Development Of Inhibitor For The Corrosion Resistance In Steel Using Polyvinyl Alcohol

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Abstract : Corrosion of steel is the biggest problem in the construction field. In order to reduce the corrosion, various methods are adopted like use of corrosion resistant steel like stainless steel, epoxy coating on steel bars, etc. Here we used Polyvinyl Alcohol (PVA) is used as a corrosion inhibitor in our project. The thickness of coating on steel bars are 340 µm, 400 µm and 420 µm. The Polyvinyl Alcohol (PVA) coated bars are tested for pH, molarity, viscosity, temperature and pull out test. With the help of electrochemical test corrosion resistance of Polyvinyl Alcohol (PVA) is determined. pH value of Polyvinyl Alcohol is in the range of 7 to 8. So, pH value of the Polyvinyl Alcohol not affected the concrete alkalinity nature. Molarity determines the concentration of the gel. Three samples are tested for molarity test. From the results of molarity test it was found that suitable value of molarity for Polyvinyl Alcohol was 4.53 M. Viscosity test is done to determine the fluidity nature of the Polyvinyl Alcohol gel. Three different molarity value Polyvinyl Alcohol (PVA) gels are tested for viscosity. From that results, low molarity gel has the high fluidity value. In temperature test, the rods are under the examination for long term temperature and it was found that at 320˚C the coating was melted, which is sufficient for commercial uses. Pull out test is done to determine whether the coating affect the bonding between concrete and steel bars. From the results of pull out test, the load required to pull the bars from the cubes is almost equal to the both uncoated and coated bars. Therefore the Polyvinyl Alcohol (PVA) coating on steel bars does not affect the bonding between the concrete and steel bars. Electrochemical test is done to determine the corrosion resistance of the Polyvinyl Alcohol (PVA). It is observed that corrosion resistance of Polyvinyl Alcohol (PVA) is increased when the thickness of coating is increased. The corrosion resistance of Polyvinyl Alcohol (PVA) is found to be 49.27%.

Keywords : Corrosion, Polyvinyl alcohol, Steel rods, Reinforcement, Coating.

1. INTRODUCTION

Corrosion of constructive steel is an electrochemical process that definite quantity the presence of moisture and oxygen. Irons in steel is oxidized to produce rust which occupies around six times volume of original material[1,2]. Corrosion of steel reinforcement is one of major causes inducing the decline in quality of reinforced concrete structures. It results in weakening of concrete structures and falling of concrete[7]. Due to corrosion cracks are formed in concrete structure. Corrosion is reduced and cure by the some respective chemical action. The bonding between concrete and steel is also affected by corrosion[3]. Sometimes strength capacity of member is reduced and maintenance cost also increased. TMT (Thermo Mechanically Treated) steel bars are mostly used for reinforcement because of high strength capacity[4,5]. TMT increased tensile strength. Their manufacturing process consider hot rolled steel wires passed through with water. Basically main reason behind using steel bar for reinforcement is strengthening of structure. The corrosion inhibitor is added to a liquid or gas, decreases the corrosion rate of material[6,8]. The corrosion agents are generally oxygen, hydrogen sulfide and carbon-di-oxide. In these research polyvinyl alcohol is used as corrosion inhibitor which is water soluble synthetic polymer[10]. Basically 8mm, 10mm, 12mm diameter of steel bars are used for building[12]. So, for our research experimental with these three types of bars. TMT to provide strength in tension, bending, shear as well as in compression. Their properties are higher strength with better elongation, excellent weld- ability[11,14]. Resistance to fire hazard, more ductility, better bonding strength, good corrosion resistance[13]. For corrosion resistance there are many methods are used. One of method is epoxy coating on basis but we are using the polyvinyl alcohol coating. It is used in papermaking, textile and variety of coating. PVA is unique among polymer but that is not built up in polymerization reactions from single unit precursor molecules known as monomers[16]. Reacting of monomers in chemical reaction to make polymer chains that is polymerization. Dissolving of polymer and polyvinyl acetate in an alcohol like methanol and reacting with an alkaline catalyst like sodium hydroxide that makes PVA. Chemical structure of PVA is [CH2CH(OH)]n. PVA has resistance to grease, oil and solvents. It has no odour and non- toxic and also excellent adhesive and film forming properties. It has high oxygen and aroma barrier properties. Density of PVA is 1.20-1.30 g/cm3. The poisson's ratio is between 0.40 and 0.46. PVA has melting point of 180ºc to 190ºc. It can undergo pyrolysis at high temperature. Heating of organic material at high temperature in absence of oxygen is the process of pyrolysis[15]. It involves the change of chemical decomposition of material and also pyrolysis process is irreversible.

