Development of a Red Mud-Epoxy Intumescent Coating for Steel Structures

by

Mohd Amir Bin Mohd Asmadi

15021

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical)

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CERTIFICATION OF APPROVAL

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Approved by,

____

(AP. DR. Puteri Sri Melor)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2015

CERFITICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHD AMIR BIN MOHD ASMADI

ABSTRACT

The effect of red mud as filler in an intumescent coating with mixture of ammonium poly phosphate (APP), melamine (MEL), boric acid (BA), expandable graphite (EG), bisphenol A epoxy resin BE188 (BPA) and ACR hardener H-2319 was presented. Red mud is a waste product from Bayer process. It produces twice amount of red mud as waste compared to the alumina production. The amount of red mud was varied from 0 – 5 grams as to investigate the influence of red mud on the basic intumescent coating formulation on its fire retardant performance. The char expansion, residual weight of the intumescent coating and fire penetration test were executed. The coating went for furnace test at 500°C for 30 minutes as to analyze the char expansion and char structure. The optimum red mud amount as to get the largest char expansion was at 2 gram which is 3.69 times of the initial thickness. Fire test was conducted as to evaluate the heat penetration to the coated steel. The temperature of steel plate was recorded for 60 minutes at an interval of 1 minute. The results showed intumescent coating with red mud content protected steel at lower temperature compared to the constant formulation. With 2 gram of red mud, the coating successfully stabilized an impacting fire below 150°C for 60 minutes. The coating was characterized using thermal gravimetric analysis (TGA) at 10°C/min under N_2, over the whole range of temperature between 50-800°C. The red mud increased the residual weight by 1.86% at 1g of red mud while decreased the residual weight for 11.05% at 3g of red mud and constant residual weight produced as to compare to the constant IC formulation when 5g of red mud was used. Therefore, red mud influenced the performance of the basic intumescent coating on its fire retardant properties. Utilization of red mud as filler reduced the environmental pollution as well as contributing to the safety of the society.

ACKNOWLEDGEMENT

First and foremost, all praise and gratitude to Allah, by His blessing and guidance for me to complete this project. I would like to express my special gratitude to the project supervisor, AP. DR. Puteri Sri Melor Binti Megat Yusoff, who gives strong commitment to guide and assist me all the way through this project. Special appreciation to Ms Adiat Hadiyat, Mr. Ziahar, Ms. Qandeel Fatimah, Ms. Eza and Mr Ezran for sharing advices and guiding me to complete the project.

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NOMENCLATIVE

IC	Intumescent coating
RM	Red Mud
APP	Ammonium Poly Phosphate
BA	Boric Acid
EG	Expandable Graphite
MEL	Melamine
XRD	X-ray Diffraction
SEM	Scanning Electron Microscope
TGA	Thermal gravimetric analysis

CHAPTER 1

INTRODUCTION

1.1 Background

Steel is a common structural material which is used in offshore structures. However, steel will lose its structural strength at elevated temperature above 500°C. Thus, the main function of intumescent coating is to protect the steel for more than 1 hour where it can gives ample time for rescue and evacuation process if there is any fire accident happens. The coating will create an insulative char barrier as to prevent steel structure to sudden ruptures or collapse while creating more time for evacuation and extinguishing the fire [1].

In addition, the intumescent coating act as thermal insulation for a structural steel, as it can help to resist the spread of fire and maintain the steel composition in longer period of time. The synonyms of intumescent coating is passive fire protection (PFP) which means an insulating system designed to decrease heat transfer from fire to a structure. Commonly, intumescent coating consist of minimum of three main compositions; an acid source (ammonium polyphosphate), a blowing agent (melamine) and bounded by a resin binder.

As an intumescent coating is exposed towards heat, the surface begins to melt into highly viscous liquid and a series of chemical reactions occur. The acid source will decomposed into phosphoric acid which then combines with carbonic agent to form carbonaceous char. At the same time, the blowing agent decomposes releasing large volumes of non-flammable gases which cause the binder to expand many times from the initial thickness providing insulating protective char layer. As a result, a protective carbonaceous char is form to act as an insulative barrier between the fire and substrate.

The aim of this project is to investigate the influence of red mud in the basic intumescent coating formulation with different amount of red mud fillers. Hence, the optimum performance of intumescent coating will be investigated by conducting several tests. Red mud is a waste product produced in Bayer process. In order to extract alumina from bauxite ore, red mud is produced twice amount of the alumina production.

1.2 Problem Statement

Red mud (RM) is a waste product generated from the alumina refining of bauxite ore. From production of 1 ton of alumina, between 1 and 1.5 tons of red mud is generated [2]. Red mud has high pH value of 10.5-12.5. The alkaline seeps into the underground water due to instability of storage. The alkaline air borne dust also impacts on plant life [3]. Without any utilization and management of RM waste, it will pollute and damage the environment in the future. Thus, with this enormous supply of RM waste, this project will focus on investigating the potential application of red mud to act as filler in intumescent coating.

1.3 Objectives

The objective of this project was to investigate the influence of red mud in the basic intumescent coating formulation on its fire retardant performance. By adding red mud in 0 - 5 g, coatings were tested with furnace test and fire test. Results from both tests will determine the capability of red mud to be used as filler in a basic intumescent coating formulation.

1.4 Scope of Study

The project involved investigation on the influence of red mud in the basic intumescent coating formulation. Originally, red mud has large particle size and has high physically water bond content. In the early stage, dry and fine red mud were prepared by using oven and grinder respectively. The red mud was mixed into the basic intumescent coating formulation with curing agent which was epoxy and hardener. The coating heat resistance was tested with Bunsen burner test. The temperature of the steel plate is measured by using data logger. Besides, furnace test was used to measure the maximum char expansion of the coating. The char expansion thickness was measured using vernier caliper. The char morphology was characterized by using scanning electron microscope (SEM). Lastly, the residual weight of the intumescent coating will be test using Thermal Gravimetric Analysis (TGA).

CHAPTER 2

LITERATURE REVIEW

2.1 Materials

2.1.1 Red mud

Red mud is a reddish brown colored waste product generated from the alumina refining of bauxite ore [2]. It is the by-product of Bayer process which digests bauxite ore in concentrated sodium hydroxide (NaOH) solution at appropriate temperature and pressure. In addition, 1 tons of alumina generates between 1 and 1.5 tons of red mud according to the bauxite ore [2]. The red mud has high pH value within 10.5-12.5 and consists of iron, aluminum, titanium-oxide and hydroxide [3].

Table 2.1 shown below is the typical composition of red mud [3]. By knowing the red mud composition, excellent understanding of the chemical reaction and equation can be achieved.

Table 2.1: Typical composition of red mud [3]

Composition	Percentage
Hematite, Fe_2O_3	30-60%
Alumina, Al_2O_3	10-20%
Quartz, SiO_2	3-50%
Sodium Oxide, Na_2O	2-10%
Calcium Oxide, CaO	2-8%
Titania, TiO_2	trace-25%

To be more specific, Table 2.2 shows the major composition of red mud Australia. Red mud has high solid composition of Hematite (Fe_2O_3) follow by Alumina (Al_2O_3) and Quartz (SiO_2). [4]

Table 2.2: Composition of red mud generated at Australia [4]

Country	Major composition (wt%)				
	Fe_2O_3	Al_2O_3	SiO_2	TiO_2	Na_2O
Australia	40.5	27.7	19.9	3.5	1-2

In many research, red mud was not specifically used in intumescent coating. Mostly, red mud is applied in other fields such as building materials, metal recovery from red mud and ceramic production. Figure 2.1 shows the current potential applications of red mud. However, none of these applications has been economically applied on an industrial scale [4-5].

