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CORROSION BEHAVIOUR OF LOW CARBON STEEL SHEETS FOR CAR BODIES

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ABSTRACT

This paper is a study on the corrosion behaviour and performance between coated and uncoated steel sheets which are used in car body manufacturing. The samples used are coated and uncoated steel plates taken from 3 different car models. ASTM B 117-90 Salt Spray (Fog) and ASTM D 2933-74 Corrosion Resistance of Coated Steel Specimens (Cyclic Method) corrosion test are carried out in order to study the corrosion behaviour and performance. The corrosion behaviour was determined by analyzing the surface and cross section of the samples by using scanning electron microscope whereas the corrosion performance was determined by mass loss method and visual examination. From the analysis it was found that for all three models the uncoated samples were attacked by uniform corrosion. Model 1 showed the best corrosion performance; followed by Model 2 and Model 3. The coating system for all three were able to protect the steel substrate from corrosive environment. However, blisters have formed on the surface of coated specimen of Model 3 after salt spray (fog) test which was due to the initial micro scratches on the coating.

***Keywords** : Corrosion, car body coatings*

1.0 INTRODUCTION

The current car users are facing a major problem because of corrosion which affects almost all parts of a car body. Corrosion of a motor car body is the result of the flow of electricity from one region of the metal (of the car) which is not well oxygenated (which acts as negative electrode) to another region which is plentifully supplied with oxygen (which is the positive electrode) and in the presence of water or an electrolyte [1]. Bad design consideration is the major cause of corrosion of car body. Usually car body designer address sales potential by designing attractive shapes and accountants monitor costs to meet price competition. Therefore, lack of consideration on corrosion prevention occurs. This factor increases the potential of corrosion to occur [1].

Car body normally suffers from crevice and general corrosion. Crevice corrosion usually occurs when constricted gaps are filled with water. When sheet metal component are welded together or onto members, brackets, etc., narrow gaps are almost invariably formed between the sheets. General corrosion mainly occurs in vehicles in large areas of uncoated steel, often wheel arches, where gravel thrown up by the wheels has worn away the protective surface coating of paint and underbody compound. General corrosion also occurs in underbody members and pillars that are penetrated by dampness [2].

Thus coating plays a major role on the protection of car body from corrosion. Various types of coating are used by car manufacturers to produce better car bodies to fulfill the customers need. However, cost factor limits this protection.

2.0 MATERIALS AND TEST METHODS

This research is based on car body coatings which are currently available in the market. Three cars which referred as Model 1, Model 2 and Model 3 are selected. The coated and uncoated plate of these car bodies are subjected to two accelerated corrosion tests which are the Salt Spray (Fog) Test (ASTM B 117-90) [3] and Corrosion Resistance of Coated Steel Specimens (Cyclic Method) Test (ASTM D 2933-74) [4]. The effectiveness of the coating was studied by comparing the corrosion behaviour and performance between the coated and uncoated plates of each car and finally comparison was made between all three car bodies coated and uncoated plates.

The as-received car body plates were cut to smaller samples with dimensions of 100mm x 50mm x 1mm. Seven plates were allocated for coated samples and five plates for uncoated samples. The uncoated samples were prepared by removing the coating layers by using the paint remover which is a well known high thinstopic gel to remove all type of paints and varnish.

Compositional analysis have been conducted on the coating layers and steel substrate by using Energy Dispersive X-Ray Analysis (EDX) and Arc Spark Spectrometer to identify the elements present and determine the composition of each layer.

For corrosion test; the samples were gently washed in clean running water and immediately dried with a stream of compressed air. The samples were then prepared in accordance to ASTM G 1-90 [5].

The samples were subjected to ASTM B 117-90 Salt Spray (Fog) Test and ASTM D 2933-74 for 14 days continuously. The samples were cleaned with the electrolytic solution of a mixture of 75g Sodium hydroxide (NaOH), 25g Sodium sulfate (Na_2SO_4), 75g Sodium carbonate (Na_2CO_3) and 1000ml of distilled water followed by ultrasonic cleaning [5].