1.1. FORMATION OF GEL FROM POWDER

Polyvinyl alcohol powder is mixed with water to form the gel. For that we determine the ratio of 1:5 (PVA : water). The ratio was determined by trail and error method. Initially we adopt the ratio of 1:10. But, in that ratio PVA become a liquid state. PVA is mixed with water at temperature of 100ºc till the gel stage occurs. After that it was cooled at room temperature for one hour. Power of Polyvinyl Alcohol shows in Figure. 1. Gel formation of PVA shows in figure. 2.

1.2. COATING APPLIED ON STEEL BARS

PVA coating is applied on steel bars with help of brush. The thickness of coating are 300µm, 360µm and 400µm. Above 400µm thickness of coating affect the bonding between the concrete and steel bars.

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Fig.1 *Polyvinyl Alcohol*

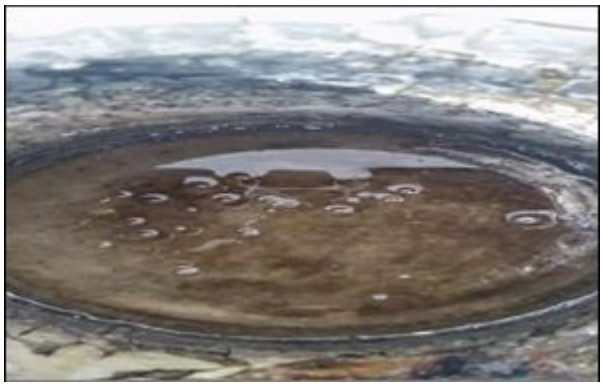

Fig.2 *Polyvinyl Alcohol gel*

2. EXPERIMENTAL APPROACH

For the checking of inhibitors stability there are three methodology are followed they are pH, molarity, viscosity test. PH test is for checking the gel either the acidity or basicity of an aqueous solution[16]. Molarity test is to check the concentration of coating consistency in steel bars[18]. Viscosity test is conducted for measures the shear strength of coated steel bar[20]. For the steel bar coated concrete specimen there are three tests are followed, they are Pullout, Electrochemical, Temperature test. Pullout test is conducted for to check the level of bond between the steel and concrete[21]. Electrochemical test assess the state of corrosion in concrete. It means to calculate the corrosion efficiency of chemical[22]. Temperature test is tested for knowing the high melting point of coated steel bars[23].

3. EXPERIMENTAL INVESTIGATIONS:

3.1. pH Testing

Determination of pH value of the Polyvinyl Alcohol gel by using pH paper as shown in Figure3. 10 g of Polyvinyl Alcohol (PVA) is taken for the pH test. pH paper is initially in one colour, when it was immersed in particular chemical colour was changed. The change in the pH paper compared with the standard colors. That color changes indicates whether the chemical is acid or base. pH paper was just inserted in the 10 g of Polyvinyl Alcohol (PVA). The color change occur in the pH paper indicates the pH value of the Polyvinyl Alcohol (PVA) as shown in Figure4. From that pH value we determine whether the Polyvinyl Alcohol gel (PVA) affect the concrete or not.

