates ASTMD 2794	On coated rods ASTM D14
GPR	220	7.585	14.919	P	P	P
GP1	226	8.122	15.564	P	P	P
GP2	210	8.831	16.581	P	P	P
GP3	223	7.892	15.260	P	P	P
GP4	219	7.746	15.93	P	P	P
GP5	210	7.961	15.075	P	P	P
GP6	238	8.814	16.814	P	P	P
GP7	238	8.213	15.690	F	P	P
GP8	229	5.171	10.494	P	F	F
GP9	221	10.150	20.635	P	P	P
GP10	227	12.123	23.617	P	P	P

Table-3: Results of Mechanical Properties of Coatings

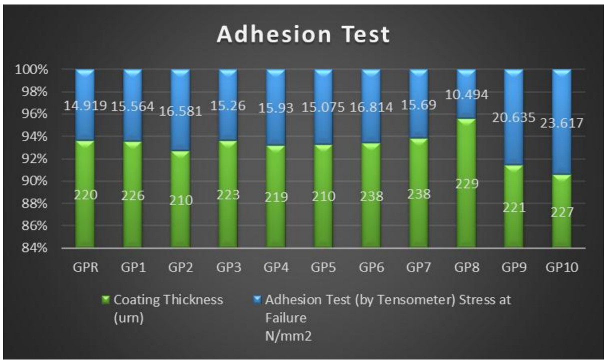

Chart-1: Adhesion strength data of ten combinations of Geopolymer coated plates resulted from Adhesion test

All the coated plates with scribed on one side and the other side as unscribed are edge sealed using wax and were exposed to open atmospherefor a period of 60 days (1400 hours). Four times a day, 3% NaCl was sprayed on the plates and observation was made in respect of corrosion. Except the coating GPR shows the mark of creepage and remaining all other coatings showed no mark of creepage and therefore no failure of coatings due to corrosion creepage. This was accredited to the excellent adhesion strength between the steel plate and the coating. However, the coatings GPR earned the rating of 4 respectively at the end of 60 days" exposure.

4. SUMMARY

Geopolymer is an inorganic polymer, an alkali-activated binder which has gained worldwide interest and its high anticorrosion property made it a novel coating material. The reaction of solid aluminosilicate material with highly concentrated aqueous alkali hydroxide or silicate solution produce a synthetic alkali aluminosilicate material generically called "geopolymer" and can be compared in performance with the traditional cementitious folders in a range of applications, but with the supplementary benefit of suggestively concentrated greenhouse releases.

The geopolymer solution can be tailored by correctmix and processing to optimise properties such as flexibility, adhesion and to offer excellent corrosion resistance properties with reduced cost for given coating applications. Therefore, by considering the advantages offered by geopolymer binder such as greener material, good corrosion and alkali, acid resistance, fire resistance and also excellent adhesion to steel substrate with high electrical insulating effects, the geopolymer binder is chosen with different kind of aluminosilicate materials.

Ten different geopolymer based compositions using fly ash, OPC, Microsilica, Rice husk ash, Clay, Eluru Clay, Kaolin, FerrosiliconPowder, Vanadium Pentoxide, Silica fume and Fe_2O_3 as functional pigments and fillers were formulated and brush able coating materials were synthesised. The geopolymer solution (binder solution) was prepared in 1:3 ratio, of NaOHand Na_2SiO_3 and mixed thoroughly.

5. CONCLUSION AND FUTURE WORK

A systematic study on all the prepared ten geopolymer coatingsresulted the following observations.

- ❖ The average thickness of the studied coating varies from 210 µm to 238µm.Coating thickness above 210 µm has no role in performance only the ingredients has main role in protection.
- ❖ GP16 showed poor adhesion strength perhaps due to the presence of ferrosilicon and poor cross link formation. The multiple hydroxyl group in GP12 developed good adhesion with the steel plate and chemical anchoring in addition to mechanical anchoring of coating.
- ❖ The presence of rice husk ash in the coating formulation improved the drying and thus results tight bonding between the steel plate and coating. GP7 and GP8 8.213 N/mm^2 were failed at 3mm diameter of the cone and passed at 6mm diameter of the same cone. Further all the other coatings were found to possess very good flexibility characteristics. The additives such as microsilica, rice husk ash do not possess required amount of aluminium oxide

(Al_2O_3) for the dense cross linking and therefore poor flexibility.

- Also, during film formation, evaporation of water from the film lefts with micro voids and that reduces the strength against flexibility.
- Pencil hardness test has been carried out on all the coated panelsand the results suggested that all the studied coatings werepassed in this test.
- The coating GP9 and GP10 performed better in all the test produces including electrochemical tests.
- Field exposure studies also give GP9 and GP10 as good coatings.
- In electrochemical impedance spectroscopy test, the coatings GP7, GP8, GP9 and GP10 were found high resistance coating even after 30 days of periodical test, this is due to chemical and mechanical anchoring of the coating with plates.
- GP8, GP9 and GP10 have performed excellently under salt spray test conducted for a period of 60 days (1400 hours). The performance was attributed to the strong adhesion of betweenthe plate and the coating.

In conclusion, GP9 and GP10 have passed all the examinations as per the experimental conditions adopted in the present study and may be very well utilized for preventing or decelerating the corrosion rate of steel rebars inconcrete.

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