Finally, the samples are labelled and divided to each accelerated corrosion test as indicated in Table 1.

Table 1: Samples allocated for ASTM B 117-90 and ASTM D 2933-74 test

	ASTM B 117-90		ASTM D 2933-74	
	type of sample	type of sample	no. of samples	no. of samples
model 1	Uncoated Coated	Uncoated Coated	S4, S5 S5, S6, S7	S2, S3 S2, S3, S4
model 2	Uncoated Coated	Uncoated Coated	S4, S5 S5, S6, S7	S2, S3 S2, S3, S4
model 3	Uncoated Coated	Uncoated Coated	S4, S5 S5, S6, S7	S2, S3 S2, S3, S4

3.0 RESULTS AND DISCUSSION

3.1 Compositional Analysis

Normally, a car body contains two or three layers of different types of coatings. These are the metallic sacrificial coating, primer (antirust) coating and the paint (color and gloss) coating.. However, some car manufacturers exclude sacrificial metallic coating due to the economic factor.

For Model 1, the coating system consists of sacrificial metallic coat, primer coat and paint coat. As for Model 2 and 3, the coating systems consist only of primer and paint coatings. Table 2 shows the result of EDX analysis on each layer of the coating system for all the three models. Model 1 has additional Zn-Fe sacrificial metallic coat. The primer and metallic based paint coat of all the three models is nearly the same since the elements present are similar. All the three models use TiO_2 (whites) as pigment in their metallic based paint. Titanium oxide is one of the most popular white pigment used in car body paint or finishing coat.

From the compositional analysis using the Arc Spark Spectrometer, the substrate metal is identified as ultra low carbon steel. Steel substrate of Model 1 and Model 2 contains 0.01% of carbon whereas Model 3 contains 0.043% of carbon.

Table 2: Elements present in coating system

	Sacrificial metallic coating	Primer (antirust) coating	Paint (color and gloss) coating
Model 1	Zn-Fe alloy	Al, Ti, O, Si, Pb	Ti, C, O, Si, Mo, Al
Model 2	-	Fe, O, Pb, Si, Al, Ti, Zn	Ti, C, Si, Al, O
Model 3	-	Si, Al, Mg, Ca, Zn	Ti, C, Al, O

3.2 Corrosion Behaviour

Microscopic examination is applied for both coated and uncoated samples. The samples were analyzed both on the surface and at cross section in order to determine the form and corrosion behaviour respectively. Figures 1 and 2 show the microscopical comparison between all the models' uncoated sample on surface and cross section respectively whereas Figures 3 and 4 show the microscopical comparison between all the models' coated sample on surface and cross section respectively.

For Model 1 the uncoated sample corroded uniformly all over the surface for both tests but the salt spray result was more severe than the cyclic test result. Thus the form of corrosion here can be concluded as uniform corrosion. In addition there were no cracks, pits and other form of corrosion attack (cross section) observed. On the other hand, the coated samples did not corrode but the color and glossiness faded. There was no corrosion product under the coating film (filiform corrosion). Besides, EDX test result shows, there is no chloride ion at the intermediate of the coating films (Figure 5a). Thus, it can be concluded that the density of cross linking of model 1 coating system is good.

For Model 2, the microscopical examination and EDX analysis (Figure 5b) shows the same result as for Model 1 in both tests except the uncoated sample of Model 2 corrodes more severely than the uncoated sample of Model 1. This phenomenon occurs because there is no zinc layer present for model 2's uncoated sample. Thus the steel substrate was vulnerable to the corrosive environment.

For Model 3, the uncoated sample rusts almost similarly as the uncoated sample of Model 2 in both tests. Both these models have no zinc or any other sacrificial metallic coating. For the coated sample, blisters were observed on the surface of the plate eventhough the coating system used in Model 3 is almost similar to Model 2. This is caused by the initial micro scratches on top of the paint coating surface. Analysis on cross section of the samples shows that there was no corrosion product under the coating film or signs of filiform corrosion. However, chloride ion was detected at the intermediate of the coating films (Figure 5c). This proves that the chloride ion has already penetrated the coating system.

