INVESTIGATION OF CORROSION BEHAVIOUR OF STEEL IN REINFORCED CONCRETE WITH SCM

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Abstract -*Cement concrete is the most widely used material for various constructions. Here we have investigated the corrosion behavior of steel in reinforced concrete with Supplementary Cementitious Materials (SCM). SCM's like metakaolin and silica fume are often used to reduce cement contents and improve the workability of fresh concrete and enhance the strength and durability properties of hardened concrete. Here the compressive strength characteristics of M_{35} concrete is evaluated with varying percentages of silica fume (10%, 15%, 20%) and metakaolin (10%, 15%, 20%) separately as partial replacement of cement. The effect of silica fume and metakaolin on the corrosion of steel in reinforced concrete using Half cell potential method. For this the specimens with optimum percentages of silica fume and metakaolin are choosed. It measures the potential difference and electrical resistance between the reinforcement and concrete surface(in accordance with ASTM C876). So, through replacing the cement by supplementary cementitious materials we can minimize the use of cement and we can reduce the probability of corrosion.*

***Key Words*: SCM, Silica Fume, Metakoalin, Cement, Corrosion resistance, Compressive strength.**

1. INTRODUCTION

Cement concrete is the most widely used material for various constructions. Supplementary cementitious materials (SCM) can be used for improved concrete performance in its fresh and hardened state. They are primarily for improved workability, durability and strength. The main supplementary cementitious materials are silica fume, metakaolin, fly ash and GGBS. SCMs are known to improve the durability of concrete by making it less permeable, and increasing its compressive strength. Compared to traditional concrete, it is a much eco-friendly material. Cement substitutes are used to enhance certain qualities of cement and reduce the environmental effect. Usage of slag as cement replacement in concrete seems to be a good solution against chloride-induced corrosion, such as in marine environment.

The corrosion of steel reinforcement in concrete is the most significant durability problem encountered in reinforced concrete structures. Corrosion is a natural process that occurs when the steel rebar with in reinforced concrete structure rusts. As the steel bar corrodes the volume of steel increases and this expansion creates a tensile stress in the concrete, which eventually leads to cracking. Rebar corrosion occurs mainly due to the chloride ion and moisture penetration into the concrete.

SCMs when added to concrete improves the inter particle arrangement, improves aggregate paste bonding and increases the impermeability there by the corrosion resistance of concrete increases. The corrosion behavior of the reinforcement was evaluated based on the half-cell potential.

2. MATERIALS USED

2.1 Silica Fume

Silica fume also known as micro silica is an amorphous polymorphs of silicon dioxide. Because of its chemical and physical properties, it is a very reactive pozzolan. The average particle diameter is 150nm. Concrete containing silica fume can have very high strength and can be very durable. Placing, finishing, and curing silica-fume concrete require special attention.

2.2 Metakaolin

Metakaolin is a highly reactive pozzolana formed by the calcination of kaolinite (China clay). It is a product manufactured when kaolin is heated to a temperature between 600°C and 800°C. Therefore, considerable CO_2 emissions are associated with the production of metakaolin. Size of metakaolin ranges from 1- 20µm.

2.3 Cement

Cement is used as a binding material in concrete and it imparts various strength properties to the concrete. In the present experimental work, Dalmia OPC 53 was used. As per the standard testing procedure, the compressive strength of cement will be obtained after 28 day. It provides long lasting durability to concrete structures. Specific gravity, initial setting time, final setting time, fineness and standard consistency of cement were tested.

2.4 Fine Aggregate

Fine aggregate is basically sand obtained from the land or marine environment. It consists of natural and crushed stone which passes through 4.75 mm sieve. Its size range from 4.75 mm to 75 microns as per IS 383-1970. Here manufactured sand (M-sand) is used as fine aggregate.

2.5 Coarse Aggregate

Coarse aggregates are commonly considered as inert fillers. The coarse aggregates of size ranging from 20 mm to 4.75 mm are used for casting. The maximum allowable water absorption is 2% as per IS 383:1970. The various properties of aggregates include shape and texture, size gradation, moisture content, specific gravity, reactivity, soundness and bulk density.

2.6 Super Plasticizer

Super plasticizers (SPs), also known as high range water reducers, are additives used in making high strength concrete. Their addition to concrete or mortar allows the reduction of the water to cement ratio without negatively affecting the workability. Arment - Aqua Arm proof WP 10 was used for the experimental work.

