EFFECTS OF FIBER LENGTH ON FIRE PERFORMANCE OF INTUMESCENT FIRE RETARDANT COATING

By

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DISSERTATION

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Department of Mechanical Engineering
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
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(Mechanical Engineering)

Approved:

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Project Supervisor

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TRONOH, PERAK

December 2012

CERTIFICATION 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 that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Ahmad Zuhairie Bin Yahya

ABSTRACT

The purpose of this study is to examine the effects of fiber reinforcement on the intumescent fire retarding coating to explore the mechanical and chemical properties in order to increase the fire performance of the intumescent fire retardant coating. The coatings were formulated using Ammonium Polyphosphate (APP) as acid source, Expandable Graphite (EG) as carbon source, Melamine as blowing agent, Boric acid as additives, Epoxy as binder and fiber glass was added in strengthening intumescent coating. Different intumescent formulations were developed and fiber glass composition was varied from 0%, 2%, 4%, 6% and 8% and for fiber length were 3mm and 5mm. The steel substrate coated with fire retardant coating was tested using Bunsen Burner Test for fire performance test. The char expansion was measured in experiment of furnace test at 500°C and 800°C. Thermo Gravimetric Analysis (TGA) and X-Ray Diffraction (XRD) were used for residual weight and char composition analysis respectively.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

The safety issues are seriously discussed in industry nowadays especially when exposed to fire burning. During 1980s and 1990s, there were many cases reported related to the fire deaths in UK. The scenario reacted with the enforcement of law in terms of fire hazards. The fire protecting system has improved from years to years along with the improvement of technology. In recent years, the usage of intumescent coatings as the fire protection for structure has dominated the market.

Steel is a non-combustible material which exhibits a good ductility but begins to lose its structural properties at temperature between 470°C to 500°C [1]. The adding of fiber glass to reinforce the coating can increase the protecting system of intumescent coating by strengthens up the char. The fiber glass reinforcement will enhance the mechanical properties of the coating to increase the ability to protect the steel.

This proposed project focuses on the effect of different fiber length and composition to the fire performance of the coating. The coating formulation will be divide into two sets; one set use fiber glass with length of 3mm while second set use 5mm of length. Each set contain four different intumescent formulations varying with composition of fiber glass (2%, 4%, 6% and 8%). Efficiency of intumescent coating on steel will be investigates using Bunsen Burner Test. The samples also test with furnace test at 500°C and 800°C for one hour. TGA and XRD will be used to get data for residual weight and char composition.

1.2 Problem Statement

Current intumescent fire retardant coating lacks of strength when exposed to high temperature that affects the efficiency of coating in protecting the base structure. When exposed to high temperature, intumescent coating expands and forms a char layer. Poor strength of char layer reduces the protection performance.

The weakness of current coating strength has led to recent interest in developing a better coating formulation that improves the strength. There are several studies about the effect of using fiberglass to increase the fire performance. It is important to run further study about the effect of fiber length and composition of fiber glass reinforce to the coating to increase the effectiveness of the coating and find for the best formulation for Intumescent Coating that can provide fully protection to the base structure.

1.3 Objectives

- To develop a range of formulation of intumescent coating with varying percentage of fiber glass content and length.
- To investigate the effect of fiber glass length and composition on the fire performance of IFRC

1.4 Scope of Study

- To develop Intumescent Fire Retardant coating containing:
    1. Fiber glass length (3mm and 5mm)
    2. Fiber glass content (0%, 2%, 4%, 6% and 8%)
- Bunsen Burner Test on the sample.
- Furnace Test (1 hour at temperature 500°C and 800°C).
- Thermo Gravimetric Analysis (TGA) for residual weight.
- X-Ray Diffraction technique (XRD) for analysis of char compound.

CHAPTER 2

LITERATURE REVIEW

2.1 Intumescent Fire Retardant Coating

Intumescent Fire Retardant Coating is one of the easiest, oldest and most efficient ways to protect steel from fire [2-3]. Intumescent define as swelling and expanded of coating when exposes to high temperature to form the protecting layer when exposes to high temperature [4-5]. Under the high temperature, the coating decomposes and intumesces to form the non-flammable protecting layer known as char that insulates and protect the base structure from the rapid increase of temperature that will cause the structure to lose its properties [6]. There are several advantages of using Intumescent coating for fire protection: it can prevent heat from penetrating and flames from spreading, it does not change the intrinsic properties of material [7] and also easily processed and may also be used onto several materials including metallic materials, polymers, textiles and wood [8]. Intumescent coatings are designed to perform under severe conditions and to maintain the base structure integrity for one up to three hours when the temperature of the surroundings is exposing to temperature of 1100°C [1].

Intumescent coating basically has three main ingredients which are an acid source (normally ammonium polyphosphate or mineral acid), a carbon source (char forming polymers such as Expandable Graphite and starch) and a blowing agent (e.g. melamine). The formulation of the coating has to be optimized in terms of physical and chemical properties to form an effective protective char [9-10]. Chemical interactions between the main ingredients in the formulations lead to formation of intumescent char [10]. The formulation of Intumescent Coating has a relatively high thermal conductivity, whereas the char layer formed by the swelling acts as a thermal insulator with a low thermal conductivity [11]. Layer of char may go to a thickness of twice more than the original thickness of the coating and it strength is adequate to protect base structure from rapid high temperature for a certain time [12-13]. This protective char limits the heat transfer from heat source (fire) to the base structure and the mass transfer from base structure to the heat source (fire), resulting in protection of underlying material [10].

2.2 Intumescent Mechanism

The mechanism of intumescent is usually explained as follows [1-2] : first, the acid source breaks down to yield a mineral acid, then the carbonization agent dehydrate to yield the carbon char, after that the blowing agent decomposes to yield the gaseous products and char swell and provides an insulating multi-cellular protective layer.