Oxygen and water molecule can diffuse through a penetrated coating system. However, car body coating system is one of the most dense cross linking system which resists or limits this diffusion. However, in this case aggressive ion chloride could penetrate the coating system due to mechanical failure of the paint such as scratches. The result shows that the substrate steel is still protected by the coating system by the end of the exposure period and the blisters observed were caused by the diffused distilled water molecule and not by corrosion product. However, there is no formation of blisters observed in the cyclic test. This is due to the short period of exposure in salt fog environment.

3.3 Corrosion Performance

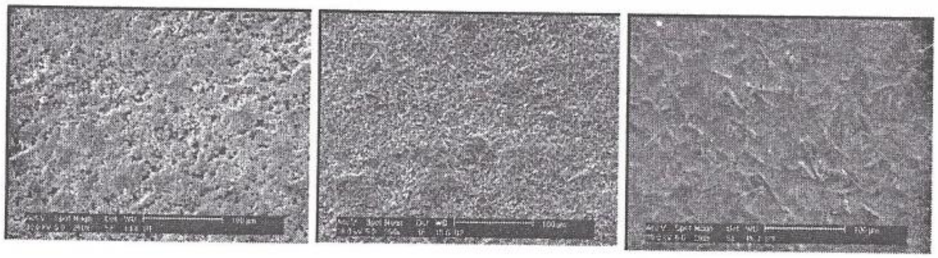
3.3.1 Corrosion Rate Based on Mass Loss Method

As mentioned earlier, mass loss method is a conventional method to determine the corrosion rate. This method is only applicable to uncoated samples. The mass loss method is used to determine the corrosion rate based on salt spray (fog) test (ASTM B117-90) and corrosion resistance of coated steel specimens (cyclic method) test (ASTM D 2933-74). The corrosion rate is calculated in mils per year (mpy). The constant, K for the calculation of corrosion rate is 3.45×10^6.

Tables 4 and 5 show that the uncoated sample corrode more rapidly when exposed to salt spray test compared to cyclic test. It shows that salt fog environment is more corrosive than the cyclic environment.

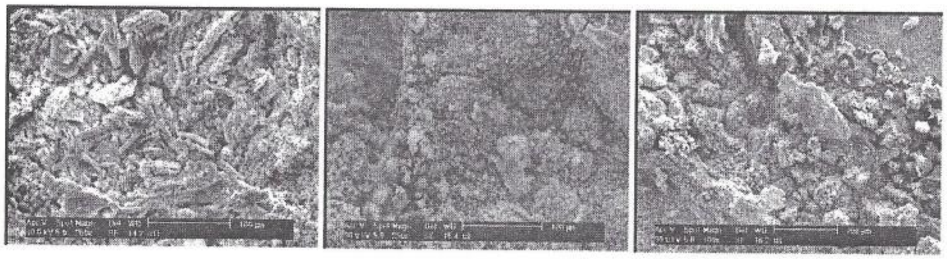
Model 1 corrodes the least compared to Models 2 and 3 in both tests. This is because of the Zn-Fe sacrificial metallic coating that has a high corrosion resistance property. The severity of uniform corrosion of Model 2 and 3 is almost similar (based on microscopical examination on the surface topography of the models after corrosion tests) since both do not have any extra sacrificial metallic coating. However, their corrosion rates are not similar. This may due to the carbon and impurities content in both steel substrates.

The calculated corrosion rate of Model 1 uncoated sample is only approximate since the density used in the calculation is not the density of Zn-Fe alloy but the density of pure zinc. Furthermore, the corrosion might occur on the steel substrate after the Zn-Fe layer fully corrodes. Thus, the corrosion process involves two anodes which is zinc and steel substrate. Therefore, the corrosion rate determined by mass loss method for this sample is only an approximate.