3. METHODOLOGY

Based on the Indian Standard (IS:10262-1982), Design Mix for M_{35} grade of concrete was prepared and tests were conducted by partially replacing the cement to evaluate optimum percentage of silica fume and metakaolin in M_{35} equivalent concrete at various replacement levels of cement by weight (10%,15%,20%). Cubes of size 150 mm × 150 mm × 150 mm were casted. These were tested using a compression tester for 7 days,14 days and 28 days after curing. For identifying the corrosion behaviour three cylindrical specimens of height 30 cm and diameter 10 cm were prepared. The specimens were inserted with 10 mm rod (TMT bars) at the centre to do the corrosion tests. For this the specimens with optimum percentages of silica fume and metakaolin are choosed. The half-cell potential measurement test essentially consists of measurement of absolute potential at the concrete surface with a reference electrode. It is the only corrosion monitoring technique standardized in ASTMC876-15. It measures the potential difference and electrical resistance between the reinforcement and concrete surface (in accordance with ASTM C876).

Figure-1: Casting of specimen

Table-1: Details of replaced concrete specimens

% replacement	Quantity of materials (Kg)				
	Cement	FA	CA	SF	MK
0%	6.45	10.32	16.77	0	0
10%	5.81	10.32	16.77	0.65	0.65
15%	5.49	10.32	16.77	0.96	0.96
20%	5.16	10.32	16.77	1.29	1.29

1. TEST RESULTS

1.1 Compressive strength of Silica fume

The Cubes casted were tested for compressive strength by using the Compressive testing machine for a time duration of 7 days, 14days and 28 days which is obtained by dividing the Load by Area. $M_{35}SF_{10}$, $M_{35}SF_{15}$, $M_{35}SF_{20}$ are the main specimens which are M_{35} equivalent concrete containing 10%, 15%, 20% silica fume.

Table-2: Compressive strength results of silica fume added concrete

Sl No	Mix Designation	Compressive strength (N/mm^2)		
		7 day	14 day	28 day
1	M_{35}	22.67	31.55	35.11
2	$M_{35}SF_{10}$	24.80	32	37.33
3	$M_{35}SF_{15}$	22.22	31.55	34.22
4	$M_{35}SF_{20}$	21.78	29.33	33.33

Table-3: Percentage increase or decrease when strengthened using silica fume

Sl No	% addition of silica fume	Compressive strength (N/mm^2)	% Increase or decrease
1	0%	35.11	0%
2	10%	37.33	6.32
3	15%	34.22	-2.53
4	20%	33.33	-5.06

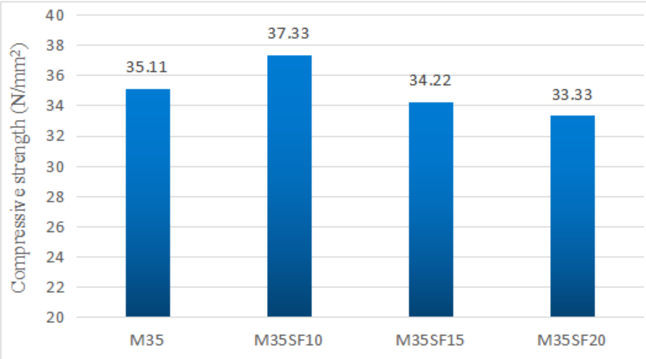

Chart-1: Compressive strength of silica fume

Therefore the addition of silica fume up to 10% is the optimum percentage where we can get the maximum compressive strength.

1.2 Compressive strength of Metakaolin

$M_{35}MK_{10}$, $M_{35}MK_{15}$, $M_{35}MK_{20}$ are the main specimens which are M_{35} equivalent concrete containing 10%, 15%,20% metakaolin.

Table-4: Compressive strength results of metakaolin added concrete

Sl No	Mix Designation	Compressive strength (N/mm^2)		
		7 day	14 day	28 day
1	$M_{35}MK_{10}$	22.67	31.55	34.66
2	$M_{35}MK_{15}$	23.99	25.33	36.88
3	$M_{35}MK_{20}$	21.78	30.22	33.77

Table-5: Percentage increase or decrease whenstrengthened using metakaolin

Sl No	% addition of metakaolin	Compressive strength (N/mm^2)	% Increase or decrease
1	0%	35.11	0%
2	10%	34.66	-1.28%
3	15%	36.88	5.04%
4	20%	33.77	-3.81%

Therefore the addition of metakaolin up to 15% is the optimum percentage where we can get the maximum compressive strength.