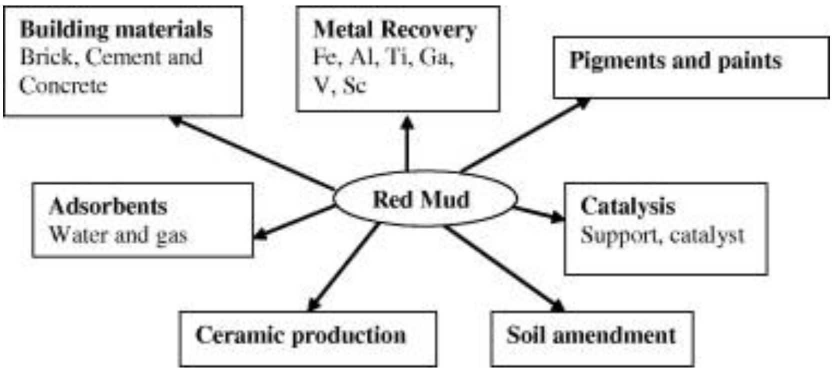


Figure 2.1: Potential applications of red mud [4]

2.2 Intumescent Coating basic formulation

An intumescent fire retardant coating is a substance when exposed to fire, it is able to expand as many times as its thickness forming an insulating layer of char which capable to protect steel structure from fire and retain the structural integrity. The intumescent coating will prevent the steel from rising to a critical temperature of 550°C and maintain the steel’s integrity for longer period in the event of fire [6].

Intumescent coating must consist of five basic compound groups; acid and carbon sources, blowing agent, a binder and pigments. In this project, ammonium polyphosphate (APP) is used as acid source, melamine (MEL) as blowing agent, boric acid (BA) as adhesion component between the coatings and steel, expandable graphite (EG) as carbon source, epoxy-amine resin used as binders and red mud (RM) as filler or pigment [6-10].

2.3 X-ray Fluorescence (XRF)

X–Ray fluorescence (XRF) is a method to determine the average percentage of red mud element composition in its oxidized form. XRF will also show the presence of traces such as Cr, Mn, Ni, Zn, Ga, As, Y and Pd elements in red mud. From XRF results, it is worth noting the dominant red colour of red mud due to the fair well dispersed particles of iron oxide (Fe_2O_3)[11-12].

2.4 X-ray Diffraction (XRD)

X-ray diffraction (XRD) is a method to determine the compound composition that is available in any material. The compositional differential of red mud is depending on the geographical location of bauxite from which it was obtained [12]. Many literature shows different results despite having some common composition that proven to be the main material in red mud.

Figure 2.2 (neglecting the XRD pattern for Bauxite) shows the x-ray diffraction (XRD) pattern of red mud sample from Awaso, Ghana, Africa. The peak from the pattern will prove the existence of a specific compound composition in red mud.

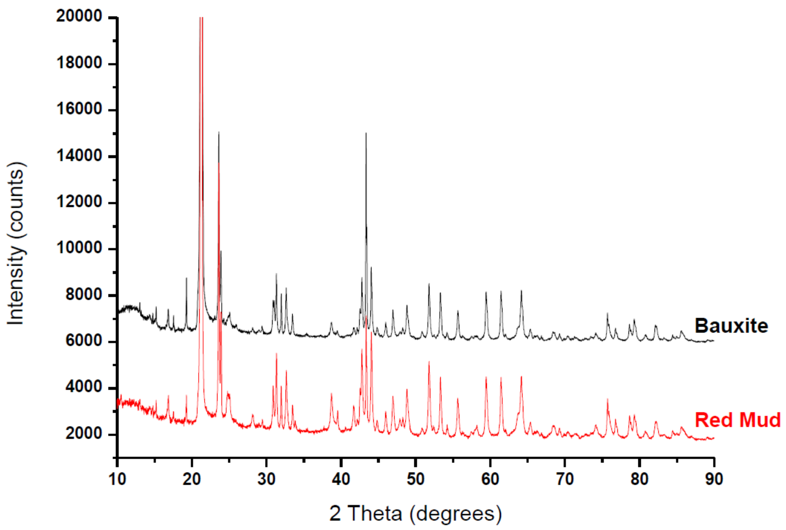


Figure 2.2: XRD pattern of red mud [12]

Table 2.3 is the interpretation of the XRD pattern of red mud. In many literature reviews, Hematite is commonly found in red mud and have the highest amount compared to other minerals regardless the location of red mud sampling [12].

Table 2.3: Main mineral phases of red mud [12]

Mineral	Formula	Card no.
Hematite	Fe_2O_3	33-0664
Rutile	TiO_2	21-1276
Perovskite	$CaTiO_3$	22-0153
Quartz	SiO_2,	18-1166
Sodalite	$Na_2O \cdot Al_2O_3 \cdot SiO_2$	16-0612
Boehmite	AlO(OH)	21-1307
Goethite	FeO(OH),	26-0792
Gibbsite	$Al(OH)_3$,	33-180
Calcium alumina silicate	$Ca_2Al_2(SiO_4)(OH)_8$,	03-0798

2.5 Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) can determine the mineralogy shape and size of any material. In Figure 2.3 and Figure 2.4, the red mud (particle diameter, 600 nm § 300 nm) are polycrystalline poorly-crystallized or amorphous. The sample with diameter of 300 nm shows more basic nature indicating higher surface area of contact with the base during alumina extraction process. This highly white colouration is expected as bauxite is digested in concentrated sodium hydroxide [13].

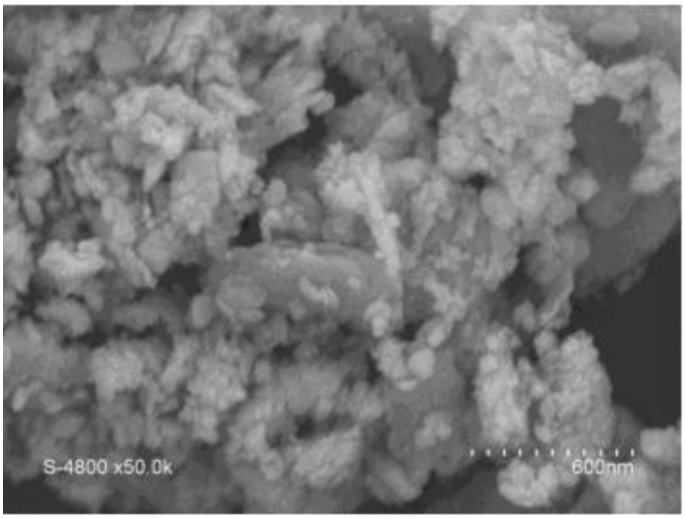


Figure 2.3: SEM image of red mud (particle diameter 600 nm) [13]

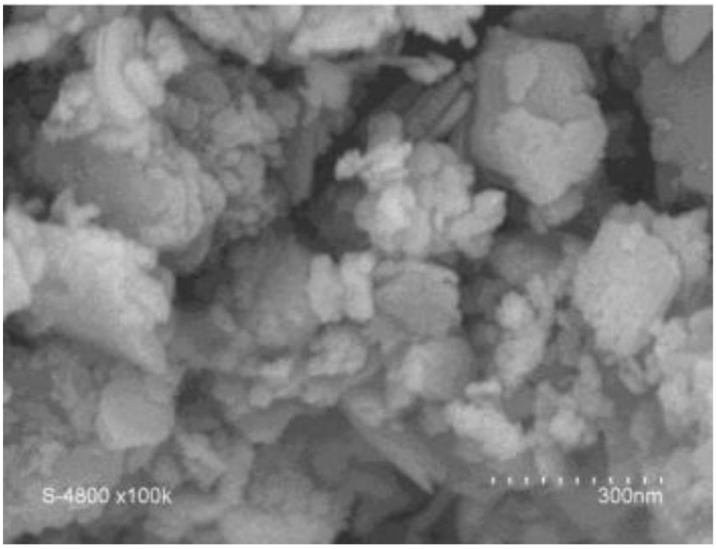


Figure 2.4: SEM image of red mud (particle diameter 300 nm) [13]

CHAPTER 3

METHODOLOGY

3.1 Flow Chart

The overall project flow chart is shown in Figure 3.1. The intumescent coating fire performances were tested using furnace test and Bunsen burner test. The coating and char were characterized using thermal gravimetric analysis (TGA) and scanning electron microscope (SEM) respectively.