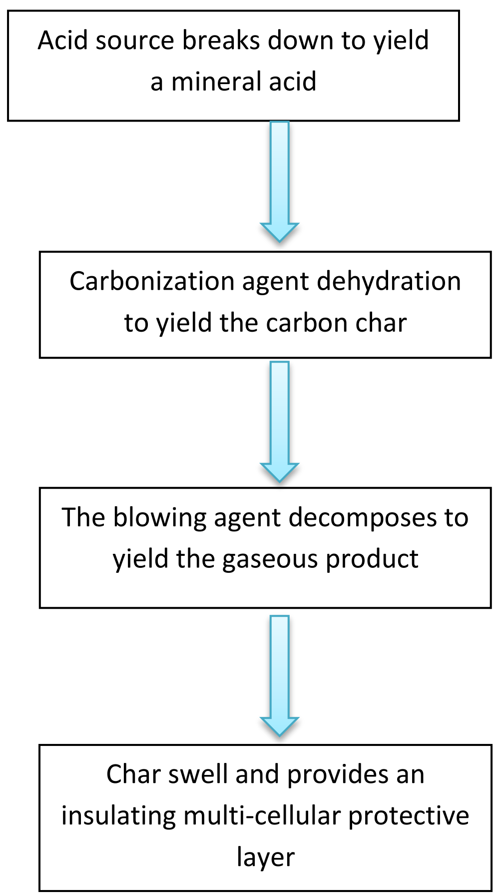

Figure 1: Intumescent coating mechanism [1]

When the temperature of coating surface expose to the flame and reaches a critical temperature, the surface begins to melt and is converted into highly viscous liquid. Simultaneously, reactions are initiated that result in the release of inert gases with low thermal conductivity. These gases are trapped inside the viscous fluid (formation of bubbles). It cause the expansion of foaming of the coating to form a protective carbonaceous char (Fig. 2) that acts as a insulate barrier between the fire and base material [2, 14, 15].

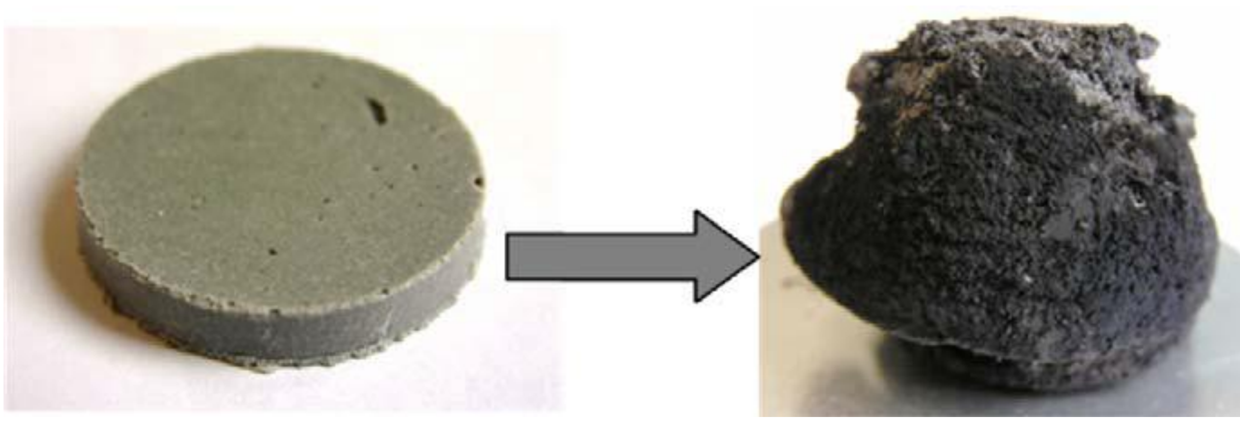

Figure 2: Swelling of Intumescent coating. [1]

2.3 Fiber Reinforcement

The used of reinforced fiber in engineering application is increasing. Common fiber reinforced composites are composed of fibers and a matrix. Fibers are the reinforcement and the main source of strength while the matrix “glues’ all the fibers together in shape. Sometimes, fillers or modifiers might be added to smooth manufacturing process, impart special properties and reduce cost. There are many types of fibers such as glass fiber, ceramic fiber, boron fiber and many more.

Glass fiber usually choose to be used as reinforced for Intumescent Coating because it have good thermal properties, mechanical properties, electrical properties, low weight and low cost [16]. Moreover, glass fiber susceptible to combustion and fire damage due to ‘candlewick effect’ which is caused by glass fibers. The interpretation of “candlewick effect” is that in the combustion process of glass-fiber reinforced polymer matrix composites; glass fiber could transfer the flammable pyrolysis products of polymers to the flame zone through capillary action, speed the heat flowing back to polymers and increase the mass loss rate of polymer matrix [17-18].

2.4 Effect of Fiber Reinforced to Intumescent Coating

Reference [13] summarize that intumescent coating reinforced with fiber have a stronger char’s properties and characteristics compare to non-reinforced. Based on the experiment done in this paper, the intumescent coatings without fiber reinforced will expanded highest when expose to temperature 400°C, but the expanded char has a crisp and brittle with thin layers of char and has many big voids. These characteristics of char showing the weakness of char that will affect the performance of intumescent coating. It is reported that without additives or reinforcement, old intumescent coatings consisting APP/PER/MEL are known to produce a fluffier barrier of fire retardant, which is easily penetrated by fire. To overcome this, high temperature fillers were used to form a compact microstructure in the charred layer [19].

2.5 Effect of Length on Fiber Glass Attributes

Several factors affect the mechanical behavior of fiber reinforced such as characteristics of matrix and fiber, interfacial bonding, fiber content, void volume, fiber orientation distribution and fiber length distribution [20]. The use of short length of fiber within the composites does not give maximum possible stiffness, strength and toughness properties. Hence, in the past decade, a trend has developed to use more long length of fiber as the reinforced of structure. Some advantages of using long length fiber products are better mechanical properties, better impact resistance and enhanced creep performance [20]. The increasing of fiber glass attributes will affect the performance of intumescent coating performance in the fire.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

First step taken to achieve the objectives of this project is to done some researches on resources from books, journals and technical papers. Various journals and technical papers were read to get the general understanding on this project. It is also needed to identify the objective of this project and come up with planned schedule on the executing of the project. Diagram below explains activities flow chart for this project.

