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CORROSION BEHAVIOR STUDY OF STEEL POLE IN DIFFERENT COATING TECHNOLOGY

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Abstract—**Corrosion of steel pole is a serious issue as they used steel pole to support overhead power line in distribution. A lot of money and time are spent for maintenance and repair of existing steel pole. This paper presents investigation on various coating technologies of steel pole for initial corrosion activity. Five types of coating were used on steel samples; epoxy, VEF polyglass, galvanized, epoxy galvanized and polyglass galvanized. The accelerated ageing test, salt spray test and water absorption test were used to determine coating degradation and severity of corrosion process. It was found that, the corrosion rate for epoxy galvanized and VEF polyglass galvanized were higher as the samples were undergoing accelerated ageing test. While VEF polyglass steel showed higher percentage of weight loss during salt spray test. In addition, the results of water absorption behavior showed that epoxy steel gave higher average of absorption rate. The results obtained lead to low degradation of coating as the corrosion rate seem to be uniform**

Keywords— **Corrosion rate, degradation, coating, steel, testing**

I. INTRODUCTION

IN the distribution sector, energy utilities used various types of pole to support overhead power lines and their accessories which carry low voltage power to distribute the power to customers. Most of the energy utilities used steel poles to carry the load power as steel pole gives more benefits over wood pole [1]. Thus, the design of steel pole must be long life, high strength, relatively light weight, low maintenance cost and environmentally friendly [2]. However, steel is prone to rust and corrosion of steel poles become critical damaging problem as the corrosion activity is reduced mechanical strength and affect performance of steel poles. Besides, rusting or corrosion process caused the poles surface to become unsightly. There are many reasons and environmental factors influence the corrosion of poles, such as temperature, pH (level of acidity and alkaline) and salinity. Corrosion activity due to environmental factors are difficult to control. The corrosion process is take place as electrochemical reaction at the metal interface occur with presence of water, oxygen, and corrosion ion (Cl^- and F^-) [3]. Furthermore, the process will be accelerated as the acidic gases such as carbon dioxide, carbon monoxide and sulphur dioxide are combine between the chemical reaction [4]. Hence, for these reasons the steel poles are protected by various corrosion protection methods. For example, by using decreasing potential (cathodic protection and lowering oxidant concentration), increasing oxidation potential (anodic protection and oxidising additives), increasing pH, separating metal (metallic, paint and organic coatings) or alternatively use of alloys [5]. In this paper, five technologies of pole coating are used to act as steel protection. The coating technologies are epoxy, VEF polyglass, galvanised, epoxy galvanised, and VEF polyglass galvanised are used as steel poles protection.

Epoxy steel coating is a coating compound consists of two elements, which are epoxy resin and polyamine hardener as a catalyst. When both of these elements are mixed in chemical reaction, it creates cross-linked between the elements. Thus, when the epoxy coating is fully cured, it produced excellent mechanical properties such as hardness, durability, abrasion, and chemical resistance. Epoxy coating is widely used in marine as protection of metallic materials from corrosion activity due to high efficiency in seawater [6]. Epoxy coating have good mechanical properties as it has high density of cross-linked, well adhesion to metal substances [7], good in acidic solution approach up to 97% efficiency [8], good chemical and corrosion resistance [9], flame retardant additives [10] and long-lasting layer of protection. The structure of epoxy is brittle but by chemical modification and additional of thermoplastic and inorganic phases this limitation could be overcome [11]. While galvanised steel coating, is a zinc protective layer on steel to prevent corrosion activity to occur. Galvanisation of steel results in formation of metallic bond of zinc with steel substrate which gives high integrity of coating. The galvanisation of steel provides double protection to the steel surface, as the zinc forms a compact oxide layer on its surface and acted as barrier protection. In corrosion process, zinc will sacrifice itself and provides cathodic protection to the steel pole [12]. The galvanised steel is widely used in application such as construction, utilities, transport infrastructures and so on. Usually, hot-dip galvanizing method is used as the process is simple and provide long term corrosion protection on steelwork. Besides that, it is a cost-effective method. During the process, a metallurgical bonded coating is created to protect the steel for both external and internal within hollow sections from harsh environments. Galvanised steel has been used as its beautiful appearance, good corrosion resistance, good mechanical properties and acted as sacrificial coating [13,14]. However, in normal industry environment corrosion of zinc is 25 times slower than steel even though zinc is more electronegative than iron [15]. The lifespan and durability of galvanised coating is depend on thickness of zinc coating deposited on the steel surface. Therefore, due to meet minimum weight prescribed in standards and economize the production cost, the thickness of zinc coating is reduced [16]. Hence, after exposed to rugged environments the galvanised is inherently more active and prone to corrosion. Next, VEF polyglass is vinyl ester or acrylic co-polymer loaded with flake glass and reinforced with fibre. Usually this coating is applied direct on the wet surface by spray application, after surface preparation is done. This coating technology has excellent resistance for demineralised water and good resistance to many solvents. Besides, VEF polyglass is potable water application. Therefore, in this study accelerated ageing test, salt spray test, and water absorption test are performed to simulate relative performance of steel pole coating technologies and corrosion severity due to corrosion activity.