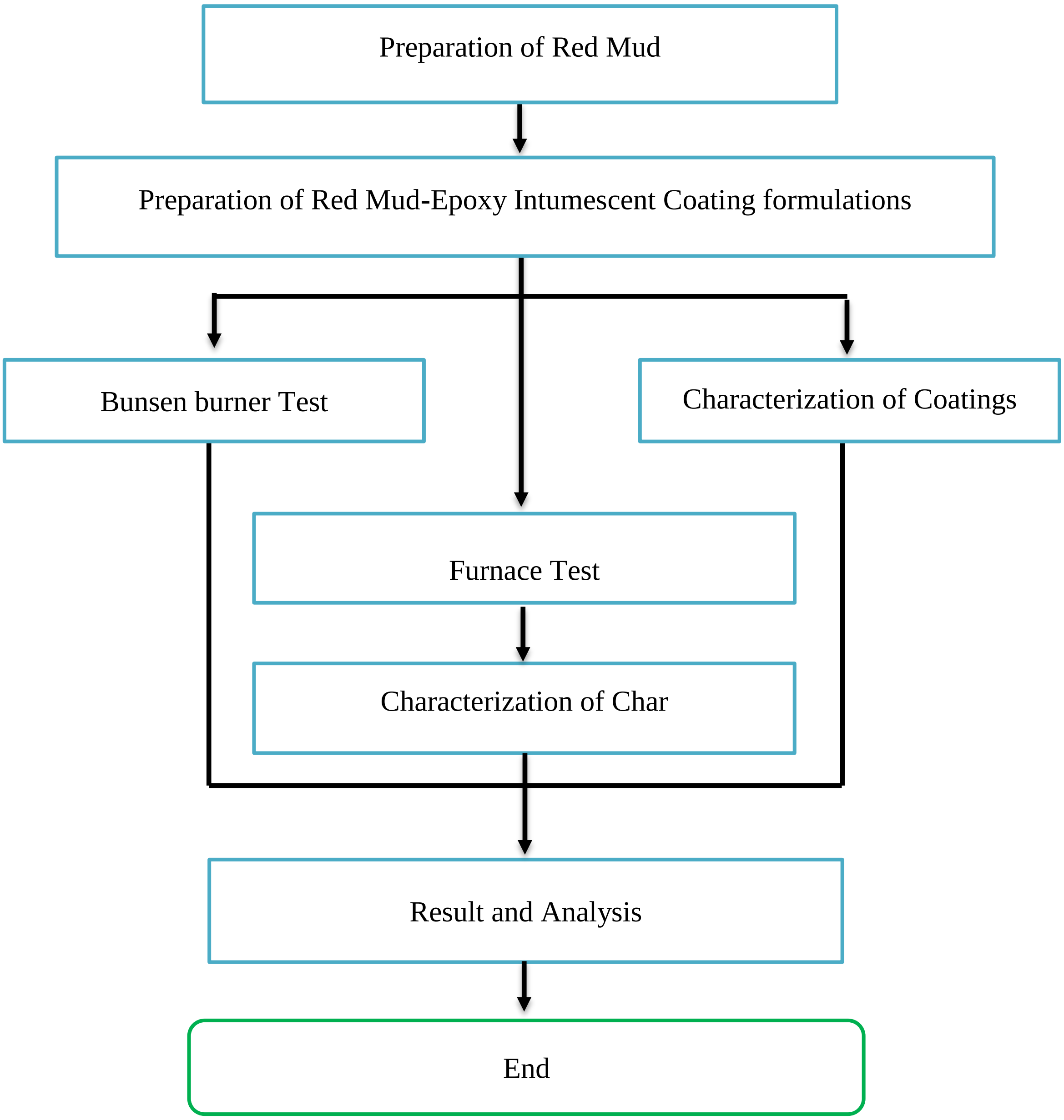


Figure 3.1: Project flow chart

3.2 Preparation of red mud

The red mud was dried in the Carbolite 450 oven at 105°C for 24 hours as shown in Figure 3.2. The drying of the red mud is to remove physical water bonding and to prevent clogging during sieving process.

Figure 3.2: Carbolite 450 Oven

Figure 3.3 shows the red mud which was cooled to room temperature in a container containing hygroscopic composition which absorbs moisture from air. This is to ensure the red mud do not create new bonding with moisture which is available in air.

Figure 3.3: Cooling of red mud at room temperature

In Figure 3.4, the red mud was crushed using mortar and pestle. This process is necessary as to produce smaller particle size for sieving process preparation.

Figure 3.4: Grounding with mortar and pestle

Figure 3.5 shows the crushed red mud was sieved at size 63 µm using sieving shaker. Uniform sized powder was obtained after sieving process. The smaller the sieving size, the more effective the red mud as pigment for intumescent mixture.

Figure 3.5: Sieving process using 63 microns sieve

3.3 Preparation of red mud-epoxy intumescent coating formulations

Using a predetermined formulation, 0 – 5 g red mud was added with ammonium polyphosphate (APP), melamine (MEL), boric acid (BA) and expandable graphite (EG) mixture. Table 3.1, shows the composition of 7 different formulations investigated. Each composition was based on 100% by weight. The mixture of APP-MEL-BA was on 3:1:3 ratio.

Table 3.1: Composition of the intumescent coating formulations

S/N	APP (g)	MEL (g)	BA (g)	EG (g)	RM (g)	Epoxy (g)	Hardener (g)
F1	13.125	4.375	13.125	4.375	0	43.42	21.71
F2	13.125	4.375	13.125	4.375	0.5	42.92	21.46
F3	13.125	4.375	13.125	4.375	1	42.76	21.38
F4	13.125	4.375	13.125	4.375	2	42.10	21.00
F5	13.125	4.375	13.125	4.375	3	41.42	20.71
F6	13.125	4.375	13.125	4.375	4	40.76	20.38
F7	13.125	4.375	13.125	4.375	5	40.10	20.06

Each formulation was weighed using digital weight machine and mixed together in a plastic cup as shown in the Figure 3.6.

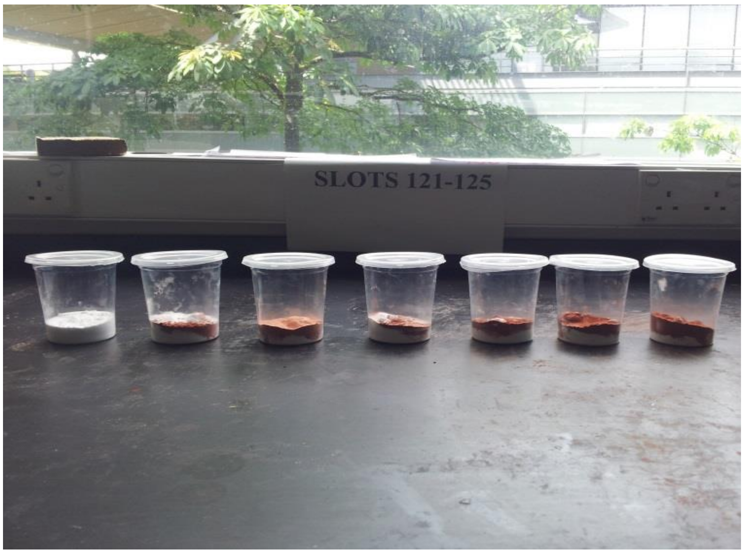


Figure 3.6: 7 Intumescent coating mixtures

In Figure 3.7, the mixtures were crush using mortar grinder for 60 seconds as to get uniform size and better spread of each composition in the mixture.

Figure 3.7: Mortar grinder used for mixing

Figure 3.8 shows the mixture before grinding while Figure 3.9 shows after grinding process. The powder was uniformly crushed and finer compared to the original size.

Figure 3.8: Before grinding process

Figure 3.9: After grinding process

The base formulation was prepared by mixing epoxy and expandable graphite for 10 minutes using shear mixture at 40 rpm as shown in Figure 3.10. After 10 minutes, both crushed mixture and hardener were mixed together into the base formulation. In Figure 3.11 shows the coating was continuously mixed for 20 minutes at 40 rpm.

Figure 3.10: Base formulation preparations

Figure 3.11: Mixing of IC composition

The coatings were applied on 100 mm x100 mm x 3mm and 40 mm x 40 mm x 3 mm steel plates with a plastic spatula. The coating was allowed to cure at room temperature for 7 days as shown in Figure 3.12.