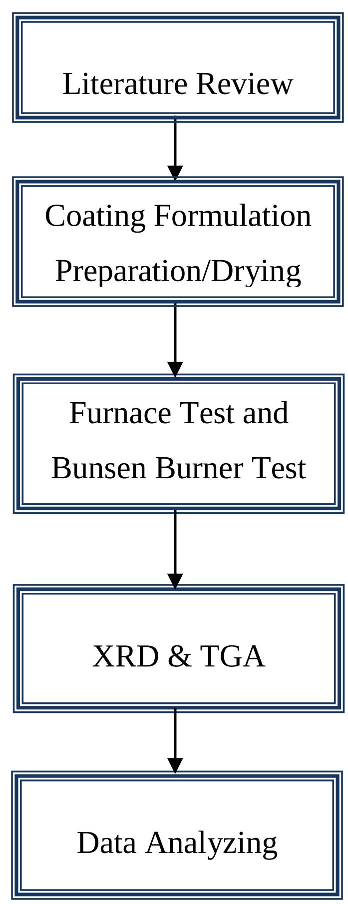

Figure 3: Project Activities Flow Chart

3.2 Project Activities

First level of experiment process is to prepare the formulation of intumescent coating. 9 formulations varying with fiber contents and length have been prepared. The intumescent coating formulation then applied onto steel plates and left for curing process for 3 weeks at room temperature. Sample then tested with Bunsen burner test and furnace test and the results further analyzed via X-Ray Diffraction (XRD) and Thermo Gravimetric Analysis (TGA). Diagram below showed the experimental process of this project.

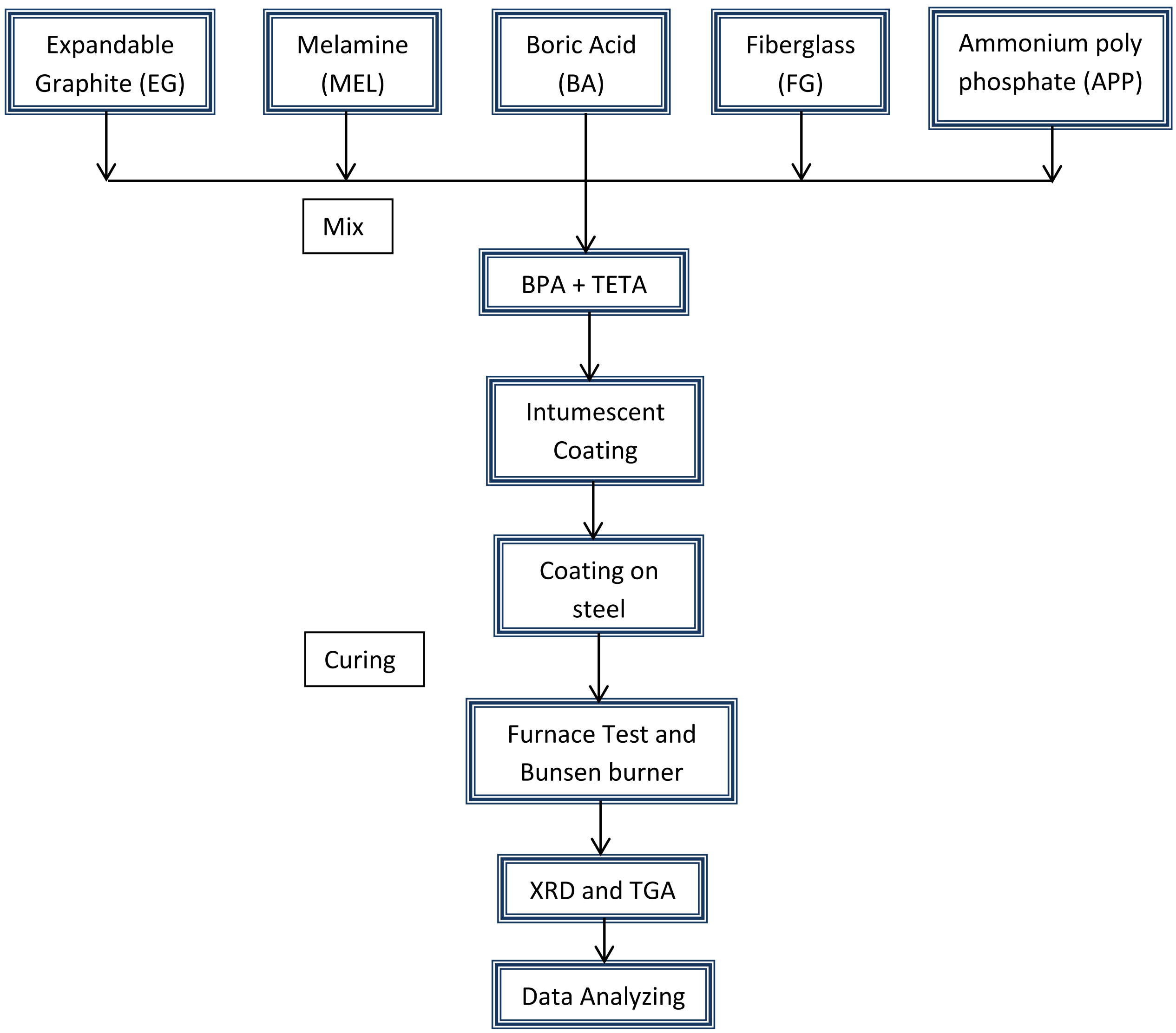

Figure 4: Experimental process overview

3.2.1 Formulation Preparation Experimental Details

Nine formulations have been prepared; four for formulations reinforced with 3 mm length of fiber glass, four for formulations reinforced with 5 mm length of fiber glass and one for formulation without fiber reinforced. Each of formulations has been coated into mild steel plates. Ingredients of Intumescent Fire Retardant Coating that used were Ammonium poly phosphate (APP) as the acid source, Expandable Graphite (EG) as carbon source, Melamine as blowing agent and boric acid as additives with the filler of chopped short fiberglass (FG) of length 3.0 mm and 5.0 mm. The formulation is bind with Bisphenol A epoxy resin BE-188 (BPA) with ACR Hardener H-2310 polyamide amine also known as Tetraethylene Tetramine (TETA).

Table shown below is the portion of ingredients in the formulation.

