INVESTIGATION OF FIRE RESISTANT PROPERTIES OF GLASSWOOL AND ROCKWOOL HYBRID FIBRE REINFORCED INTUMESCENT COATING

By

Muhammad Hafiz bin Roslan

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CERTIFICATION OF APPROVAL

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Approved by:

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Tronoh, Perak

MAY 2015

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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Muhammad Hafiz bin Roslan

ABSTRACT

Intumescent fire coating is widely used in world industry for protecting steel from high temperature. However due to its strength deficiency its performance is poor. Due to that, a study of fibre reinforced intumescent fire coating has been conducted recently. The project 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 study will focus on the glasswool and rock wool fibre as fibre reinforced for intumescent fire coating. Previously, various research regarding intumescent fire coating using single fibre to enhance the fire performance. The study will investigate the fire resistance of the coating using hybrid fibre as well as various composition of fibre and fibre length. In this project, a few samples of different formulations were be created and tested. The properties and performance of coatings were based on the char develop by the coatings in the furnace test and Bunsen burner test. The chars' residual weight were analyzed using Thermo Gravimetric Analysis (TGA). It was found that intumescent coating with single and short fibre glass wool has the expansion of 3.48 mm, the highest among others in furnace test. Besides that, intumescent coating with single fibre Rockwool recorded the lowest temperature in Bunsen burner test which is 79°C. In Thermo Gravimetric Analysis, intumescent coating with single fibre Rockwool has the highest residual weight at maximum temperature which is 78 weight percent at 790°C. It is found that the fire performance of intumescent fire can be improved with fibre that has high insulation. For intumescent coating with hybrid fibre content, the sample that higher composition of Rockwool has better performance than other samples. Finally, single fibre Rockwool shows a better fire performance than hybrid fibre which consist of glass wool and Rockwool.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, the fire protecting system has develop along with technology. The application of intumescent coatings as the fire protection for material is skyrocketing throughout the world.

Most materials that is use widely such as steel and wood are unable to withstand high temperatures. The adding of glasswool and Rockwool to reinforce the coating can improve the fire performance of intumescent coating by strengthens up the char. The glasswool and rockwool reinforcement will increase the properties of the coating to improve the ability to protect a material.

The proposed project concentrates on the effect of different fiber length and composition ratio of glasswool and rockwool to the fire performance of the coating.

1.2 Problem Statement

The current intumescent fire retardant coatings mostly are lack of strength. This affects the efficiency of coating in protecting the base structure when exposed to high temperature. At high temperature, intumescent coating expands and forms a char layer. A char layer is a poor conductor which prevent heat transfer, thus avoid damage to a protected material. However char layer can be depleted by physical erosion and chemical processes such as oxidation, thus its protection capability is reduced. The depletion cause it to crumble and without sufficient strength, a char layer will easily falling off and fail to protect a material.

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

i. To develop and synthesize intumescent coating hybrid fibre reinforced intumescent coating using glass wool and Rockwool fibres
ii. To investigate the effect of fibre length and composition of intumescent coating hybrid fibre reinforced towards its fire performance

1.4 Scope of study

The scope of research includes the comparison of intumescent coatings with various fibre content and length. In the sample preparation process, intumescent coating are produced with mix formulations of single fibre 10 wt. % glasswool, 10% Rockwool, and hybrid fibre 7 wt. % glasswool 3 wt. % Rockwool, 3 % wt. glasswool 7 wt. % Rockwool, and 5 % glasswool 5 % wt. Rockwool. The length of fibre are also varied with 6mm and 12 mm. In order to illustrate the effect of glasswool and Rockwool fibre addition towards the fire resistance properties of the intumescent coating, furnace test are done to determine the expansion of each intumescent coating. Besides that, the Bunsen burner test is also conducted to evaluate the conductivity of the coatings, as well as Thermo Gravimetric Analysis to study the residual its residual weight. By completing the tests and analysis of the results, a definitive understanding of the properties were obtained through further correlation.

CHAPTER 2

LITERATURE REVIEW

2.1 Intumescent fire coating

Currently, the materials protection from fire has become a vital issue in the construction industry. An intumescent flame-retardant coating is a very effective method to protect materials against fire since it is very economical and easy to manufacture. The two main benefits of the coating is that it can prevent heat transfer to protected material and spreading of flames. Furthermore it does not change the original properties of the materials.