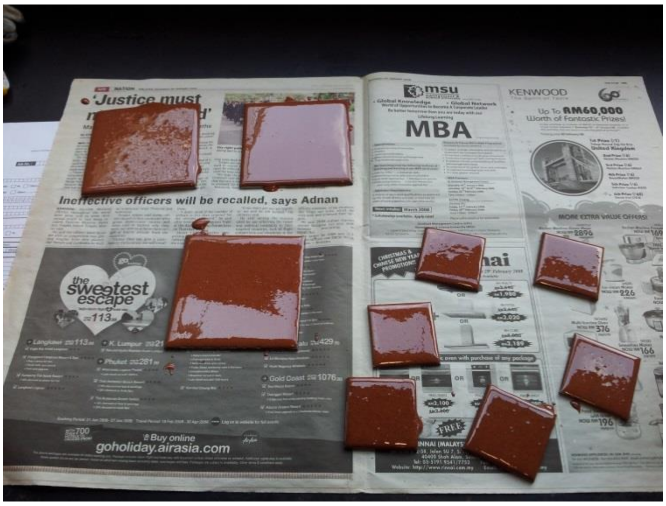


Figure 3.12: Intumescent coating on steel plates

3.4 Characterization of Coatings

The intumescent coatings were characterized for thermal properties using thermal gravimetric analysis (TGA) by which degradation transitional temperatures, degradation products and residual masses were determined.

3.5 Bunsen burner Test

The set of coated steel plates with dimensions 100 mm x 100 mm x 3 mm were subjected to heat from a portable Bunsen burner as shown in Figure 3.13. The distance of the coated steel and the burner was maintained 7 cm. Three thermocouples types K were connected to the back of the coated steel and the other end of the three thermocouples were connected to Anarittsu Data Logger, Input Channel 6 model AM-8000K with Anarittsu software. The temperature of the steel plate was recorded for 60 minutes at an interval of 1 minute. Butane gas was used during Bunsen burner test and temperature of the flame was determined using K type thermocouple. All temperature reading was recorded by data logger. The time taken before reaching the critical temperature of 500°C will also be recorded as a measure of the heat shielding efficiency.

Figure 3.13: Bunsen burner test setup

3.6 Furnace Test

Intumescent coating coated steel plates of dimension 40 mm x 40 mm x 3 mm were located in the Carbolite furnace as shown in Figure 3.14 and fired to a temperature of 500°C for 30 minutes. The furnace test was used to analyze the physical properties of char such as char expansion and char structure. The char expansion is measured using digital vernier caliper for four times as to get the average of the char expansion.

Figure 3.14: Furnace test setup

3.7 Characterization of Char

The char morphology was studied and elemental analysis carried out with the scanning electron microscope (SEM). SEM can show the char structure and distribution of composition throughout the coating. Besides, the char was characterized using thermal gravimetric analysis (TGA) at 10°C/min under N_2, over the whole range of temperature between 50-800°C by using TGA Q50 Perkin Elmer.

3.8 Research Timeline

The project will be carried out methodically based on the following timeline (Table 3.2 and Table 3.3). Each experiment will be carried out according to the timeline located.

Table 3.2: Gantt chart for phase I

2014 DEVELOPMENT OF RED MUD-EPOXY INTUMESCENT COATING															
No	**Description**	**Week**													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Identify Problem Statement, Objective and scope	■	■	■											
2	Literature Review		■	■	■	■	■								
3	Methodology:														
	Preparation of Red Mud							■	■	■					
	Preparation of RM-Epoxy IC formulations										■	■	■		●

Table 3.3: Gantt chart for phase II

2015 DEVELOPMENT OF RED MUD-EPOXY INTUMESCENT COATING															
No	**Description**	**Week**													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Furnace Test	■	■			●									
	Characterization of Char		■	■			●								
2	Bunsen burner Test			■	■	■		●							
3	Characterization of Coatings					■	■		●						
4	Data Analysis Phase:						■	■							
	Result and Experimental Analysis								■	■	●				
5	Final Report										■	■	■	●	

Progress	■	Milestone	●

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Treated Red Mud

63 micron red mud was prepared as shown in Figure 4.1. The red mud was ready to be used as filler in the basic formulation of intumescent coating.

Figure 4.1: 63 microns red mud

As for comparison, Figure 4.2 is the original red mud while Figure 4.3 shows the processed red mud. The difference can be detected in terms of powder size and colour. Figure 4.2 shows darker colour represents high water content in the red mud while Figure 4.3 had lighter colour since it was dried for 24 hours.

Figure 4.2: Original red mud

Figure 4.3: Processed red mud

4.2 X-ray Diffraction (XRD)

Both Figure 4.4 and 4.5 are the same result but Figure 4.5 shows the smoothened graph which can give more detailed information for analysis process. The graph shows the effect of x-ray intensity at different diffraction angle on the red mud specimen.

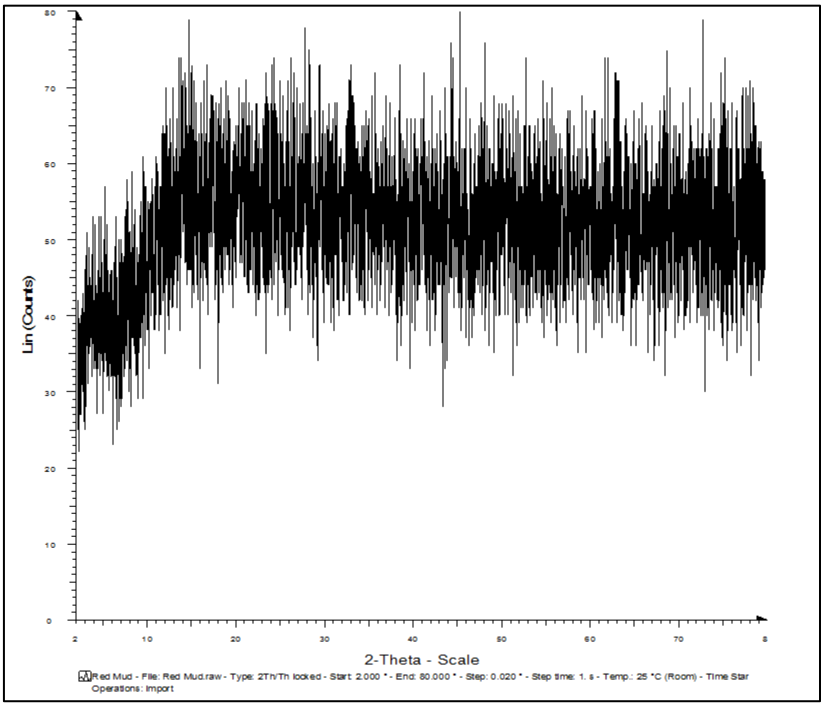


Figure 4.4: XRD raw graph of the red mud

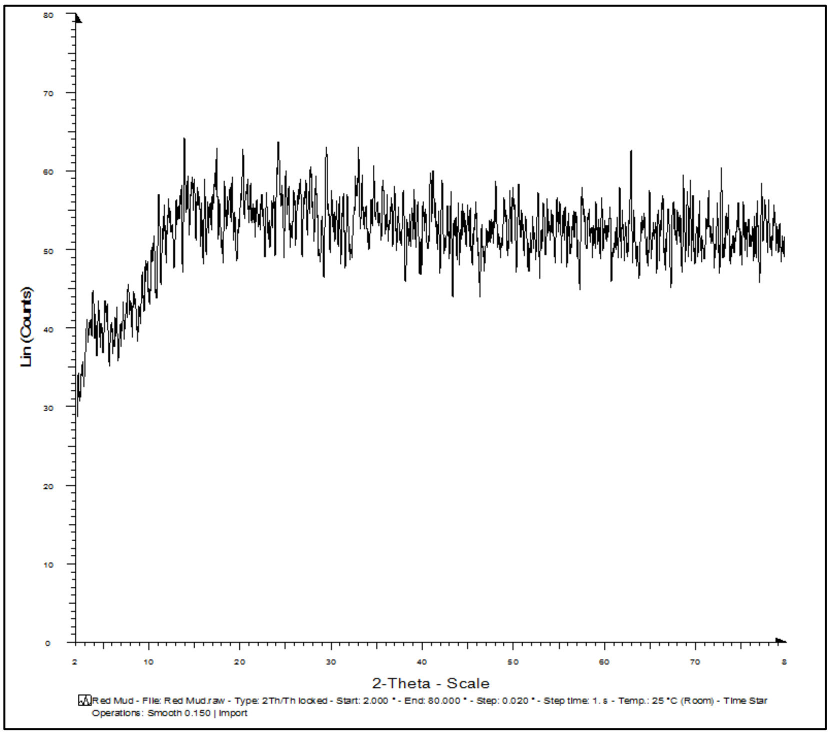


Figure 4.5: XRD smoothened graph of the red mud

Based on the XRD graph in Figure 4.5, there is no significant difference between each data at different diffraction angle. The graph implies no crystallization components since it is constantly diffracted in the range of 45 to 60 counts. Thus, the XRD graph shown above cannot determine the compound composition of the red mud. Therefore, the red mud must be further treated with heat treatment since there is possibility that an amorphous material could cover the crystalline phase.