	Binder		Intumescent Fire Retardant				
	BPA (Epoxy)	TETA (Hardener)	APP	EG	MEL	BA	FG
1.	44.44	22.22	11.11	5.56	11.11	5.56	0
2.	43.44	21.22	11.11	5.56	11.11	5.56	2
3.	42.44	20.22	11.11	5.56	11.11	5.56	4
4.	41.44	19.22	11.11	5.56	11.11	5.56	6
5.	40.44	18.22	11.11	5.56	11.11	5.56	8

Table 1: Intumescent fire retardant coating formulation portion

Abbreviation:

BPA	Epoxy Resin Bisphenol A
TETA	Triethlyene-Tetramine
APP	Ammonium Polyphospate
EG	Expandable Graphite

MEL	Melamine
BA	Boric Acid
FG	Fiber Glass

3.2.2 Formulation Preparation Process

1. The process started with the measure of APP, Melamine and Boric acid based on the formulation portion.
2. All of them mixed together and the mixture powder is grinded for one minute in Rocklabs grinder.
3. Expandable graphite and fiber glass then added into the grinded mixture powder and manually mixed them together until uniformly dispersed.
4. The epoxy and hardener is prepared based on the formulation portion and being stir via mixer until a white milk layer is produced.
5. Powder and fiber glass mixture is poured simultaneously into the mixture of epoxy and hardener. The blend is mixed and stir using mixer with speed of 30-40 rpm until well mixed.
6. The coating is evenly applied with metal spatula onto primer coated 5cm x 5cm steel and 10cm x 10cm steel plate.
7. The coating was left to dry at room temperature. It takes about three weeks for the coating to fully cure.

3.3 Tools and Equipment

- X-Ray Diffraction (XRD)
- Thermo Gravimetric Analysis (TGA)
- Bunsen burner
- Furnace
- Data logger
- Mixer
- Grinder
- Digital weighing machine

Figure 5: Furnace used for furnace test.

Figure 6: Rock Labs Grinder for grinding process

3.4 Gantt Chart and Project Milestones

Several targets have been set for FYP I and FYP II. Figure 5 and Figure 6 shows the project activities and key milestones for FYP I and FYP II respectively.

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic								MID SEM BREAK							
2	Literatures Review															
3	Submission of Extended Proposal															
4	Modeling the Formulation of Intumescent Coating															
5	Proposal Defense															
6	Modeled Experiments Execution															
7	Submission of Interim Draft Report															
8	Submission of Interim Report															

Legends:

Project Activity

Key Milestone

Table 2: Gantt chart FYP

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Modeled Experiments Execution and Optimization								MID SEM BREAK								
2	Submission of Progress Report									○							
4	Analyze the Result of Experiments																
5	Pre-EDX												○				
6	Submission of Draft Report													○			
7	Submission of Dissertation (soft bound)														○		
8	Submission of Technical Paper														○		
9	Oral Presentation															○	
10	Submission of Project Dissertation (Hard Bound)																○

Legends:

Project Activity

○ Key Milestone

Table 3: Gantt Chart FYP

CHAPTER 4

RESULT AND DISCUSSION

4.1 Thickness Measurement

Prior to sample testing, measurement of coating thickness is done using a venire caliper in each side of the coating. Average thickness is considered as the reading for the coating thickness.

Measurement Technique:-

Thickness 1

(T1)

Thickness 2

(T2)

Thickness 4

(T1)

Thickness 3

(T3)

Figure 7: Sample of intumescent coating for 5cm x 5cm steel

Average thickness = (Thickness 1 + Thickness 2 + Thickness 3 + Thickness 4) / 4

4.2 Experiment Results

All of the samples have been labeled as below.

Formulation	Test Pieces	FG composition (%)	FG Length (mm)
1	C1, C2, C3	0	-
2	T1-2, T2-2, T3-2	2	3
3	T1-4, T2-4, T3-4	4	3
4	T1-6, T2-6, T3-6	6	3
5	T1-8, T2-8, T3-8	8	3
6	F1-2, F2-2, F3-2	2	5
7	F1-4, F2-4, F3-4	4	5
8	F1-6, F2-6, F3-6	6	5
9	F1-8, F2-8, F3-8	8	5

Table 4: Samples labeling description

4.2.1 Applied Coating and Curing Process

Provided below are the images of some of the coatings during curing process and after fully cured. It takes for about three weeks to have a fully cured intumescent coating that ready for any test or experiment. Nine formulations of sample have been leave in room temperature environment for curing process.

Figure 8: Picture of Intumescent Coating on the Curing Process

Figure 9: Intumescent coating (3mm) after fully cured

4.2.2 Furnace Test Results

Each of the samples has been test for furnace test to test the char expansion of the coating when applied to high temperature.

Figure 10: Intumescent coating C1, T1-2, T1-4, T1-6 and T1-8 after furnace test of 500°

Figure 11: Intumescent coating C2, T2-2, T2-4, T2-6 and T2-8 after furnace test of 800°C

Figure 12: Intumescent coating F1-2, F1-4, F1-6 and F1-8 after furnace test of 800°C

Sample	Temperature (°C)	Thickness (mm)		Expansion (mm)
		Before	After	
Formulation 0% Fiber Glass C1	**500 Degree Celsius**	2.62	17.75	6.77
Formulation 2% Fiber Glass of 3mm length T1-2		2.58	18	6.98
Formulation 4% Fiber Glass of 3mm length T1-4		2.40	18.85	7.85
Formulation 6% Fiber Glass of 3mm length T1-6		2.80	19.05	6.80
Formulation 8% Fiber Glass of 3 mm length T1-8		2.90	20.25	6.98

Table 5: Result of intumescent coating reinforced with 3mm fiber glass in temperature of 500°C

Sample	Temperature (°C)	Thickness (mm)		Expansion (mm)
		Before	After	
Formulation 2% Fiber Glass of 5mm length F1-2	**500 Degree Celsius**	2.50	17.75	7.10
Formulation 4% Fiber Glass of 5mm length F1-4		2.45	19.45	7.94
Formulation 6% Fiber Glass of 5mm length F1-6		2.80	19.40	6.93
Formulation 8% Fiber Glass of 5 mm length F1-8		2.75	20.30	7.38

Table 6: Result of intumescent coating reinforced with 5mm fiber glass in temperature of 500°C