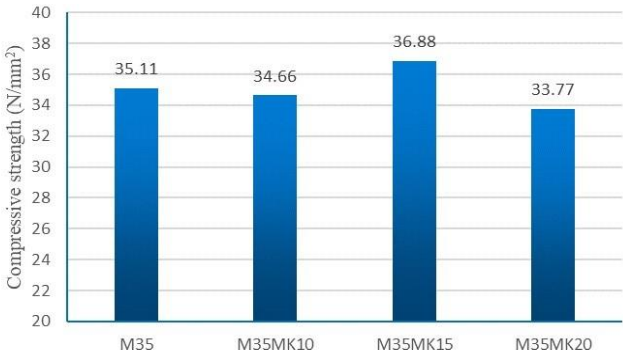

Chart-2: Compressive strength of metakaolin

Therefore the addition of metakaolin up to 15% is the optimum percentage where we can get the maximum compressive strength.

2. REINFORCEMENT CORROSION

Three cylindrical specimens of height 30 cm and diameter 10 cm were inserted with 10 mm rod (TMT bars) at the center were casted to do the corrosion tests. Optimum percentage of silica fume and metakaolin are chosen for the casting of specimens. The main three specimens are M_{35}, $M_{35}SF_{10}$, $M_{35}MK_{15}$.For this mark three points (a,b,c) on the cylinder with 10 cm spacing from the tip of the bar. And measure the values on two sides of cylinder.

Figure-2: Specimens for corrosion test

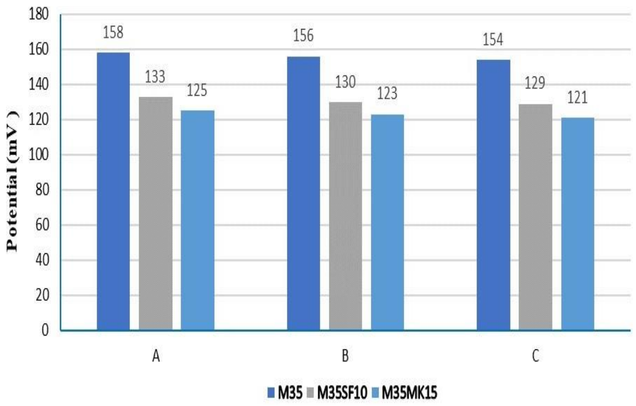

Chart-3: Test results of specimens on 30th day

Table-6: Corrosion probability (as per ASTM C876)

Point	Measured potential in 2 sides (mV)			
	30th day test		60th day test	
A	-158 mV	-158 mV	-210 mV	-211 mV
B	-156 mV	-155 mV	-209 mV	-209 mV
C	-155 mV	-154 mV	-207 mV	-208 mV

Table-7: Corrosion test of M_{35} cylinder

Point	Measured potential in 2 sides (mV)			
	30th day test		60th day test	
A	-132 mV	-133 mV	-168 mV	-168 mV
B	-130 mV	-130 mV	-166 mV	-165 mV
C	-129 mV	-129 mV	-165 mV	-164 mV

Table-8: Corrosion test of $M_{35}SF_{10}$ cylinder

Point	Measured potential in 2 sides (mV)			
	30th day test		60th day test	
A	-125 mV	-125 mV	-160 mV	-160 mV
B	-123 mV	-124 mV	-159 mV	-159 mV
C	-120 mV	-121 mV	-158 mV	-157 mV

Table-9: Corrosion test of $M_{35}MK_{15}$ cylinder

Measured potential (mV)	Probability of corrosion
<-200	Less than 10%
-200 to -350	Uncertain
>-350	More than 90%