II. MATERIAL AND METHODS

A. Material –

In this testing, the study samples are uncoated steel pole as reference, epoxy steel pole, VEF polyglass steel pole, galvanized pole, epoxy galvanized pole and polyglass galvanized pole. Each sample are labelled as in Table 1. The tested pole samples are cut in rectangular shape with 101.35mm length and 25.10mm width as shown in Fig 1. Table 2 is show chemical composition of coating for each sample.

Table -1 Tested samples

Sample	**Type of sample**
Sample A	Steel pole
Sample B	Epoxy steel pole
Sample C	VEF polyglass steel
Sample D	Galvanised pole
Sample E	Epoxy galvanised pole
Sample F	VEF polyglass galvanised pole

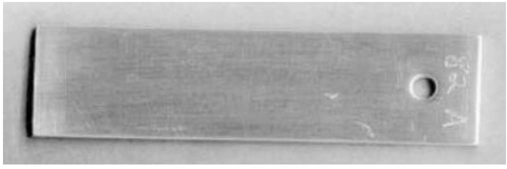

Fig. 1.Coupon size for testing sample

Table -2 Chemical composition of each sample

Material (%)	Mn	Fe
Sample A	1.03	98.36

Material (%) Sample B	Ti	V	Cr	Mn	Fe	Co
	30.91	0.664	0.089	0.5	66.07	1.2
	Cu	Ni	Zn	Zr	Nb	Mo
	0.226	0.183	0.056	0.046	0.009	0.008

Material (%) Sample C	Ti	V	Mn	Fe	Co	Ti
	38.27	0.808	0.403	52.24	1.8	38.27
	Cu	Zn	Zr	Nb	Mo	Cu
	0.226	6.03	0.046	0.013	0.014	0.226

Material (%)	Zn	Fe
Sample D	99.01	0.75

Material (%) Sample E	Ti	V	Mn	Fe	Co
	38.27	0.808	0.403	52.24	1.8
	Cu	Zn	Zr	Nb	Mo
	0.226	6.03	0.046	0.013	0.014

Material (%)	Ti	V	Fe	Zn	Zr	W
Sample F	29.2	0.404	0.781	64.22	0.025	5.22

B. Accelerated Aging Test –

The accelerated aging test consists of the following cycle, in the beginning the samples are exposed to 8 hours at 60 °C (± 2.5 °C) to ultraviolet (UV) radiation in a modified commercial QUV Accelerated Weathering Tester as show in Fig 2 [17]. For solar reflectors the lamp type UVA-340 is used. The lamps emit radiation in short wavelength-range of 295 to 365 nm with peak emission is at 340 nm. The radiation of UV emitted by UVA-340 lamps are almost same to natural sunlight as the spectral power distribution (SPD) of UVA-340 is very close to sunlight (see Fig 3). After that, the samples are

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exposed to 4 hours at 50 °C (± 2.5 °C) to condensation (100% relative humidity with 1.55 W/m2/nm irradiation) [18]. The total duration of one cycle is 12 hours (see Fig 4). Thus, in this work the samples are exposed to control environment based on American Society of Testing and Materials (ASTM) D5894-96 and ASTM D4587 as shown in Table 3. The testing is run for 1,968 hours.