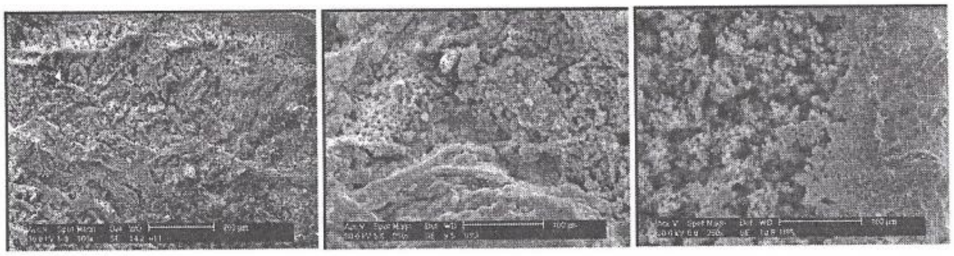
Model 1 Model 2 Model 3

(a) Before accelerated corrosion test



Model 1 Model 2 Model 3

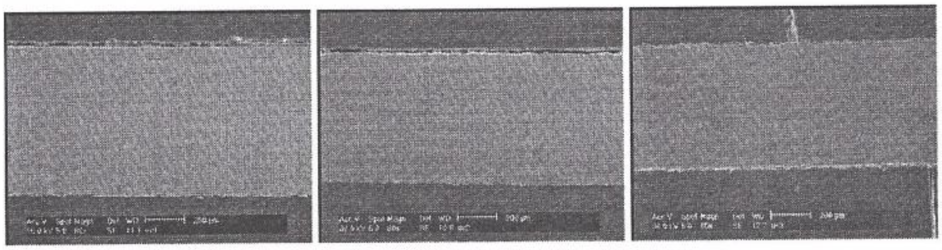
(b) After ASTM B 117 salt spray test



Model 1 Model 2 Model 3

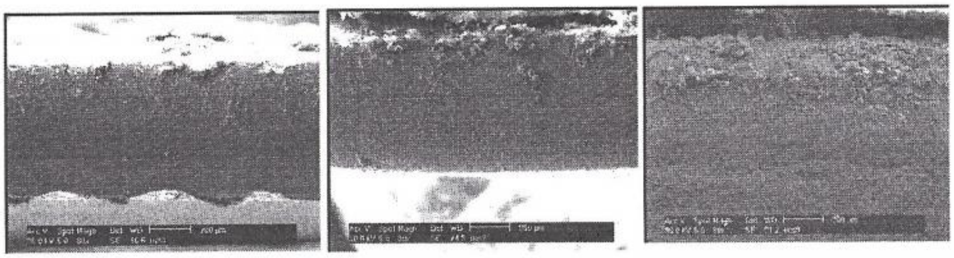
(c) After ASTM D 2933 corrosion resistance of coated steel specimens (cyclic test)

Figure 1: Comparison between all the models' uncoated sample (surface topography)