Sample	Temperature (°C)	Thickness (mm)		Expansion (mm)
		Before	After	
Formulation 0% Fiber Glass C2	**800 Degree Celsius**	2.70	17.75	6.57
Formulation 2% Fiber Glass of 3mm length T2-2		2.50	17.80	7.12
Formulation 4% Fiber Glass of 3mm length T2-4		2.52	18.72	7.43
Formulation 6% Fiber Glass of 3mm length T2-6		2.84	18.84	6.63
Formulation 8% Fiber Glass of 3 mm length T2-8		2.70	19.35	7.17

Table 7: Result of intumescent coating reinforced with 3mm fiber glass in temperature of 800°C

Sample	Temperature (°C)	Thickness (mm)		Expansion (mm)
		Before	After	
Formulation 2% Fiber Glass of 5mm length F2-2	**800 Degree Celsius**	2.65	17.95	6.77
Formulation 4% Fiber Glass of 5mm length F2-4		2.50	18.80	7.52
Formulation 6% Fiber Glass of 5mm length F2-6		2.80	18.85	6.73
Formulation 8% Fiber Glass of 5 mm length F2-8		2.70	19.40	7.19

Table 8: Result of intumescent coating reinforced with 5mm fiber glass in temperature of 800°C

Based on the result of furnace test at 500°C, the intumescent coating samples that showed the highest expansion are Sample F1-4 followed by T1-4 and F1-8. Sample F1-4 recorded an expansion of 7.94 mm, T1-4 with 7.85 mm and F1-8 with 7.38mm. The char observed to have a rough crumbly surface and sufficiently attached to the steel substrate.

Results of furnace test at 800°C showed that sample F2-4 recorded a highest expansion followed by T2-4 and F2-8. Sample F2-4 recorded an expansion of 7.52 mm, T2-4 with 7.43 mm and F2-8 with 7.19 mm. The char expansion of sample having furnace test at 800°C recorded to be slightly lower compare to sample that exposed to temperature of 500°C.The samples that having furnace test at 800°C observed to have a white powder (ashes) at the surface of expanded char. The formation of ashes was due to very high temperature of furnace.

4.2.3 Bunsen Burner Test Result

Each of the samples has been test for Bunsen burner test to test for the fire performance of coating. The purpose of Bunsen burner test is to record for temperature of back of the steel to analysed for the thermal properties of the coating. A digital thermocouple was attached to the back of sample to record for temperature of back steel. The temperature versus time measurements was taken using electric data logger.

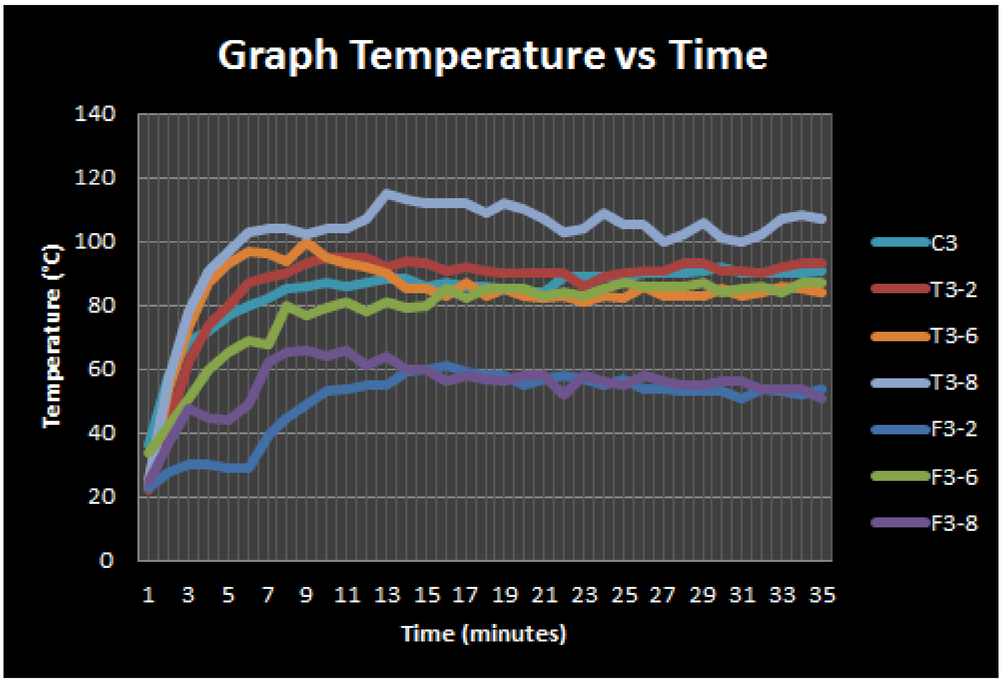

Figure 13: Graph of Temperature vs. Time of Tested Samples

Sample F3-8 which is coating reinforced with fiberglass 5 mm length and 8% composition recorded the lowest temperature after 60 minutes of exposure. It can be concluded that the use of longer fiberglass with higher content of fiberglass in the intumescent coating formulations help to increase the thermal insulation properties of the coating, prolong the lifetime of steel structures and improved the strength of the char.

4.2.4 X-Ray Diffraction (XRD) Analysis

X-Ray Diffraction technique is been used to collect and analyze data of chemical composition of the expanded char. The expanded char is taken from the sample of intumescent coating tested with furnace test.