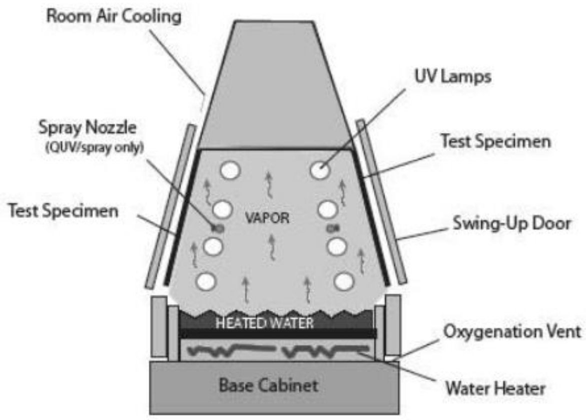

Fig. 2. QUV Accelerated Weathering chamber [17]

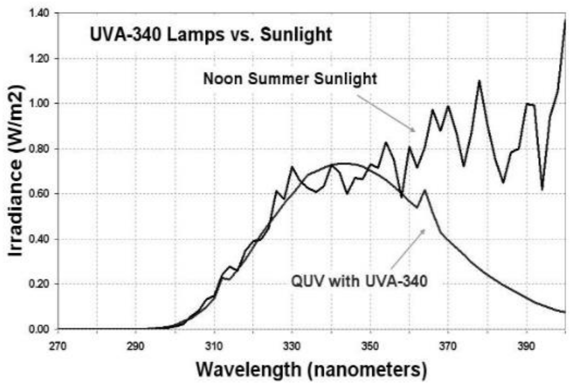

Fig. 3. UVA-340 lamps against sunlight [17]

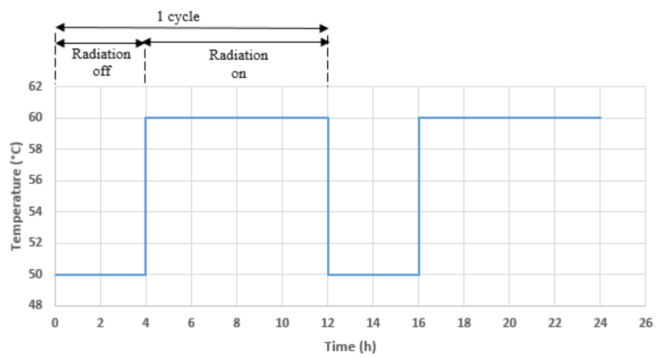

Fig. 4. Accelerated aging testing cycle

Table -3 Experiment result

Exposed condition	Condition level
Irradiance	1.55 W/m^2/nm
Wavelength	340 nm
Exposed cycle	Refer Cycle 4 based on ASTM D4587 8 hours of UV at 60 (±2.5) °C, black panel temperature 4 hours of condensation at 50 (±2.5) °C, black panel temperature Repeated continuously

C. Salt Spray Test –

The samples are tested according to ASTM B117 and this standard is widely used for salt spray testing. The samples are placed in enclosed chamber and exposed to continuous indirect of salt water solution at rate 1.0 to 2.0 ml/h on a surface of 80 cm^2 [19]. The chamber condition is set to 35 °C with a spray of sodium chloride (NaCl) solution by ratio of 5% sodium chloride and 95% of pure water, by weight. The pH of the salt solution is maintained at 6.5 to 7.2 which is used in NSS test (Neutral Salt Spray). The chamber climate is maintained under constant steady state condition and the test duration is variable, as show in table 4.