Figure-3: Half cell potentiometer

Chart-4: Test results of specimens on 60th day

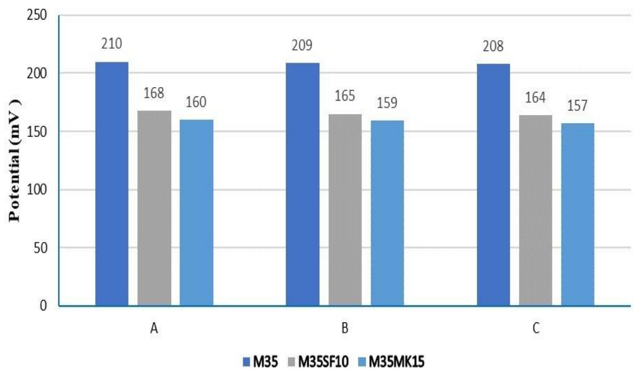

Table-10: Percentage increase or decrease ofcorrosion resistance on 60th day

Specimens	% increase or decrease of corrosion resistance on various points		
	A	B	C
M_{35}	0%	0%	0%
$M_{35}SF_{10}$	20%	21.05%	21.15%
$M_{35}MK_{15}$	23.80%	23.92%	24.52%

There for the corrosion resistance of silica fume on points A, B, C shows 20% ,21.05% and 21.15% of increase than M_{35} mix. And the corrosion resistance of metakaolin shows 23.805, 23.92% and 24.52% of increase than M_{35} mix. The test results shows that M_{35} concrete gives more probability of corrosion than silica fume. The area which is more exposed to water and air shows higher rate of corrosion.

3. CONCLUSIONS

- The optimum percentage of Silica fume in M_{35} equivalent concrete at various replacement levels of cement by weight (10%,15%,20%) based on compressive strength is determined as 10%.
- The optimum percentage of metakaolin in M_{35} equivalent concrete at various replacement levels of cement by weight (10%,15%,20%) based on compressive strength is determined as 15%.
- When compared with the optimum percentages ofsilica fume and metakaolin on M_{35} mix, M_{35} concrete mix shows less compressive strength.
- The probability of corrosion of silica fume and metakaolin on 30th day is less than10%.
- The probability of corrosion of silica fume and metakaolin on 60th day is also less than 10%.
- The probability of corrosion of M_{35} on 30th day is less than 10%and probability on 60th day is between 10-90%.
- The corrosion resistance of silica fume on points A,B, C, shows 20%, 21.05% and 21.15% of increase than M_{35} mix. And the corrosion resistance of metakaolin on points A, B, C, shows 23.80%, 23.92% and 24.52% of increase than M_{35} mix.
- M_{35} concrete shows comparatively more probability on corrosion than silica fume and metakaolin added concrete on 30th and 60th day.
- The point which is near to the tip of steel shows comparatively higher probability of corrosion than the other points.
- It shows that the probability of corrosion is decreased from that end point.
- Also the area of steel which is more exposed to water and air shows higher corrosion rate.
- The corrosion resistance of silica fume and metakaolin concrete decrease with increase in age. Therefore, SCM's when added to concrete improves the inter particle arrangement, improves aggregate paste bonding and increases the impermeability there by the corrosion resistance of concrete increases. Through replacing the cement by supplementary cementitious material we can minimize the use of cement and we can reduce the probability of corrosion.

REFERENCES

[1] Anand Kuber Parande, B. Ramesh Babu (2008), "Study on strength and corrosion performance for steel embedded in metakaolin blended concrete/ mortar", Construction and Building Materials 22, 127–134.

[2] A.R. Hariharan, A.S. Santhi, G. Mohan Ganesh,(2011) "Study of strength development of high strength concrete containing fly ash and silica fume", IJEST 3(4).

[3] G. Batis, P. Pantazopoulou, S. Tsivilis (2005), "The effect of metakaolin on the corrosion behavior of cement mortars, Cement & Concrete Composites" 27, 125–130.

[4] Kelestemur Oguzhan, Demirel Bahar (2015), "Effect of metakaolin on the corrosion resistance of structural lightweight concrete", Construction and Building Material, ELSEVIER.

[5] Lakhbir Singh, Arjun Kumar, Anil Singh (2016), "Study of partial replacement of cement by silica fume", International Journal of Advanced Research, Volume 4, Issue 7, 104-120.

[6] Rukhsana Rashid, Nishant Kumar (2016)," Study on Effect of Silica Fume on Properties of M_{40} Grade of Concrete", International Journal of Engineering Research & Technology (IJERT) Vol. 5 Issue 05.

[7] S. Arunachalam, S. Anandakumar, R. Ranjani (2021), "Corrosion resistant properties of concrete using various supplementary cementitious materials", Today proceedings , ELSEVIER.