Figure 3*. pH paper*

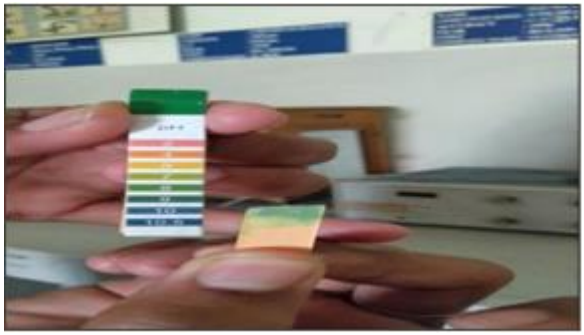

Fig.4 *pH paper colour change*

3.2. Molarity Testing

Molarity (M) is the concentration of a solution expressed as the number of moles of solute per liter of solution.
Molarity = Moles of solute / Liters of solution Take a 200 g, 400 g, 600 g of Polyvinyl Alcohol for the molarity test. These three samples were mixed with one liter of water at a temperature of 100˚C. Molarity of the first sample = (200 / 44) / one liter of water. 44 is the molecular weight of the Polyvinyl Alcohol. 4.53 M is the molarity value of the first sample. Molarity of the second sample = (400 / 44) / one liter of water.9.09 M is the molarity value of the second sample. Molarity of the third sample = (600/ 44) / one liter of water. 13.61 M is the molarity value of the third sample.

3.3 Viscosity Test

Viscosity is a measure of resistance to flow for gradual deformation by either shear stress or tensile stress. Viscosity is denoted by μ. Viscosity determines the fluidity of the liquid. Take a 50g Polyvinyl Alcohol for the viscosity test. Oil is applied on the viscometer and glass tube in order to prevent adhesive of coating on these equipment. Polyvinyl Alcohol is poured in the viscometer as shown in the Figure5. Glass tube is placed at the bottom the equipment set up. Around the viscometer bitumen was filled. Temperature is increased when machine was switched on. Due to temperature increase Polyvinyl Alcohol gel is started melted. Stop watch is started when the Polyvinyl Alcohol gel started to fall in the glass tube. Time required for the gel to fall in the

glass tube was measured. That time indicates the fluidity nature of the Polyvinyl Alcohol gel. Testing results are shows in table 1. From the results of viscosity test the fluidity nature of the Polyvinyl Alcohol gel was determined. Based on the results of viscosity test, determine whether the Polyvinyl Alcohol coating on reinforced steel bars is used as a corrosion resistant inhibitor or not.

Fig. 5 *Viscosity test on Polyvinyl Alcohol gel*

Table 1 *Viscosity Test*

PARAMETER	SAMPLE 1	SAMPLE 2	SAMPLE 3
Time required for the gel to fall in the glass tube, sec	15	18	22

3.3. Temperature Test

Take a 8 mm, 10 mm, 12 mm bars for the temperature test. The bars are coated by Polyvinyl Alcohol. The thickness of coating on 8 mm, 10 mm and 12 mm bars are 340 µm, 400 µm and 420 µm respectively. After the provision of coating on steel bars they are allowed to dry for half an hour. Then the bars are placed in the temperature test oven as shown in Figure 6. Initially the temperature was set at 10˚C in the temperature oven. Every 30 minutes temperature was increased up to 10˚C. And also in every 30 minutes bars condition is also checked. The coating behavior on steel bars and rods behavior in every 30 minutes. From which temperature the coating on steel bars is affected, that temperature was noted. At which temperature coating is melted on three different dia. of bars is also noted. That temperature is the required temperature to melt the Polyvinyl Alcohol coating on steel bars. Testing results of each temperature shows in table 2. X axis represents the temperature and Y axis represents the dia. of bars in graph. Graph shows the temperature effects on Polyvinyl Alcohol (PVA) coating on steel bars. Graph shows in figure 7.