Table -4 Test duration

Batch	Duration
First batch	180 days
Second batch	360 day
Third batch	540 days

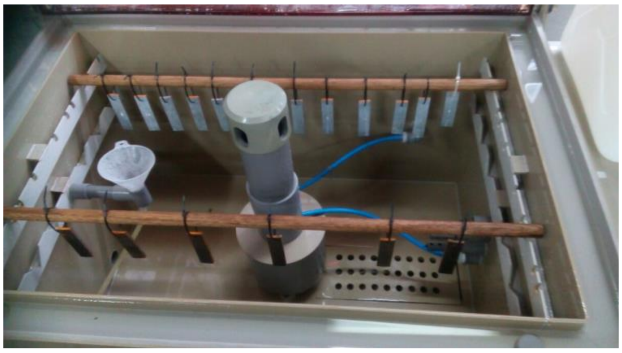

Fig. 5. Salt spray test

D. Water Absorption Test –

The water absorption test is conducted according to ASTM D570 to determine the amount of water absorbed by coated steel samples under specified conditions. The factors that influenced this testing are type of plastic, additives used, temperature and duration of exposure. The results obtained are represent the performance of the coating materials in water or humid environments. The samples were prepared by cutting into small rectangle shape with 50 mm diameter with 5 to 10 mm thick. The coating samples are initially dried in an oven for a specified time and temperature, and then placed in a desiccator to cool. In this method, the coating samples in

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initial dry weight are weighted. Next, the samples are immersed in a bath of distilled water at 23 °C and the duration of absorption as tabulated in Table 4. Each sample was removed from the water, wiped dry with a lint free cloth, and weighted again.

III. RESULT AND DISCUSSION

A. Accelerated Aging Test –

The different tests are performed to reproduce the observed degradation of steel pole coatings. By visual observation (see Fig 5), the uncoated steel pole is show signs of degradation while the other samples are still in good condition. The corrosion activity of the coated steel pole is still low as the samples are exposed to 1,968 hours in simulated outdoor condition. Therefore, coating thickness and corrosion thickness of each sample are measured to check the severity of corrosion. The coating thickness and corrosion thickness are measured by using ElektroPhysik coating thickness sensor and DM5E corrosion thickness gauge. Table 5 show the coating and corrosion thickness, while Table 6 show the weight of each sample before and after the test.

After the samples are stressed with simulated environment, it seems that the coating thickness of galvanised poles with coating of epoxy and VEF polyglass (Sample E and F) are increased to 3.39% and 0.95%. Same as galvanised pole (Sample D), the thickness is higher up to 0.95%. Inversely to steel poles, the coating thickness are decreased by -1.90% and -0.33% for epoxy and VEF polyglass (Sample B and C). The results show that the pattern of corrosion thickness and coating thickness are seem to be same. This indicate that, the corrosion thickness for galvanised poles with epoxy and VEF polyglass (Sample E and F) are increased to 21.21% and 12.35%. While steel pole coated with epoxy and VEF polyglass (Sample B and C) are decreased by -17.08% and -4.69%. Nevertheless, as predicted the corrosion activity on sample A is actively occur due to original uncoated steel. The corrosion thickness seems to be high at 17.14%. While for galvanised pole, the corrosion thickness is slightly reduced to -0.58%. In addition, the data show in table 5 is consistence to the measured data in table 6.

Table -5 Coating and corrosion thickness for different technology

Sample	Coating thickness (µm)			Corrosion thickness (mm)		
	Thickness before test	Thickness after test	Percentage different (%)	Thickness before test	Thickness after test	Percentage different (%)
Sample A	-	-	-	5.25	6.15	17.14
Sample B	5.53	5.43	-1.90	7.26	6.02	-17.08
Sample C	5.46	5.44	-0.33	5.97	5.69	-4.69
Sample D	4.90	4.95	0.98	5.13	5.10	-0.58
Sample E	5.14	5.31	3.39	4.95	6.00	21.21
Sample F	5.17	5.22	0.95	5.10	5.73	12.35