4.3 Scanning Electron Microscope (SEM)

4.3.1 SEM of Red Mud

Figure 4.6 and Figure 4.7 show the red mud microscopic structure at 1000 times and 3000 times resolution respectively. From both figures, the red mud shows random, rounded solid and crystalline structures. Figure 4.8 shows the grain size of red mud is in the range of 0.95 μm to 5.35 μm. Figure 4.9 shows three spots that were used to analyze the elements in red mud at 1000 times resolution.

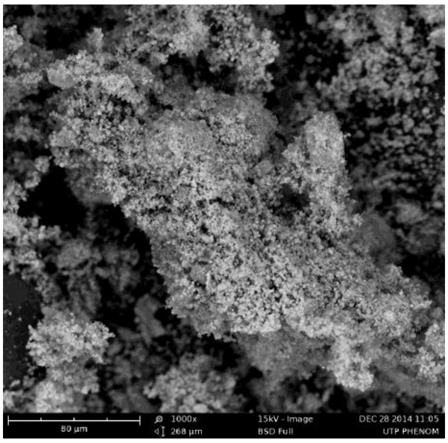


Figure 4.6: SEM image of dried red mud (1000x)

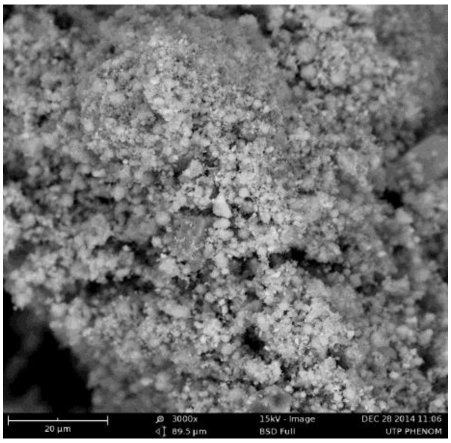


Figure 4.7: SEM image of dried red mud (3000x)

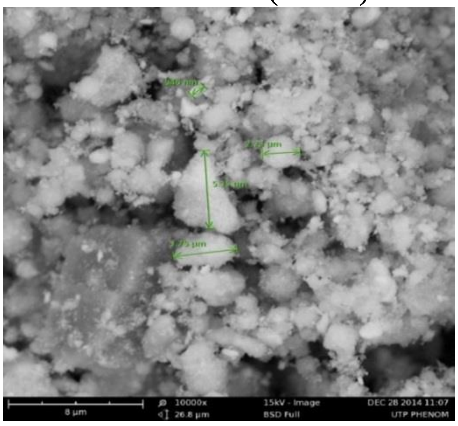


Figure 4.8: SEM image indicating grain size of red mud (10000x)

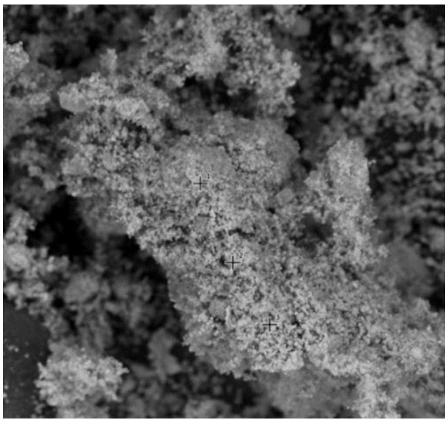


Figure 4.9: SEM micrograph of red mud (1000x)

The results in Table 4.1 shows the carbon content at spot 1 and fluorine at spot 2 and 3 have the highest concentration percentage among other elements. Small traces of aluminium were also present all 3 locations.

Table 4.1: Analysis of red mud obtained from SEM-EDX at three locations

Spot 1	Concentration (%)	Spot 2	Concentration (%)	Spot 3	Concentration (%)
Carbon	31.8	Carbon	14.7	Carbon	15.7
Nitrogen	22.9	Fluorine	42.1	Fluorine	43.6
Fluorine	23.7	Strontium	4.8	Oxygen	18.8
Strontium	2.5	Rubidium	5.1	Strontium	4.5
Oxygen	14.3	Oxygen	17.8	Yttrium	3.8
Yttrium	2.1	Yttrium	5.2	Rubidium	3.4
Rubidium	1.9	Nitrogen	7.1	Nitrogen	8.6
Aluminium	0.8	Aluminium	1.8	Aluminium	1.4
		Magnesium	1.3		

4.3.2 SEM of Red Mud Intumescent Coating

Figure 4.10, Figure 4.11 and Figure 4.12 shows the red mud intumescent coating (Formulation 7) at 500 times, 1000 times and 1500 times respectively. The intumescent coating has sharp and solid structures covered by crystalline structure which was red mud. The red mud was evenly distributed and combined with other composition of intumescent coating.

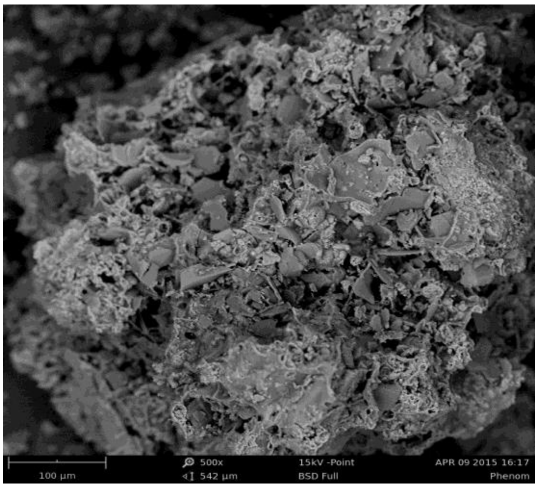


Figure 4.10: SEM image indicating grain size of red mud IC (500x)

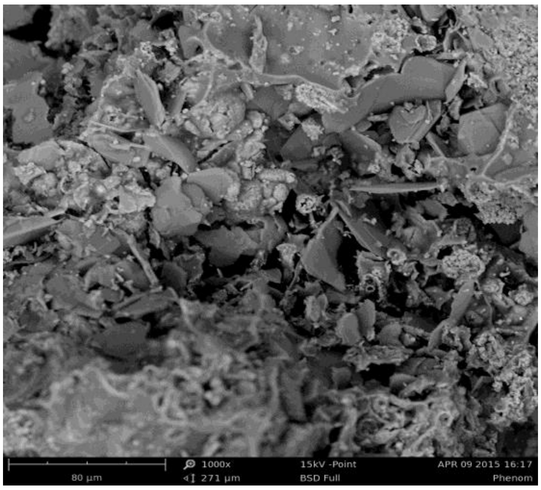


Figure 4.11: SEM image indicating grain size of red mud IC (1000x)

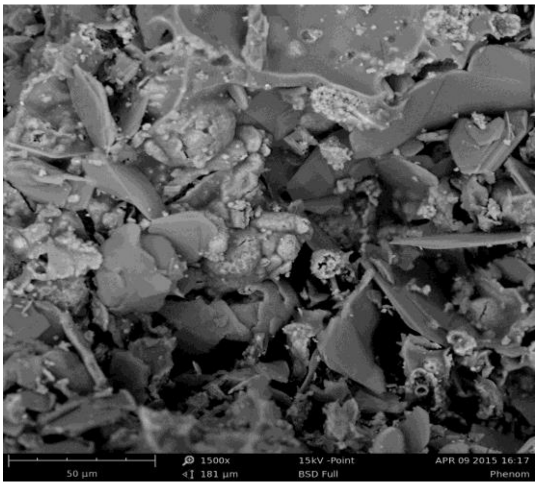


Figure 4.12: SEM image indicating grain size of red mud IC (1500x)

4.4 Intumescent Coating Formulation

7 intumescent coatings have been prepared as shown in Figure 4.13. The coatings have different colour because of the variable amount of red mud. The more weight percentage of red mud in an intumescent coating mixture, the more reddish the coating is. This is due to the high intensity of iron content in red mud. It is found that the coating was less viscous when larger amount of red mud was added.