Fig.6 *Coated rods placed in the oven*

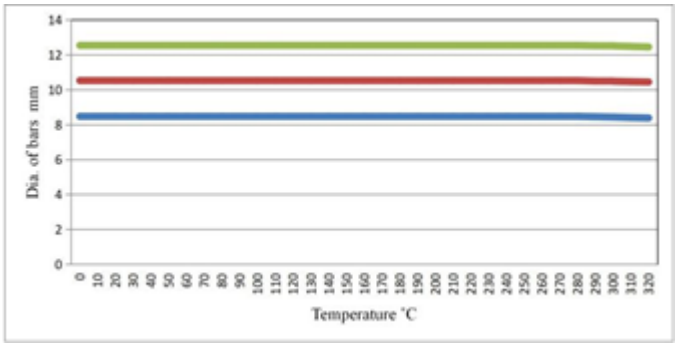

Fig.7 *Temperature test on coating*

Table 2 *Temperature Test*

TEMPERATURE ˚C	THICKNESS OF COATING (mm) (8 mm ROD)	THICKNESS OF COATING (mm) (10 mm ROD)	THICKNESS OF COATING (mm) (12 mm ROD)
10	8.47	10.52	12.53
20	8.47	10.52	12.53
30	8.47	10.52	12.53
40	8.47	10.52	12.53
50	8.47	10.52	12.53
60	8.47	10.52	12.53
70	8.47	10.52	12.53
80	8.47	10.52	12.53
90	8.47	10.52	12.53
100	8.47	10.52	12.53
110	8.47	10.52	12.53
120	8.47	10.52	12.53
130	8.47	10.52	12.53
140	8.47	10.52	12.53
150	8.47	10.52	12.53
160	8.47	10.52	12.53
170	8.47	10.52	12.53
180	8.47	10.52	12.53
190	8.47	10.52	12.53
200	8.47	10.52	12.53

210	8.47	10.52	12.53
220	8.47	10.52	12.53
230	8.47	10.52	12.53
240	8.47	10.52	12.53
250	8.47	10.52	12.53
260	8.47	10.52	12.53
270	8.47	10.52	12.53
280	8.47	10.52	12.53
290	8.45	10.49	12.51
300	8.43	10.48	12.50
310	8.40	10.46	12.47
320	8.38	10.44	12.44

3.4. PULL OUT TEST

M20 grade of concrete is casted in six 10 cm x10 cm x10cm cubes. Because, M20 is used in most of the construction works. 10 mm dia. and 1 m height of bars (without coated) are placed in the center of three cubes. Same specification bars are coated with Polyvinyl Alcohol (PVA) . The thickness of coating on steel bars were 340 µm, 400 µm and 420 µm. Then the coated bars are placed in the center of the three cubes. The cubes are allowed to settle for one day. Then the cubes are placed in curing tank for 28 days which shows in figure 8. After 28 days cubes are tested in pull out test machine. The cubes are placed at the center of the machine. Load is applied on the steel bars. At which load point the steel bars are completely taken from the cubes (pull), that load is noted for all cubes. That load is the required load to pullout the bars from the cubes. Same method was followed for the coated bars. After a test conducted, the pullout of concrete and steel shows in figure 9. The load required to pull the bars from the uncoated and coated bars determine whether PVA coating affected the bonding between the concrete and steel bars. The testing results of each three samples of coated and uncoated bars are shows in table 3.

Fig.8 *Curing of cubes*

Fig.9 *cubes after pull out test*

Table 3 *Pull Out Load*

CUBES	CUBE 1 (LOAD REQUIRED TO PULLOUT THE BAR FROM THE CUBES,kN)	CUBE 2 (LOAD REQUIRED TO PULLOUT THE BARS FROM THE CUBES,kN)	CUBE 3 (LOAD REQUIRED TO PULLOUT THE BARS FROM THE CUBES,kN)
Cubes with uncoated bars	16.35	15.50	14.75
Cubes with coated bars	16.30	15.40	14.70