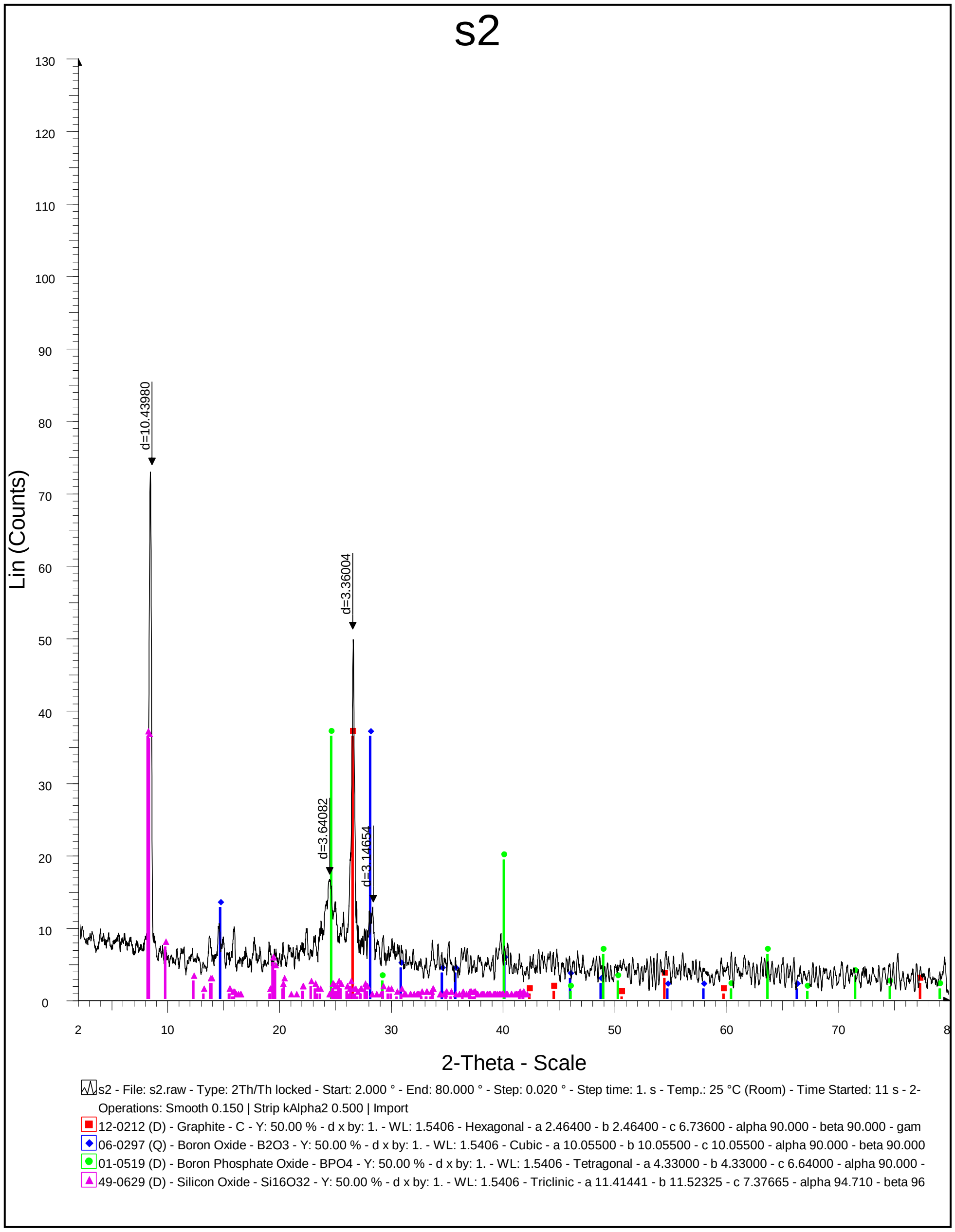

Figure 14: XRD result for sample F1-8

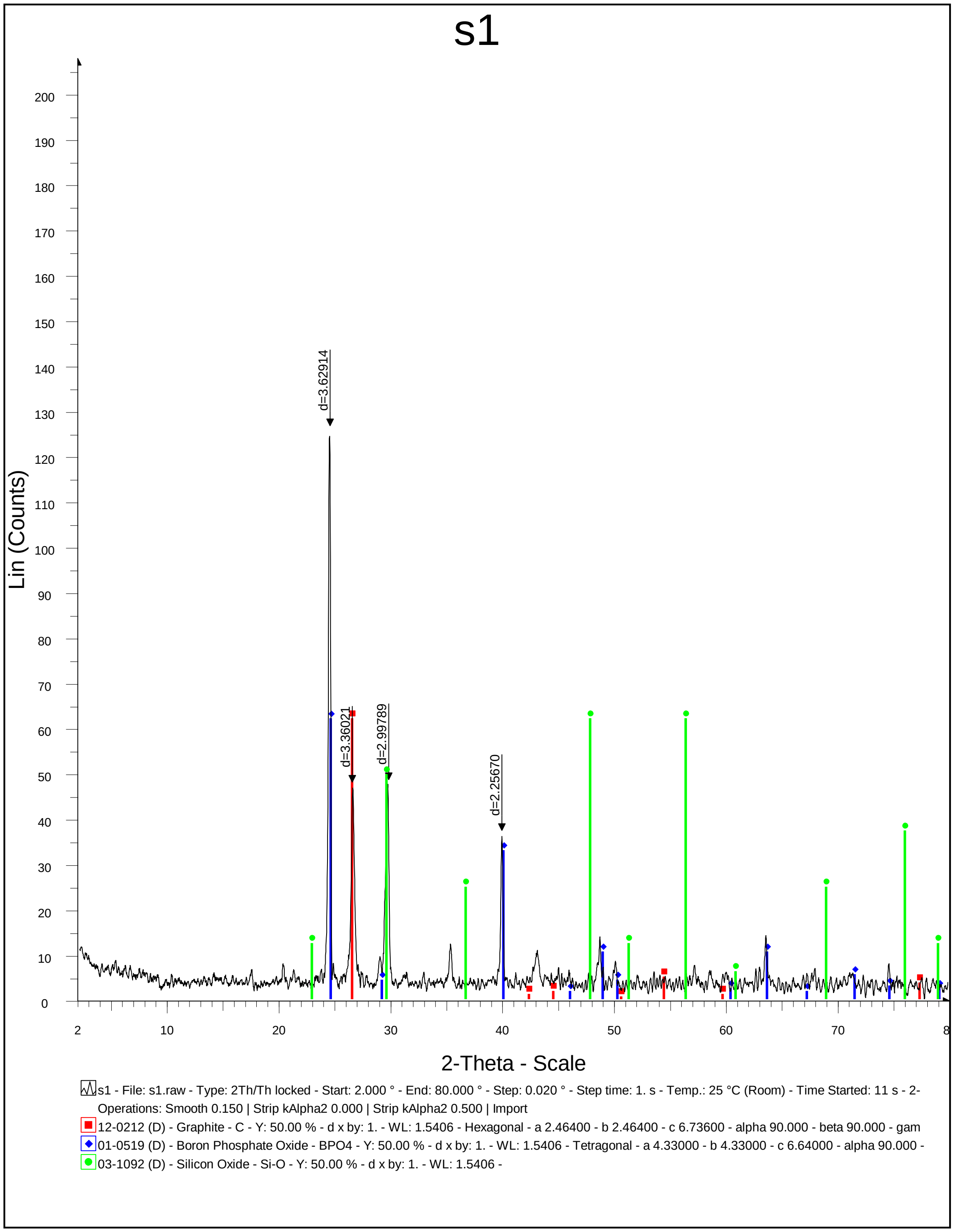

Figure 15: XRD result for sample F2-8

Based on Figure 14, for sample F1-8 which undergone furnace test at 500°C, results showed the XRD peaks of the char at 10.43980, 3.64082, 3.6004 and 3.14654. The peak at 10.43980 was assigned to Silicon Oxide, 3.64082 to Boron Phosphate Oxide, 3.6004 to Graphite and 3.14654 to Boron Oxide.