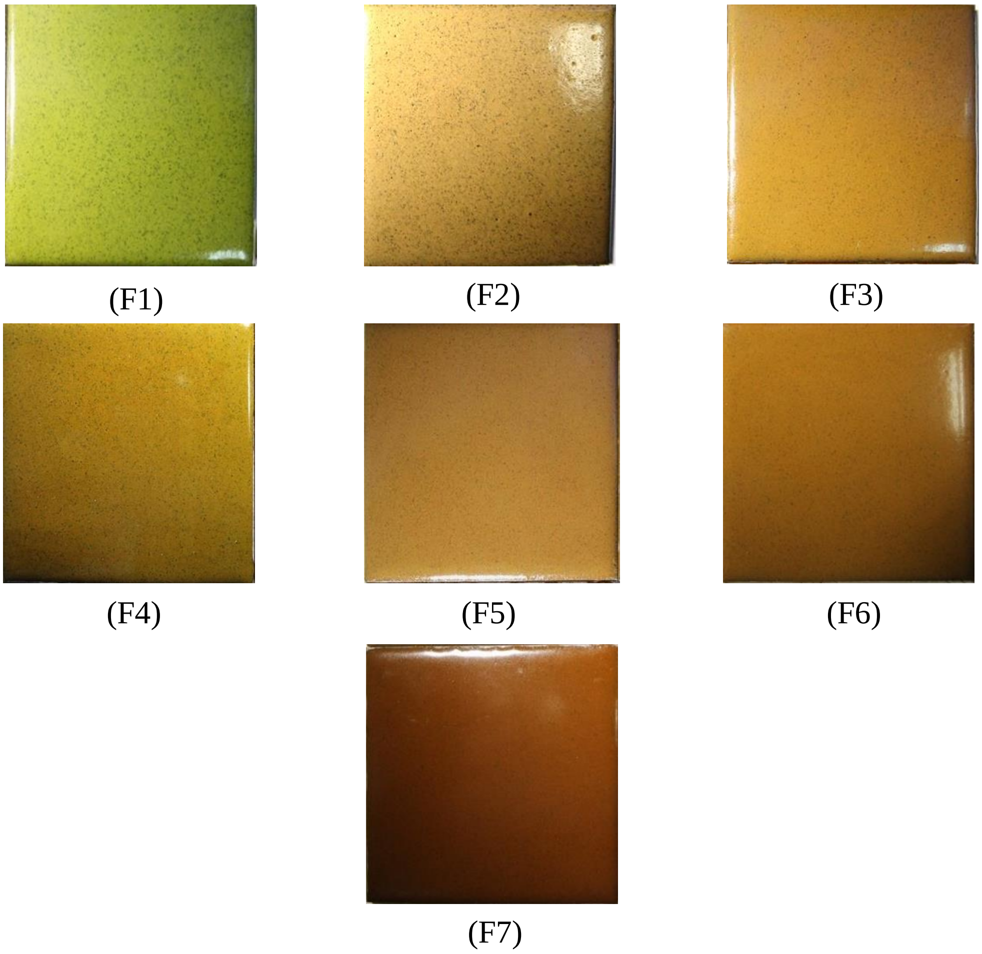


Figure 4.13:7 Intumescent coating prepared

4.5 Fire test

Appendix I shows the tabulated data of fire test result. It was observed that formulation 4 (F4) gave the best data which constantly sustain the heat below 150°C for 60 minutes. As compare to formulation 1 (F1), it proves the basic intumescent formulation (APP-MEL-BA) able to act as normal fire protective layer. However, F1 have the highest heat penetrated to the steel compare to other formulation. F1 protected the steel averagely between 240°C and 277°C for 60 minutes.

Data from Appendix I was plotted in graph shown in Figure 4.14. The graph show intumescent coatings that have red mud content protect the steel at lower temperature as to compare to the constant formulation F1. It was observed that the temperature of steel decreasing with the increment of red mud content in the intumescent coating formulation. However, the temperature begins to increase after F4. Thus, from fire test, it was found that the optimum red mud content was 2 g which was formulation 4.

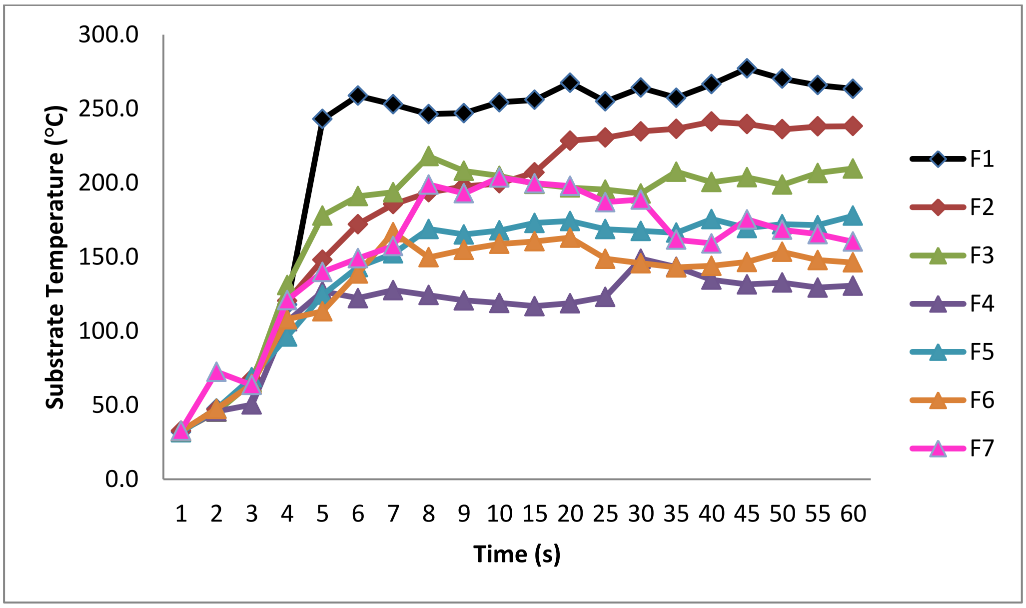


Figure 4.14: Graph of fire test result

In addition, Figure 4.15 shows the physical appearance of each intumescent coating after fire test. The oxidation of expandable graphite (EG) and cracks formation increases with the increment of red mud in the formulation.