3.5. Electrochemical Test

Take a 117 g of NaCl was mixed with one liter of water in order to make electrolyte solution. Molarity of the electrolyte solution = (117/58) / one liter of water. 2 M is the molarity if the electrolyte solution (NaCl solution). Reinforcement steel bars were coated with Polyvinyl Alcohol (PVA) gel. The thickness of coating was 340 µm, 400 µm and 420 µm on three steel bars. Depending on the thickness of coating whether rate of corrosion is reduced or not. Because of this various thickness of coating is provided on the steel bars. M20 grade of concrete was used to make the 10x10x10 cm concrete cubes. These three steel bars were inserted at the center of the cubes. Then the cubes were allowed to curing for 7 days. After 7 days cubes were placed in the electrolyte solution i.e. NaCl solution of molarity 2 M. All the electrochemical measurements were performed with a conventional electrode system. Initially the uncoated steel bars were act as a working electrode and copper sulphate electrodes are used. All these electrodes were connected to the circuit connection. 12 V and 5mA were applied on the circuit for two hours. Resistance was noted for the uncoated bars. Then Polyvinyl Alcohol (PVA) coated bars are used as a working electrode. 12 V and 5mA was applied on the circuit for two hours. From that resistance was measured for the Polyvinyl Alcohol (PVA) coated bars. Efficiency of inhibitor (Polyvinyl Alcohol) is determined by,

$\eta = (Rp - Rpo / Rp) \times 100$

Where, η is the efficiency of inhibitor,%. Rp is the resistance in the presence of inhibitor, Ω. Rpo is the resistance in the absence of inhibitor, Ω. From the above formula the efficiency of Polyvinyl Alcohol based on thickness of coating on steel

bars which shows in table 4. From the results of electrochemical test, thickness of coating on Y-axis and efficiency of inhibitor on X-axis a graph is plotted. Graph shows the resistance to corrosion based on thickness of Polyvinyl Alcohol gel (PVA) on steel bars which shows in figure 10.

Table 4 *Electrochemical Resistance*

THICKNESS	RESISTANCE IN THE PRESENCE OF INHIBITOR Rp, Ω	RESISTANCE IN THE ABSENCE OF INHIBITOR Rpo, Ω	EFFICIENCY OF THE POLYVINYL ALCOHOL, η, %
Uncoated bar	-	7.34	-
340	11.23	7.34	34.64
400	12.89	7.34	43.05