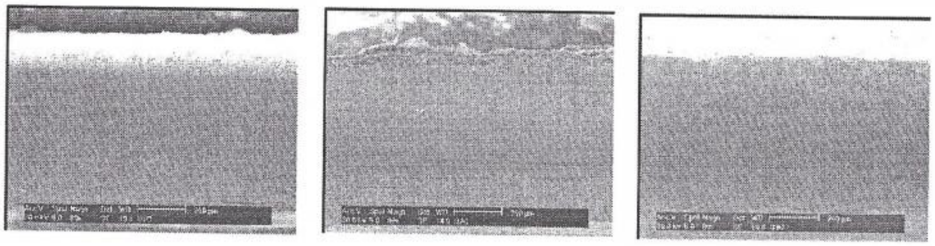
Model 1 Model 2 Model 3

(a) Before accelerated corrosion test



Model 1 Model 2 Model 3

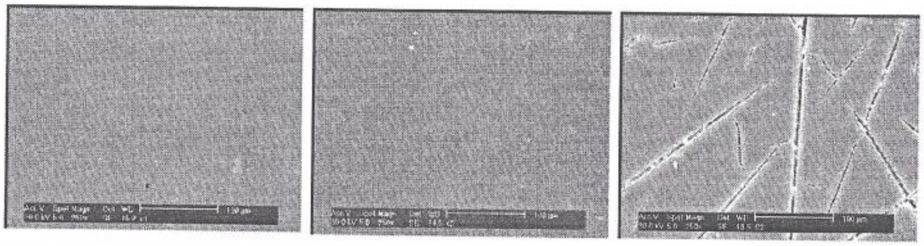
(b) After ASTM B 117 salt spray test



Model 1 Model 2 Model 3

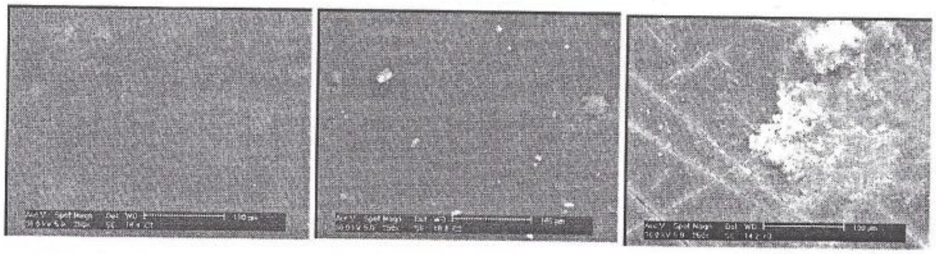
(c) After ASTM D 2933 corrosion resistance of coated steel specimens (cyclic test)

Figure 2: Comparison between all the models' uncoated sample (cross section)



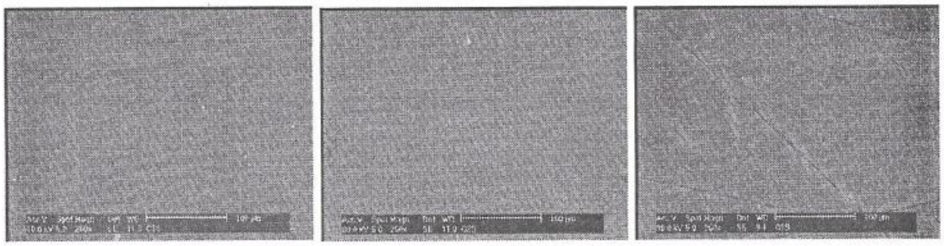
Model 1 Model 2 Model 3

(a) Before accelerated corrosion test



Model 1 Model 2 Model 3

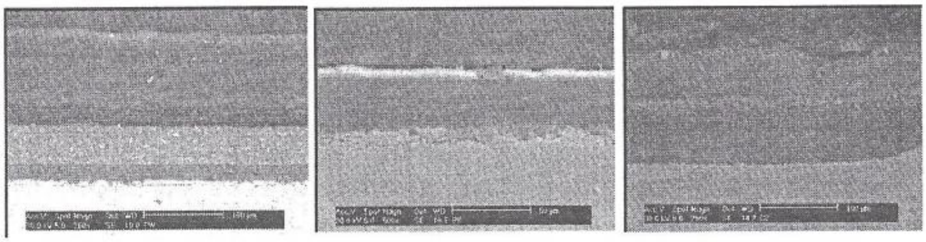
(b) After ASTM B 117 salt spray test



Model 1 Model 2 Model 3

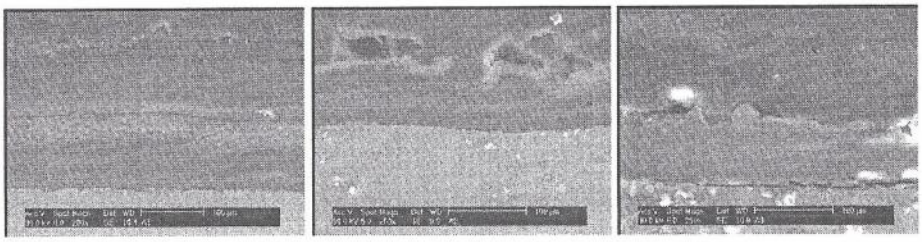
(c) After ASTM D 2933 corrosion resistance of coated steel specimens
(cyclic test)