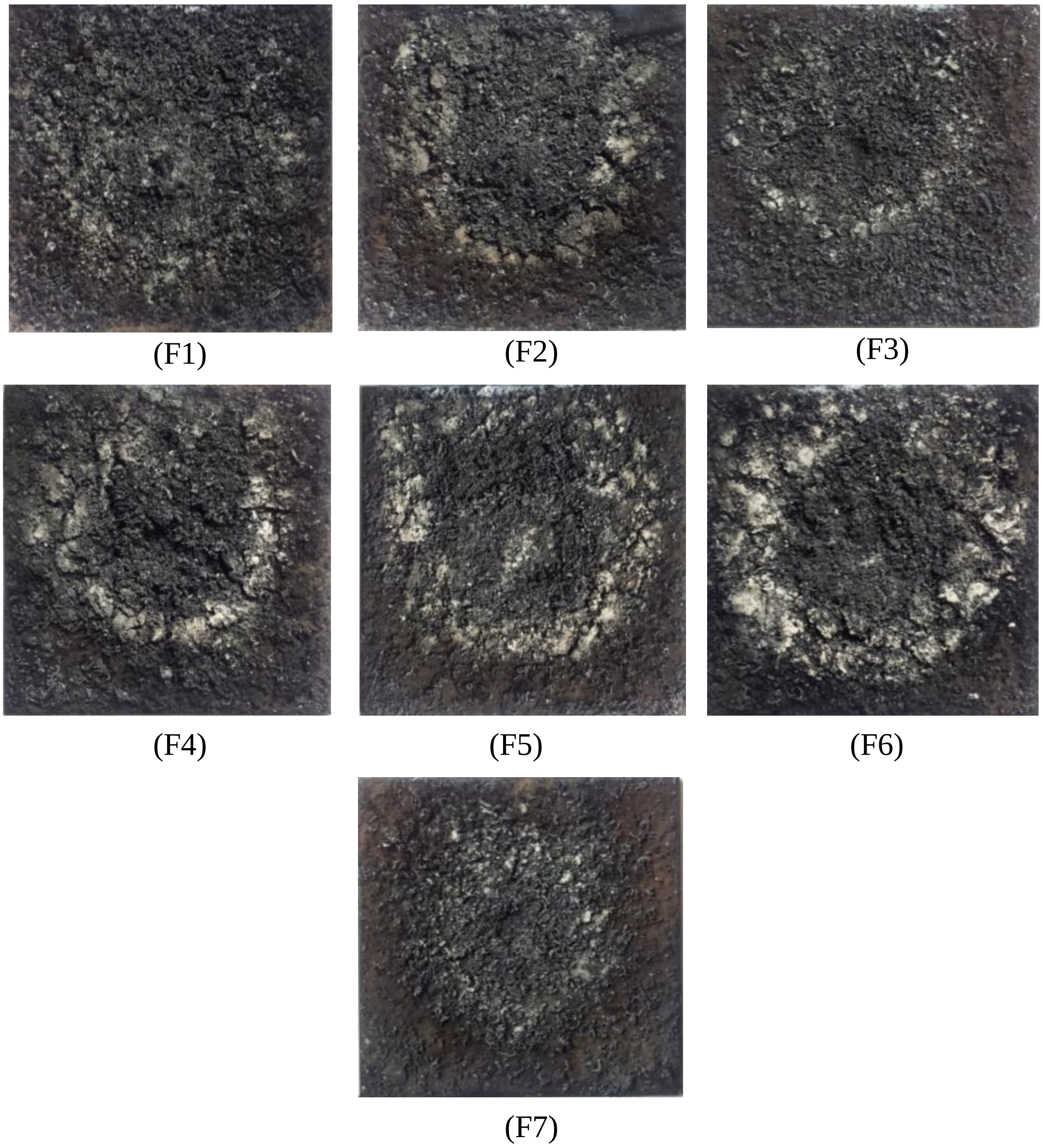


Figure 4.15: Physical observation of char after fire test

4.6 Furnace test

Figure 4.16 shows the furnace test result. It can be observed that formulation 4 had the highest char expansion which is 4.25 times from the initial thickness. The char expansion decreases after adding 0.5 g of red mud into the constant formulation (F1) and increase progressively with additional red mud content. However, the char expansion has intermittence development after F4.

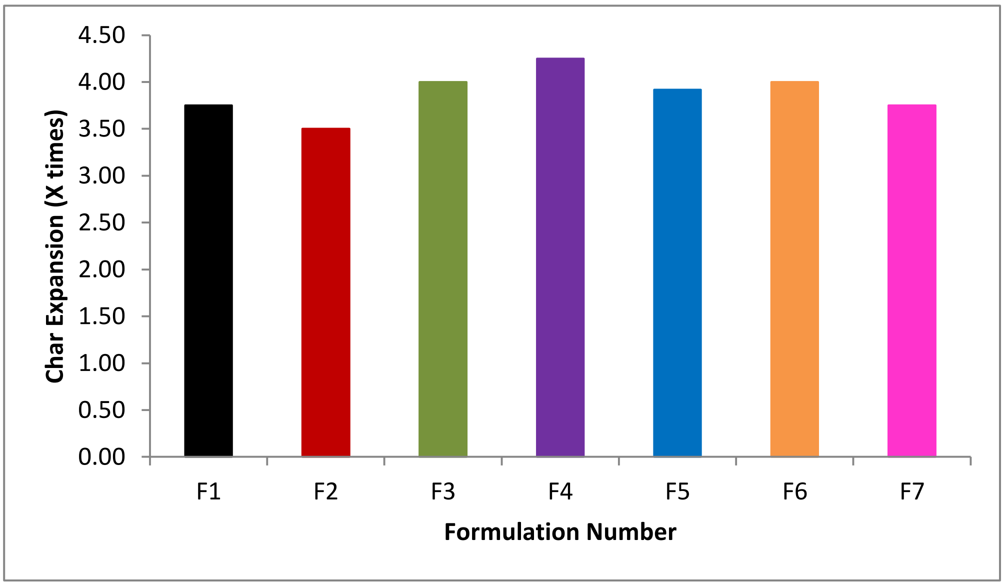
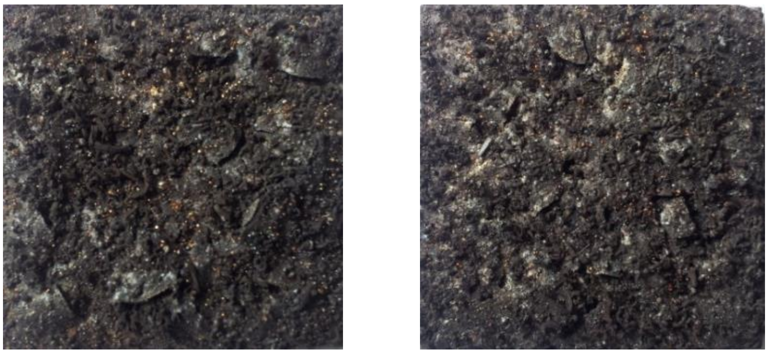
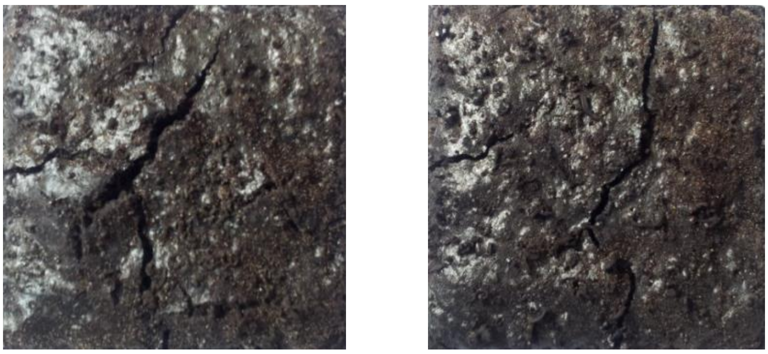


Figure 4.16: Furnace test results

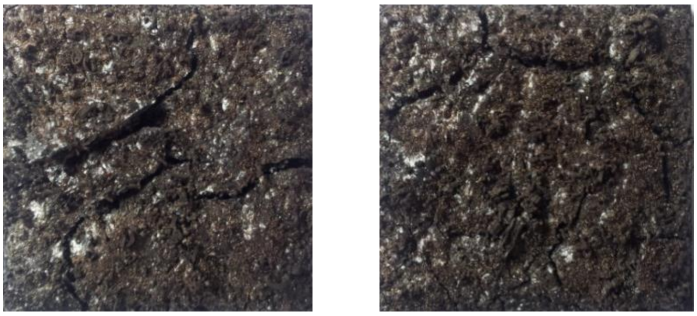
Figure 4.17 shows the physical appearance of each coating after furnace test at 50°C for 30 minutes. The bonding between coating and steel of each formulation were strong however with increasing amount of red mud in the intumescent coating formulation, the cracks getting obvious.