Table -6 Weight of tested samples

Sample	Weight before test (g)	Weight after test (g)	Percentage different (%)
Sample A	95.96	97.76	1.8
Sample B	93.32	92.51	-0.81
Sample C	100.44	100.41	-0.03
Sample D	95.79	95.77	-0.02
Sample E	87.55	91.93	4.38
Sample F	86.51	93.45	6.94

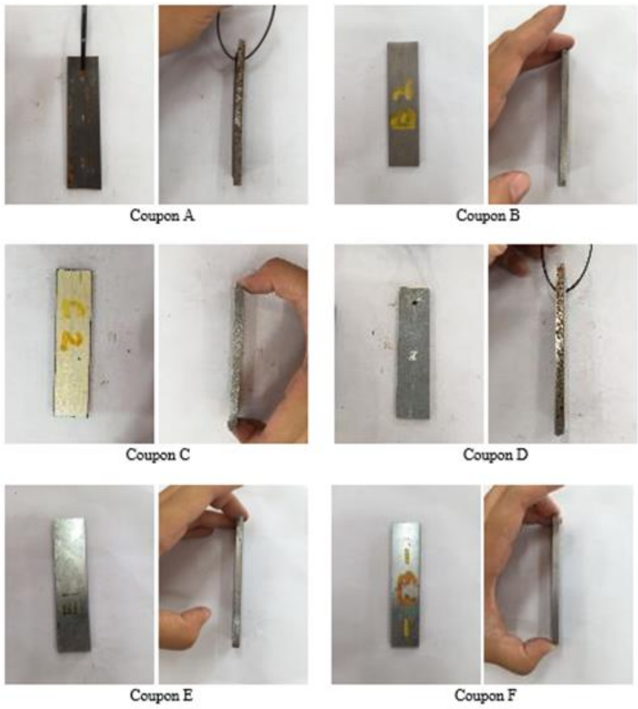

Fig. 6. Tested samples after undergo accelerated ageing life test

B. Salt Spray Test –

The salt spray test is used to evaluate corrosion process and coating degradation of each samples. The samples are tested in more realistic method by placed them in a controlled corrosive environment to produce relative corrosion information for each samples. The visual observation of corroded samples after 180 days in chamber is shown as Fig. 8. The effect of chloride was appeared on the six samples after the samples were tested for 180, 360 and 540 days. It can be seen that corrosion activity was aggressively occur at sample A as the color and physical condition of sample are changed. The sample A are heavily corroded as it is a bare steel. While for other samples, the rusting color is almost same as the corrosion activity seems to be uniform.

From the results, at 180 days the weight loss of tested samples was gaining weight as the chloride from salt spray was accumulated on the samples. Thus, it shows a negative value to

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percentage loss, as show in table 7.1. This indicate that the samples are gain of weight. Then, for next cycle at 360 days, the samples have a weight loss in between 0.7 % to 1.2 %. At this stage, acceleration of chemical reaction process was occurred due to presence of salt which acted as a catalyst to accelerate the corrosion process. From the table 7.2, sample F show the highest weight loss, 1.24 % in this process while sample B show the lowest weight loss, which gave to 0.70 % reduction of weight. As the duration was increased to 540 days, the layer of coating of samples tested were started to peel off. This process was indicated that more mass of the substrate element of the samples have fallen off due to weight loss up to 2.4 %.

Table -7.1 Weight of samples before and after salt spray test at 180 days

Sample	Before (g)	After (g)	Percentage of Weight (%)
Sample A	97.52	97.82	-0.31
Sample B	97.08	97.49	-0.42
Sample C	106.21	106.6	-0.37
Sample D	94.23	94.93	-0.74
Sample E	92.71	92.82	-0.12
Sample F	95.06	95.31	-0.26

Table -7.2 Weight of samples before and after salt spray test at 360 days

Sample	Before (g)	After (g)	Percentage of Weight (%)
Sample A	97.99	96.92	1.09
Sample B	98.22	97.53	0.70
Sample C	100.69	99.75	0.93
Sample D	97.24	96.18	1.09
Sample E	100	99.27	0.73
Sample F	93.69	92.53	1.24