Based on Figure 15, expanded char for sample F2-8 which exposes to temperature of 800°C shows the existence of Graphite, Boron Phosphate Oxide and Silicon Oxide. The result shows XRD peaks of the char at 3.62914, 3.36021 and 2.99789. The peak at 3.62914 was assigned to Boron Phosphate Oxide, 3.36021 to Graphite and 2.99789 to Silicon Oxide.

4.2.5 Thermo Gravimetric Analysis (TGA)

The residual weight of intumescent coatings was analyzed using TGA. The thermo gravimetric analysis of samples is carried out under controlled air and temperature conditions gives an overview of the degradation process of the coating. The residual weight is plotted against temperature as a result of the analysis.

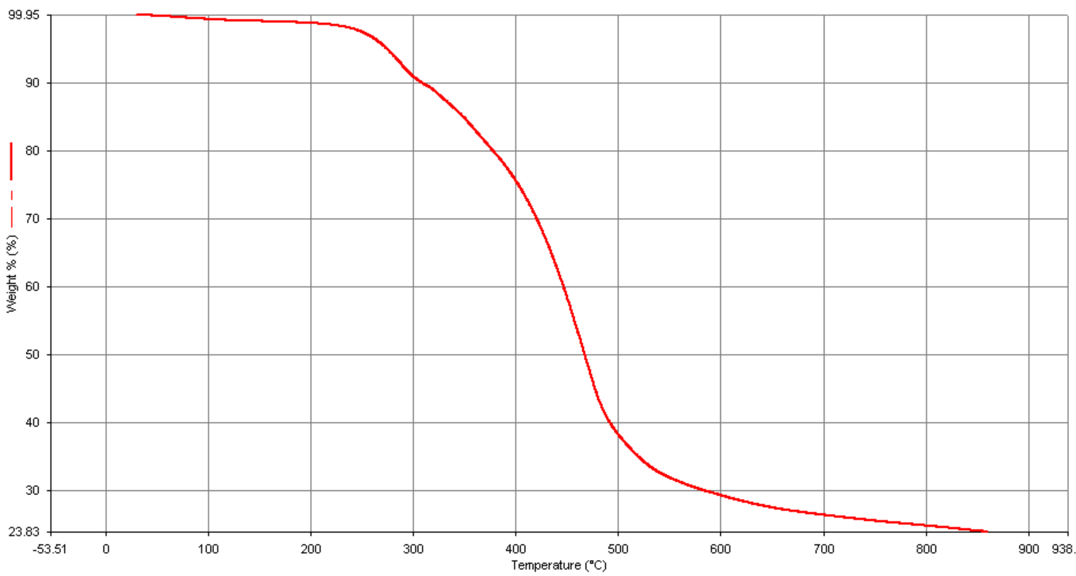

Figure 16: TGA result for C1

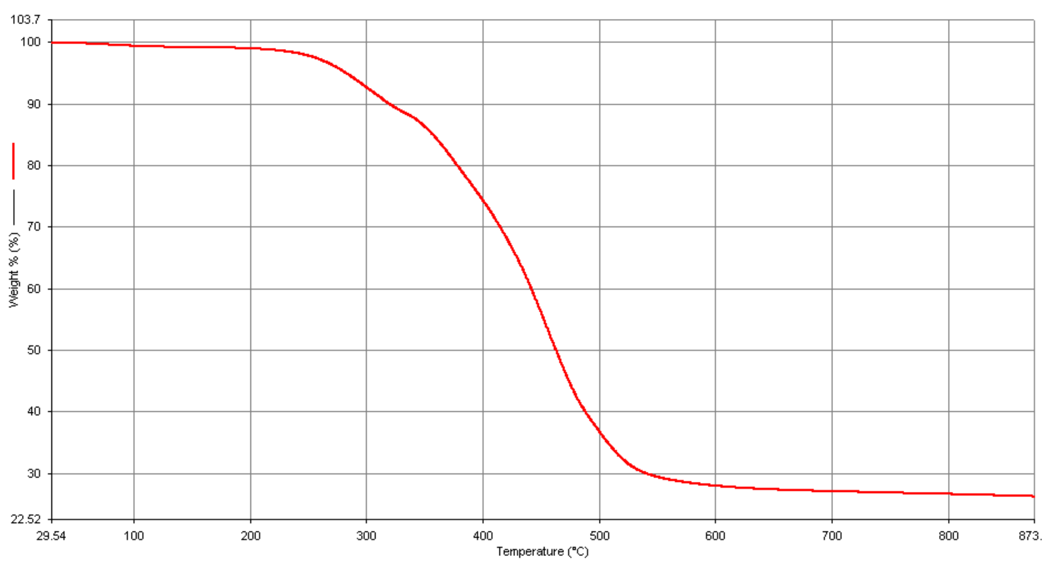

Figure 17: TGA result for F1-6

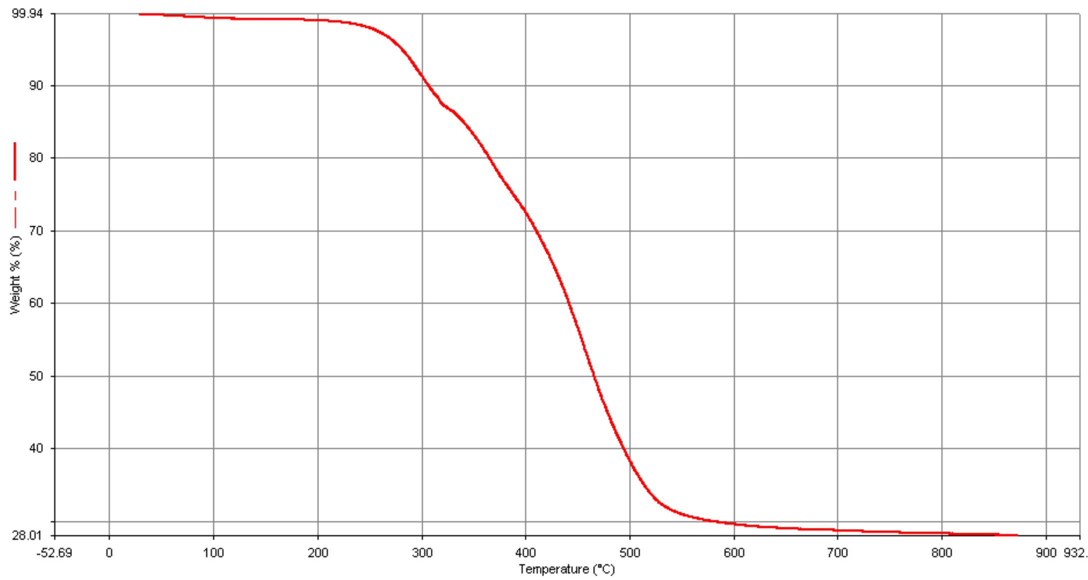

Figure 18: TGA result for F1-8

Figure 16, 17 and 18 shows the result of TGA for control sample, C1 (0% FG), F1-6 (6% FG) and F1-8 (8% FG) respectively. The residual weight is plotted against temperature to analyze for the effectiveness of intumescent coating during the burning process. The results shows that sample C1 left 23wt%, F1-6 left 26wt% and F1-8 left 28wt% residual weight at maximum TGA temperature of 800°C.

4.3 Result Discussion

Result showed that sample with longer length have a higher char expansion compare to the samples with shorter length. As an example, in 500°C furnace test experiment, the sample reinforced with 3 mm fiberglass and 8% contents of fiber glass have an expansion of 6.98 mm while the sample with same percent of content (8%) but with longer length of 5 mm have higher expansion of 7.38 mm. This showed that the increasing of fiber glass length has increased the char expansion that increases the performance of intumescent coating in high temperature.

The result achieved recorded that the samples that undergone experiment of furnace test with temperature till 800 °C has lower expansion of char compare with samples tested with 500 °C. Visual inspection shows that samples heated with 800 °C have like ash burn on the surface of the char. This showed that the expended char that reached till maximum of 800 °C is self-burn cause by high temperature that makes the height of expanded char reduces that caused of lower protection to the sub steel.

Based on Bunsen burner test result, F3-8 recorded to have lowest back steel temperature which was lower than 100°C during an hour test. It can be concluded that the use of longer fiberglass and higher content of fiberglass in the intumescent coating formulations help to increase the thermal insulation properties of the coating, prolong the lifetime of steel structures and improved the strength of the char.

X-Ray Diffraction results recorded the presence of Graphite, Boron Phosphate, Boron Oxide and Silicon for all samples that having furnace test in 500°C while samples that exposed to furnace test of 800°C shows the same residual char composition but with the elimination of Boron Oxide. Research before this shows that after the residue char of the intumescent coating was oxidized at high temperature, only some amorphous carbon and inorganic materials remained [21]. The inorganic material might be the main protecting layer at later stages of burning. Based on the results, it shows the elimination of Boron Oxide in the sample that exposed to temperature of 800°C. This means that Boron Oxide has been eliminate and destroyed during the increasing temperature from 500°C to 800°C leave only Graphite, Boron Phosphate Oxide and Silicon remaining to protect the steel in the later stages of burning. It can be concluded that at 800°C, the strength of char is lower compare to 500°C since the chemical composition is reduced by the elimination of Boron Oxide from residual char component.