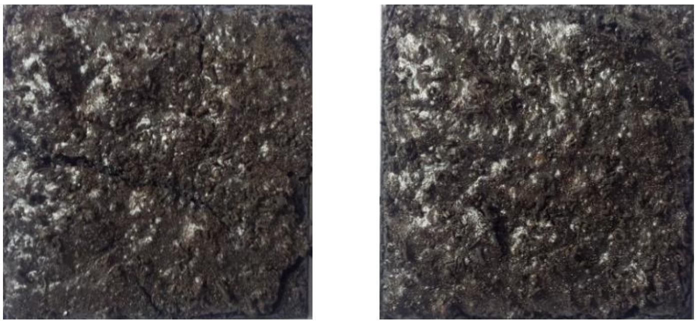
F1 samples



F2 samples

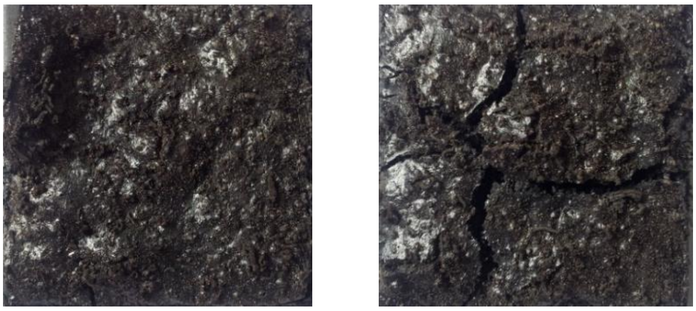


F3 samples

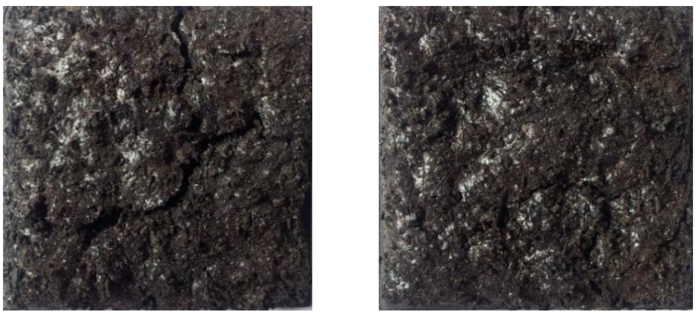


F4 samples

F5 samples



F6 samples



F7 samples

Figure 4.17: Physical appearance of char from furnace test

4.6 Thermal Gravimetric Analysis (TGA)

The residual weights of F1, F3, F5 and F7 measured were 36.34%, 38.20%, 25.26% and 36.64% respectively. The residual weight of char increased as the weight of red mud was increased (F1- F3) as shown in Figure 4.18. The result of TGA showed that red mud influences the residual weight to be increased by 1.86% when 1g of red mud was added to the IC formulation.

However, the residual weights of char decreased by 11.08% after 3g of red mud used in the formulation (F5). This degradation was due to the alkaline properties of red mud had deteriorate the acidic reaction of ammonium polyphosphate (APP) which decrease the expansion of char, subsequently reacting all composition to the heat.

The residual weight increased again by 0.3% when 5g of red mud was added into the intumescent formulation (F7). This intermittence phenomenon was due to the amorphous properties of the red mud. Based on the graph F1 and F7, the residual weight decreasing gradient more or less was same. TGA prove that red mud will not efficiently react or influence with other IC composition when the amount was large.

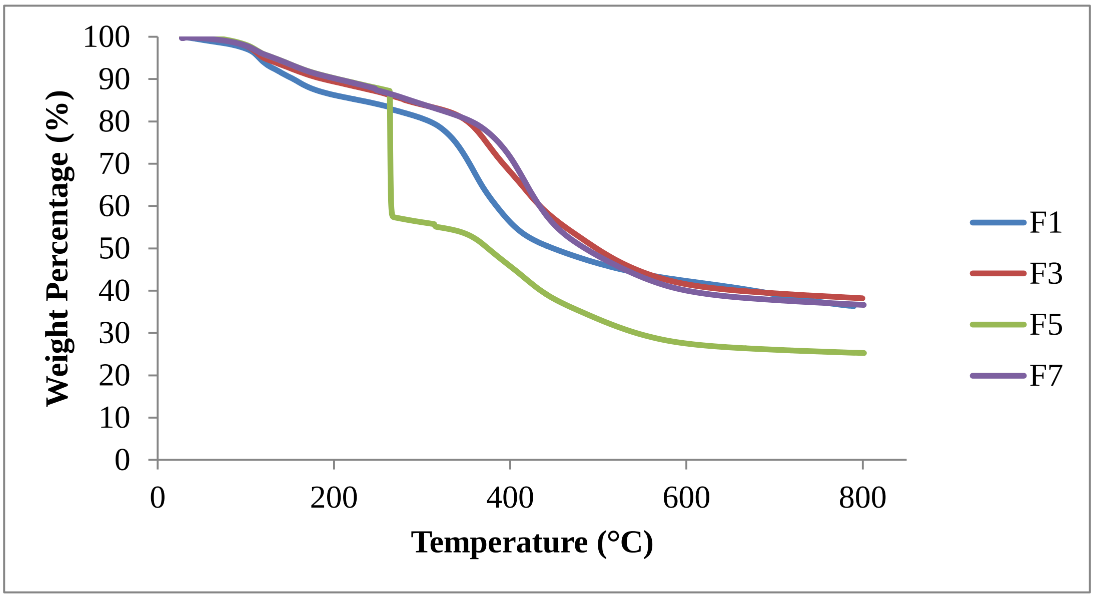


Figure 4.18: Thermal gravimetric analysis (TGA) of red mud intumescent coating

4.7 Discussions

Based on fire test and furnace result, both experiments do not have much correlation since the coating was tested under different temperature and surrounding condition. As to compare from the physical appearance of the intumescent coating after both test, it can clearly be observed that fire test burns at the center of the coating while furnace test totally burn the coating into char. Thus, both tests cannot be related as each of the experiment have different testing objective.

In fire test, control formulation F1 prevent heat penetration to the steel at highest temperature as to compare with other red mud content formulation. This is because the coating chemical reaction occurs to be at the fastest rate. The coating was highly reactive when contacting with direct fire. The char expand progressively at the center of the steel plate but getting thinner with respect to time.

As to compare the red mud formulations (F2 - F7), the coating were unreactive activities when it got contact with the fire. The coating took longer time to develop the char and expand few times compared their initial thickness. This means that red mud reduce the chemical activity in the coating which eventually reduce the char expansion. However, the temperature that was recorded was lower since the coating resulted in more compact char compared to the char developed from control formulation.

From furnace test, the coating was tested in maximum condition as to observe the char development and physical appearance. The furnace results have inconsistency trend of char expansion. This is due to poor intumescent formulation. According to literature, when filler is added to an intumescent coating formulation, the curing agent amount need to be adjusted as to gain 100% weight percentage. However, the coating produce in this project exceeded 100% weight percentage as the curing agent was set to be at constant value. With this correlation, it can be deduced that the coating have instable chemical amount and reaction which affected the char expansion to be variable and inconsistence.

Besides, the coating showed a trend of cracks with increment of red mud content in the formulation. The cracks become obvious when more red mud content inside the intumescent coating formulation. The red mud contain highly iron content which is a good catalyst of heat which may influence the cracks formulation by increase the heat activity inside the coating at highly elevated temperature. This factor may affect the coating to have a lot of cracks.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In conclusion, red mud influences the basic intumescent coating formulation by improving the passive fire protection (PFP) properties at certain amount of red mud. The optimum amount of red mud was 2 g (Formulation 4) which result the best fire protective insulation to the steel (150°C for 60 minutes), have highest expansion rate (4.25 times from initial thickness) and will increase the residual weight approximately 2% from constant formulation. Therefore, red mud influences the performance of intumescent coating for steel structure.

5.2 Recommendation

More treatment process is required as to gain neutral red mud. Originally red mud is highly alkaline which neutralize the acidic properties of ammonium poly phosphate (APP). Therefore, acid treatment is recommended to neutralize the red mud.

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APPENDICES

Appendix I: Substrate temperature profile (°C) measured from fire test

Time	F1	F2	F3	F4	F5	F6	F7
1	31.8	32.6	32.5	32.3	31.5	32.4	32.7
2	47.6	46.8	45.3	45.7	47.5	47.4	72.4
3	66.6	67.7	65.4	50.3	68.7	64.1	63.5
4	117.8	120.3	130.9	106.4	96.2	107.8	120.8
5	242.9	148.1	177.8	126.7	124.3	113.2	139.8
6	258.7	172.0	190.9	122.1	143.0	138.7	149.0
7	252.9	185.5	193.6	127.5	152.2	166.6	157.3
8	246.3	193.4	217.9	124.2	168.8	149.6	198.7
9	246.9	197.4	208.0	120.6	165.1	154.7	192.9
10	254.3	199.6	204.6	118.9	167.8	158.7	203.5
15	255.9	207.0	199.2	116.8	172.9	160.4	199.6
20	267.5	228.4	196.7	118.7	174.2	162.9	197.8
25	254.8	230.4	195.3	123.0	168.7	148.6	186.9
30	264.1	234.6	192.7	148.7	167.4	145.6	188.6
35	257.3	236.4	207.4	143.2	166.3	142.9	161.5
40	266.5	241.2	200.4	134.6	175.4	143.9	159.0
45	277.1	239.6	203.6	131.4	169.4	146.5	175.2
50	270.2	236.1	198.6	132.6	172.0	153.3	168.2
55	265.8	238.0	206.6	129.2	171.3	147.8	165.3
60	263.3	238.1	209.5	130.6	177.7	146.1	160.2