Figure 3: Comparison between all the models' coated sample (surface topography)



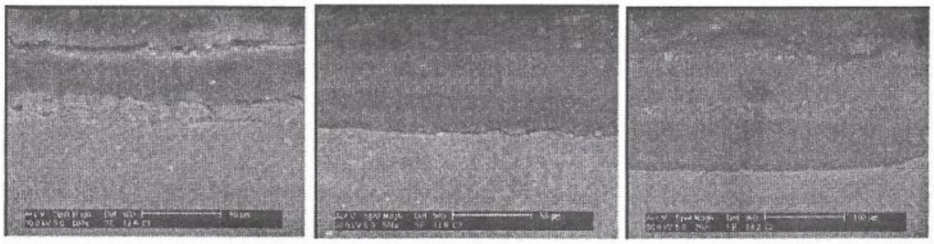
Model 1 Model 2 Model 3

(a) Before accelerated corrosion test



Model 1 Model 2 Model 3

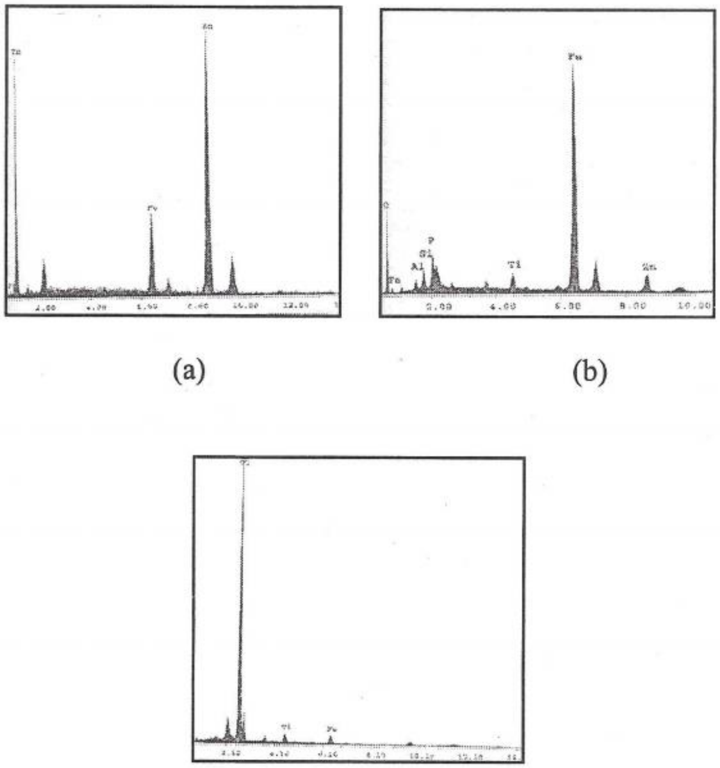
(b) After ASTM B 117 salt spray test



Model 1 Model 2 Model 3

(c) After ASTM D 2933 corrosion resistance of coated steel specimens (cyclic test)

Figure 4: Comparison between all the models' coated sample (cross section)



(a) (b)

(c)

Figure 5: Result of EDX at the intermediate of coating system after corrosion test (a) Model 1, (b) Model 2, (c) Model 3

3.3.2 Visual Examination

All samples were observed by naked eyes in reference to the standard sample to determine the percentages of the area rusted and rust grade. The rust scale is from 0 to 10; whereby 10 for no rusting or less than 0.01% of surface rusted and 0 for approximately 100% of surface rusted [6]. A typical grid is used as an evaluation aid.

This method cannot be used to evaluate the uncoated sample of Model 1 since the samples has a metallic coating (galvanized). This standard method is only used to evaluate painted steel surface. There are other standard which are used to analyze the corrosion involving metallic coating.