Table -7.3 Weight of samples before and after salt spray test at 520 days

Sample	Before (g)	After (g)	Percentage of Weight (%)
Sample A	97.55	96.16	1.42
Sample B	92.71	91.59	1.21
Sample C	100.64	98.21	2.41
Sample D	95.94	94.79	1.20
Sample E	100	99.01	0.99
Sample F	93.7	92.23	1.57

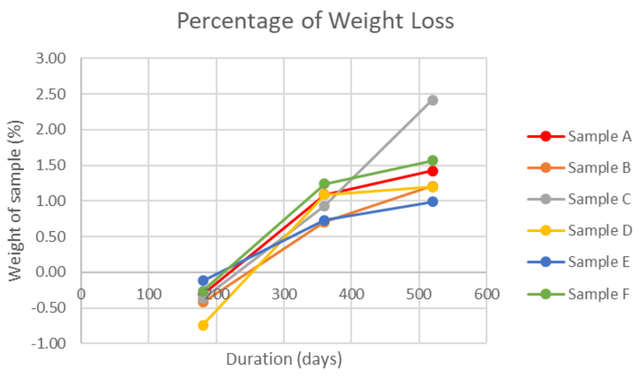

Fig. 7.Percentage of weight loss for 180, 360 and 520 days

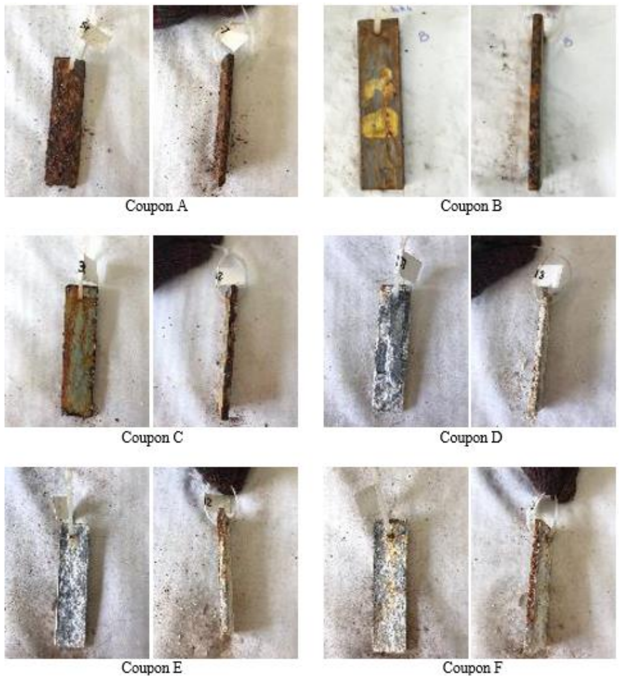

Fig. 8.Condition of each sample after undergo in salt spray chamber after 180 days

C. Water Absorption Test–

Water absorption test is conducted to determine amount of water absorbed by the steel pole coatings at specified conditions. The factors that affected the water absorption of pole coating layer are thickness of the coating layer, type of additive used, temperature of water, environment humidity and duration of sample exposure to water. The thickness of coating samples is 100 ums. In this study, the water absorption was measured by increased in weight percent. The formula used is [(Wet weight – Dry weight) / Dry weight] x 100. The absorption rates of each samples are shown in Table 8.

For this test, only four types of samples are measured as the sample A and sample D are not coated with any coating technology. From the graph, epoxy coating technology shows consistence results for steel pole (sample B) and galvanised pole (sample E). The trends for both samples are uniform, as the water absorption are decreasing (0.97 % to 0.48 % and 0.19 % to 0.1 %) against exposure time (duration). Inversely for VEF polyglass coating technology, the trend are not consistence between sample C and sample F. The trend of water absorption are increasing with maximum of 0.62 % and 0.55 % for steel pole (sample C) and galvanised pole (sample F).