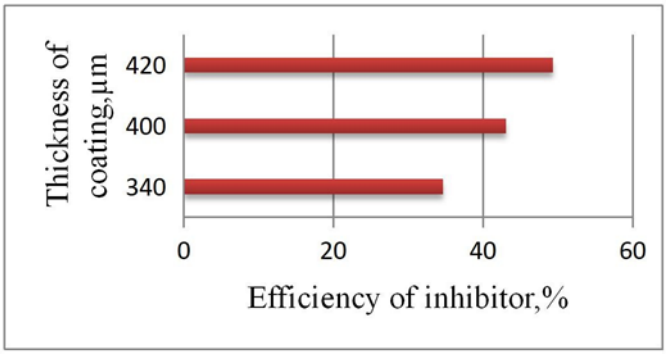

Figure 10 *Efficiency of Polyvinyl Alcohol*

4. RESULTS AND DISCUSSION

From the pH test, the pH value of Polyvinyl Alcohol (PVA) is 7 to 8. It is in alkalinity nature. Therefore, the Polyvinyl Alcohol (PVA) does not affect the alkalinity nature of concrete. So, Polyvinyl Alcohol (PVA) is used as a corrosion resistance inhibitor in reinforcement steel bars.First sample molarity is 4.53 M. It is in gel form. So, it was easy to apply on the steel bars. Second sample molarity is 9.09 M. It is also in gel from. But the concentration is more. When we applied this coating on steel bars, thickness of coating is more. This thickness affected the bonding between the concrete and reinforced steel bars. So second sample does not used as a corrosion resistant coating. 13.61 M is the molarity value of the third sample. It is a solid form. Also the concentration is more. And also the viscosity of the second and third sample was high compared to first sample. So those two samples are not used in the site. Polyvinyl Alcohol (PVA) of molarity value 4.53 M was used as a corrosion resistant inhibitor in reinforced steel bars in RCC structures.In viscosity the time required for the Polyvinyl Alcohol gel to fall in the glass tube from viscometer that shows in table. Three different molarity of Polyvinyl Alcohol gel have three different values. Because, molarity indicates the concentration of the solution. When the concentration is low viscosity is more. First sample has a molarity value of M, so it has high fluidity nature than other two samples. Second sample has more molarity than first sample, so it has moderate fluidity nature. Third sample has more molarity than first two samples, so its fluidity nature is low than first two samples. So first sample of Polyvinyl Alcohol (PVA) is used as a corrosion resistant inhibitor in steel bars in RCC structures. In the temperature test, it was noted that up to 280˚ C the thickness of coating was not affected by temperature. At 290˚ C the thickness of coating is decreased in every bars. From that thickness of coating is decreased up to 320˚ C in different dia. of bars. At 320˚ C coating was melted. The melting point of corrosion resistant inhibitors for commercial usage is above 300˚C. The melting point of Polyvinyl Alcohol (PVA) coating is 320˚C. It is suitable for commercial usage. So, the Polyvinyl Alcohol (PVA) coating is used as a corrosion resistant inhibitor in reinforcement steel bars. Testing results shows in table. In pullout test,the load required to pull out the bars from the cubes. It shows that load required to pull out the uncoated bars from the cubes are 16.35 kN, 15.50 kN and 14.75 kN. The load required to pull out the Polyvinyl Alcohol (PVA) coated bars from cubes are 16.30 kN, 15.50 kN and 14.70 kN. It shows that load required to pull out the bars is almost equal for both uncoated and coated bars. From that we conclude the Polyvinyl Alcohol (PVA) coating is not affected the bonding between the concrete and reinforcement bars. So Polyvinyl Alcohol (PVA) coating is used as a corrosion resistant inhibitor in reinforcement steel bars. In electrochemical testing indicates corrosion resistance of the Polyvinyl Alcohol (PVA) on steel bars. It showed that corrosion resistance was increased when the thickness of coating was increased on steel bars. This is due to when thickness was more penetration of oxygen and water into steel bars was reduced. So the rate of corrosion was reduced. Above the thickness of 420 µm on steel bars, thickness affected the bonding between the concrete and steel bars. So it was not possible to increase the thickness above 420 µm. The corrosion efficiency of the inhibitor-Polyvinyl Alcohol (PVA) is 34.64% when thickness of coating was 340 µm, corrosion efficiency of the Polyvinyl Alcohol (PVA) is 43.05% when thickness of coating was 400 µm and corrosion efficiency of the Polyvinyl Alcohol (PVA) is 49.27% when thickness of coating was 420 µm.

5. CONCLUSIONS

pH value of Polyvinyl Alcohol is 7 to 8.So it does not affect the nature of concrete. Molarity of the Polyvinyl Alcohol is 4.53 M. Above 4.53 M, viscosity of the Polyvinyl Alcohol gel was low. So it does not applied on the steel bars. In temperature test the melting point of Polyvinyl Alcohol gel on steel bars was 320˚C. Chemical inhibitor which was used for the corrosion resistance in steel bars was in the range of 280˚C to 300˚C. So, Polyvinyl Alcohol (PVA) is suitable for the commercial usage. In pull out test the load required to pull the steel bars from the cubes was almost equal for both uncoated and coated bars. Therefore the coating does not affect the bonding between the concrete and steel bars. Electrochemical test was done to determine the corrosion resistance of the inhibitor i.e. Polyvinyl Alcohol. It was observed that corrosion resistance of Polyvinyl Alcohol was increased when the thickness of coating was increased. From the results of electrochemical test the corrosion resistance of Polyvinyl Alcohol was found to be 49.27%. Therefore Polyvinyl Alcohol (PVA) was used as a corrosion resistance inhibitor in reinforcement steel bars.

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