Table 3: Corrosion rate based on mass loss method for ASTM B 117-90 test

Model	Samples	Initial Mass (g)	Mass After ASTM B 117 Test (g)	Mass Loss (g)	Corrosion Rate (mpy)
Model 1	uncoated				
	S 2	30.25	29.92	0.33	9.478
	S 3	30.49	30.14	0.35	10.078
Model 2	uncoated				
	S 2	24.93	24.01	0.92	28.658
	S 3	28.71	27.75	1.02	27.295
Model 3	uncoated				
	S 2	26.74	25.56	1.18	30.869
	S 3	28.50	27.26	1.20	31.892

Table 4: Corrosion rate based on mass loss method for ASTM D 2933-74 test

Model	Samples	Initial Mass (g)	Mass After ASTM D 2933 Test (g)	Mass Loss (g)	Corrosion Rate (mpy)
Model 1	uncoated				
	S 4	31.77	31.68	0.09	2.865
	S 5	30.61	30.51	0.10	2.860
Model 2	uncoated				
	S 4	27.97	27.73	0.24	6.637
	S 5	26.13	25.93	0.20	5.836
Model 3	uncoated				
	S 4	27.10	26.80	0.30	7.999
	S 5	26.50	26.22	0.28	7.647

From Tables 6 and 7, it is clear that the uncoated samples rust uniformly all over the surface for both accelerated corrosion tests. However, this method could not differentiate the severity of rusting. For example, both uncoated samples of Model 1 and 2 are graded as 0 because the entire surface rusted even though Model 2 rusts more severely than Model 1.

The coated samples of all the three models did not rust. Thus all the samples are graded as 10. However, coated sample number 4 of Model 3 shows some blistering but there are no signs of rust or other corrosion product.

It is clear that the coated samples are more corrosion resistant than the uncoated samples for all the three models. The coating system on all three models are able to protect the steel substrate in both accelerated corrosion tests.

The coating system which is used in all the car models is metallic based paint. Generally paint protects the steel substrate by insulating the steel from the environment (barrier coatings), by inhibiting the attack on the steel substrate (inhibitive pigments/primer) and by galvanic action (metallic based paints). Barrier coatings are involved in all types of paints but inhibitors and galvanic action are involved only in certain paints. Metallic based paint which is used for car body finishing covers all the three types of protection.

Table 5: Evaluation and degree of rusting for salt spray (fog) test result

Model	Samples	Area Percentage,%	Rust grade
Model 1	Uncoated		
	S 2	-	-
	S 3	-	-
	Coated		
	S 2	0	10
	S 3	0	10
	S 4	0	10
Model 2	Uncoated		
	S 2	100	0
	S 3	100	0
	Coated		
	S 2	0	10
	S 3	0	10
	S 4	0	10
Model 3	Uncoated		
	S 2	100	0
	S 3	100	0
	Coated		
	S 2	0	10
	S 3	0	10
	S 4	0	10

The corrosion process of steel substrate can be prevented or retarded by suppressing either the cathodic or anodic reaction or by inserting a high resistance in the path of the corrosion current flowing in the electrolytic cell. The cathodic reaction can be suppressed by preventing the passage of oxygen and moisture to the steel substrate. However, all types of paints, including metallic based paint is permeable to diffusion of oxygen and water to a certain degree [7].

Paint film is permeable for suppression of the cathodic reaction. The anodic reaction can be suppressed by supplying electrons from an external source and so making the potential of the iron sufficiently negative to prevent corrosion. This is achieved by using metallic based paint. Polymer based paint do not contain free electrons, so cathodic protection will not operate. However, the presence of metallic pigment in metallic based paint used for car body finishing, fulfills this role by supplying the necessary electrons to suppress the anodic reaction. Presence of inhibitors in this metallic based paint also suppress the anodic reaction by passivating the anodic areas on the steel substrate [7].