Table -8.1 Weight of samples before and after absorption test at 180 days

Sample	Before (g)	After (g)	Percentage of Weight (%)
Sample B	97.5	98.45	0.97
Sample C	106.57	107.01	0.41
Sample E	92.76	92.94	0.19
Sample F	87.79	87.95	0.18

Table -8.2 Weight of samples before and after absorption test at 360 days

Sample	Before (g)	After (g)	Percentage of Weight (%)
Sample B	95.26	95.65	0.41
Sample C	102.75	103.09	0.33
Sample E	86.95	87.05	0.12
Sample F	94.48	95.17	0.73

Table -8.3 Weight of samples before and after absorption test at 520 days

Sample	Before (g)	After (g)	Percentage of Weight (%)
Sample B	97.30	97.77	0.48
Sample C	101.22	101.85	0.62
Sample E	91.20	91.29	0.10
Sample F	93.90	94.42	0.55

Table -8.4 Summary of water absorption rate based on duration of exposure to water

Duration (days)	Water absorption rate (%)			
	Sample B	Sample C	Sample E	Sample F
180	0.97	0.41	0.19	0.18
360	0.41	0.33	0.12	0.73
540	0.48	0.62	0.10	0.55

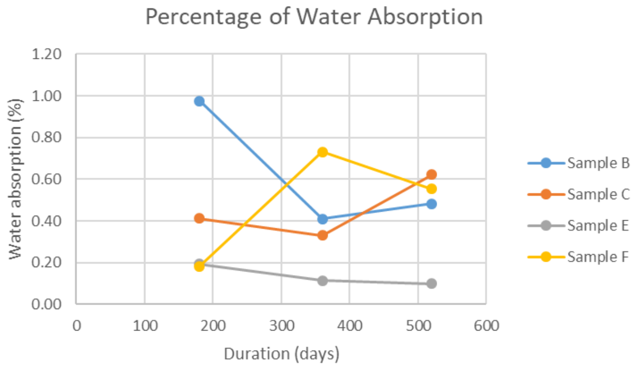

Fig. 9.Percentage of water absorption for 180, 360 and 520 days

IV. CONCLUSION

Five types of coating technologies for steel pole was studied on corrosion behavior. The steel pole was coated with epoxy, VEF polyglass, galvanised, epoxy galvanised, and VEF polyglass galvanised. In this paper, the accelerated ageing test was conducted for 8 hours of UV at 60 °C, and then 4 hours of condensation at 50 60 °C. This approach showed to lead to more realistic acceleration degradation for steel pole coating. The results showed the uncoated steel pole sample was heavily corroded, and only mild corrosion activity was occurred to the other samples. Hence, coating and corrosion thickness were measured to identify the severity of corrosion activity.

It was found that, the epoxy galvanised and polyglass galvanised poles showed a higher rate of corrosion activity as their weight and corrosion thickness are increased after the test. This indicated that formation of rust product. For example, a galvanic cell is formed as the zinc around the point of damage was corroded. The rusting products precipitate on the steel pole surface and the steel is protected because it is cathodic in relation to zinc (galvanised) coating. However, the epoxy steel and polyglass steel pole are corroded as the samples showed a weight loss and the corrosion thickness are seem to be actively reduced.

Then, the samples were placed in a closed chamber and expose to NaCl solution. The samples were tested up to 520 days. The weight of the samples was measured before and after the test. At first cycle, the samples showed a weight gain as the NaCl were accumulated on the samples. Then the samples have weight loss as the corrosion process were take part and the percentage of weight loss was between 0.73% to 1.24% at second cycle, and 1.0% to 2.4% at third cycle. VEF polyglass steel pole showed the highest weight loss followed by VEF polyglass galvanised pole. Next, the samples were immersed in water up to 540 days to identify the water absorption rate of coating technologies. The results showed that the epoxy coating of steel pole and galvanised pole gave a consistence absorption rate. The absorption rate of epoxy steel pole is higher than epoxy galvanised pole. However, for VEF polyglass coating, the results are not consistence. At first cycle and third cycle, the VEF polyglass coating for steel pole showed higher rate than galvanised pole. However, at second cycle the results are vice versa.

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