For Thermo Gravimetric Analysis (TGA), the samples that recorded higher residual weight have a better performance. Past studies stated that there should be high amount of residue left at temperature higher than 800°C in order for the coatings to effectively protect the steel [22]. The sample with high amount of residual weight is a better homogenous char. This high amount of residual will limit heat transfer to the substrate and will limit the gases feeding combustion process. Based on the result, the sample that has highest residual weight is sample reinforced with 5mm length and 8% of fiberglass. Results also show that residual weight increased due to increasing of composition percentage and length of fiberglass that provide a better protection for the coating.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The purpose of this project was focused on the study of effect of fiberglass length and content on the performance of intumescent coating. 3mm and 5mm length of chopped fiberglass and various contents of fiberglass ranging from 0% to 8% were added into the basic intumescent coating formulations. Sample F1-4 (4% of 5 mm fiberglass) recorded the best expansion when tested in furnace test with 4 times expansion than the original thickness of the coating. In Bunsen Burner Test, F3-8 recorded to have lowest back steel temperature which was lower than 100°C during an hour test. F1-8 which the sample that exposed to temperature 500°C recorded the presence of Graphite, Boron Phosphate, Boron Oxide and Silicon when analyzed in XRD. This sample also recorded to have a highest residual weight when analyzed with TGA. Based on this result, the residual weight of sample is increase with the increasing of length and content of fiberglass in the intumescent coating. Thus, it can be concluded that the increasing of fiberglass length has increase the performance of the coating and helps to enhance the thermal characteristics of the coating to provide better protection for the substrate steel.

This project has obtained the objectives as 9 varying formulation of intumescent coating reinforced with fiberglass have been developed and also the effects of fiber length and composition on the performance of coating have been studied.

5.2 Recommendations

Despite all the overall objectives of the project achieved, there are several recommendations which could be considered in order to improve the project outcome as such:

- Use variety length of fiber reinforcement
  - The effect of length study on this project used 2 different length of fiber glass which were 3 mm and 5 mm. For further research, variety of length with larger scale of length difference can be used to achieve deep studies and researches about this subject.

- Use variety type of fillers
  - In addition to fiber glass reinforcement, other types of fillers can be used to study the impact of different fillers to the fire performance of intumescent coating.

- Analysis of char morphology
  - Further analysis can be done using Scanning Electron Microscopy (SEM) to study and analyze the char morphology of the tested sample.

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