Table 6: Evaluation and degree of rusting for corrosion resistance of coated steel specimens (cyclic method) test result

Model	Samples	Area Percentage,%	Rust grade
model 1	Uncoated		
	S 4	-	-
	S 5	-	-
	Coated		
	S 5	0	10
	S 6	0	10
	S 7	0	10
model 2	Uncoated		
	S 4	100	0
	S 5	100	0
	Coated		
	S 5	0	10
	S 6	0	10
	S 7	0	10
model 3	Uncoated		
	S 4	100	0
	S 5	100	0
	Coated		
	S 5	0	10
	S 6	0	10
	S 7	0	10

Common method to suppress corrosion by painting is to impede the movement of ions through it or electrical resistance. The water molecule is small and able to penetrate into most organic coatings. Moisture can be absorbed in the intermolecular spaces or pass through the coatings. However, this is very difficult to occur in the case of metallic based paint. Thus, the use of metallic based paint protects well the steel substrate [7].

Since the environment is changed to more corrosive (accelerated corrosion test), presence of chloride ions maybe able to penetrate the paint and lower the electrical resistance. Thus, the diffusion of oxygen and moisture through the paint film will be easier and it is possible that there is a degree of ion exchange which leads to corrosion and deterioration of the coating. However, this do not occur. Thus, it can be concluded that the density of cross linking of metallic based paint which is used for all the three models is high. This conclusion is only based on 14 days exposure period in salt fog and cyclic environment. Nevertheless, over a period of time the entry of chloride ions will reduce the resistance of the paint film and this will lead to corrosion and deterioration of the coating.

All three models of uncoated steel plates corroded in both accelerated corrosion tests. However, only Model 2 and Model 3 steel plate rusted. This is because Model 2 and Model 3 are not galvanized as Model 1. Model 2 and Model 3 corrodes uniformly all over the surface with a dark brownish, Fe_2O_3 corrosion product. Model 1 also corrodes uniformly all over the surface but with white yellowish color corrosion product. The white color corrosion product is due to corrosion of pure zinc on top of the coating which is ZnO [8, 9]. The yellowish rust like corrosion product is due to corrosion of Zn-Fe alloy at the intermediate of the coating [10].

The thickness of zinc coating layer of Model 1 is approximately 6.37μm with pure zinc on top of the coating and Zn-Fe alloy layer below it. This Zn-Fe alloy layer produces brownish/yellowish, rust like corrosion product. Since zinc is corrosion resistant, the uncoated sample of Model 1 corrodes the least compared to the other two models which did not have any sacrificial metallic coatings.

For uncoated sample of Model 2 and 3, they corrode and rust almost similarly with flake shape dark brownish, Fe_2O_3 corrosion product. However, there is a difference in their corrosion rates based on mass loss. From the analysis, it is shown that the uncoated sample of Model 3 rusts slightly faster than Model 2. This maybe due to carbon content and other impurities in the steel substrate.

All models of coated samples did not corrode in both ASTM B 117 and ASTM D 2933 accelerated corrosion tests. However, the coated samples of model 3 blistered after the salt spray (fog) test. Blistering which is observed in Model 3 plate is a term used to describe a coating failure in which small or large round projections or pimples appear on the coating surface. There are two forms of blistering; one arises within the coating itself and the other is caused by corrosion of the substrate. Blistering within coatings is generally caused either by solvents which are trapped within or under the paint film, or by water which is drawn through the paint film by the osmotic forces exerted by hygroscopic salts at the paint-substrate interface. The gas or the liquid then exerts a pressure and, if it becomes greater than the cohesive strength of the paint film, the blisters break [7].

4.0 CONCLUSIONS

1. Coating is very ideal for decorative and corrosion protection purpose of ultra low carbon steel based car bodies. All the three models coating system protects well the steel substrate from corrosive environment.
2. Zn-Fe sacrificial metallic coating able to protect the steel substrate more efficiently in saturated environment compared to salty environment. This sacrificial alloy produces two types of corrosion products. First, a white color corrosion product which is ZnO (corrosion of pure zinc on top of the coating's

surface). Second, a yellowish rust like product which shows the corrosion of Zn-Fe alloy.

3. Micro scratches on a paint coating system allows the diffusion of moisture through it and forms blisters. The blisters will enlarge if the moisture continues to build under the paint coating.

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