According to TriantafylliIdis, Z. & Bisby, A. (2014), "When the coating is exposed to heat, they react and expand into a thick char layer with low thermal conductivity, thus insulating the protected to which they are applied. It commonly consist of a char-forming material, a catalyst, a blowing agent, a binder and various other fillers (Weil, 2011). Thick film epoxy-based intumescent coatings are widely used in offshore installations and industrial facilities to offer fire protection of steelwork against hydrocarbon pool and jet fires, as well as offering corrosion protection. The thickness of these coatings ranges between 5 and 25 mm, and relies on the required fire resistance, the steel section type and section factor (the ratio of heated surface area to volume of steel) and the limiting temperature adopted in design, typically based on design code requirements (Lennon and Hopkin, 2012). For fire scenarios that are credible threats in oil and gas applications, the fire protection coatings must resist highly erosive forces from ignited pressurised gases, as well as comparatively high imposed heat fluxes (HSE, 1992). Jun et al (2007) states that "The action of the flame retardant can occur across both or either of the vapor phase and the condensed phase. The combustion is a complex process: there may be different mechanisms with different matrix resins and different flame retardants. However, in our knowledge, the mechanism analysis of the flame-retardant coating is seldom reported at present."

TriantafylliIdis, Z. & Bisby, A. stated that "To develop the fire performance of intumescent coatings, continuous fibre reinforcement is often embedded within the polymer coating using a bidirectional carbon and/or glass fibre mesh. This mesh strengthens and maintains the integrity of the otherwise comparably weak char during expansion in fire. The coating remains in its unreacted state for the majority of its life and is essentially a lightly fibre-reinforced intumescent coating (FRIC)."

2.2 Composition and its ratio

Feng, C. et al research on flame retardancy and thermal degradation of intumescent flame retardant Ethylene-Vinyl Acetate (EVA) composite with efficient charring agent shows that the optimum ratio of Ammonium Polyphosphate (APP) to charring agent was 3:1 to improve fire retardancy. Based on one of Xia,Y. et al experiment, The optimal ratio of Ammonium Polyphosphate APP to PER for fire retardancy is 2:1. Guaxin,L. et al states that APP–PER–MEL coating was improved with Molybdenum trioxide (MoO3) and ferric oxide (Fe2O3) is used as modifiers because the carbon contents were enhanced with 9 wt.% MoO3 and 9 wt. % Fe2O3 at 350 °C, 580 °C and 800 °C, and the values of Cox/Ca also decreased with both MoO3 and Fe2O3 at 580 °C. Hongfei, L et al research on titanium dioxide on the flammability and char formation of water-based coatings containing intumescent flame retardants resulting Rutile type TiO2 has improved the fire retardant more anatase type TiO2. Beheshti,A. &, Heris,S.Z. evaluated that uniform-expanded char structure in the case of 20% nano-TiO2 and 15% ESP by weight, showed the best fire protection. Furthermore, Yew,M.C et al found that the finding the fire retardant sample with the addition of fillers (Al2(OH)3and TiO2) has higher performance with increased the residual weight of the coating.

In the project, the main materials use are stated below:

- Glass wool fibre
- Rock wool fibre

Glass wool is an insulating material made from fibres of glass arranged using a binder. It obtain its thermal insulation properties by trapping numerous small pockets of air between the glasses during its manufacturing process. Glass wool is formed with different thermal and mechanical properties.

Glass wool is a thermal insulation that consists of intertwined and flexible glass fibers, which causes it to "package" air, resulting in a low density that can be varied through compression and binder content.

Fiber materials that are formed by spinning or drawing molten minerals. Stone wool is a furnace product of molten rock at a temperature of about 1600 °C. The final product is a mass of fine, intertwined fibres with a typical diameter of 6 to 10 micrometers. From article Reinforced Plastics, Volume 42, Issue 1, January 1998, Page 24 The rockwool fibre mat expand 9 times its original thickness, forming thick layer that resistant to fire and erosion at 180°C.

2.3 Review of intumescent coating fire performance

The formulation of the coating has to be improved in terms of physical and chemical properties to form an effective protective char. The formation of intumescent char is relied on chemical interactions between the main ingredients in the formulations. The formulation of Intumescent Coating has a high thermal conductivity, whereas the char layer formed by the growth acts as a thermal insulator with a high insulation. Layer of char may go to a thickness of twice more than the original thickness of the coating and it strength is sufficient to protect material from rapid high temperature for a certain time.

This protective char restrict 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.

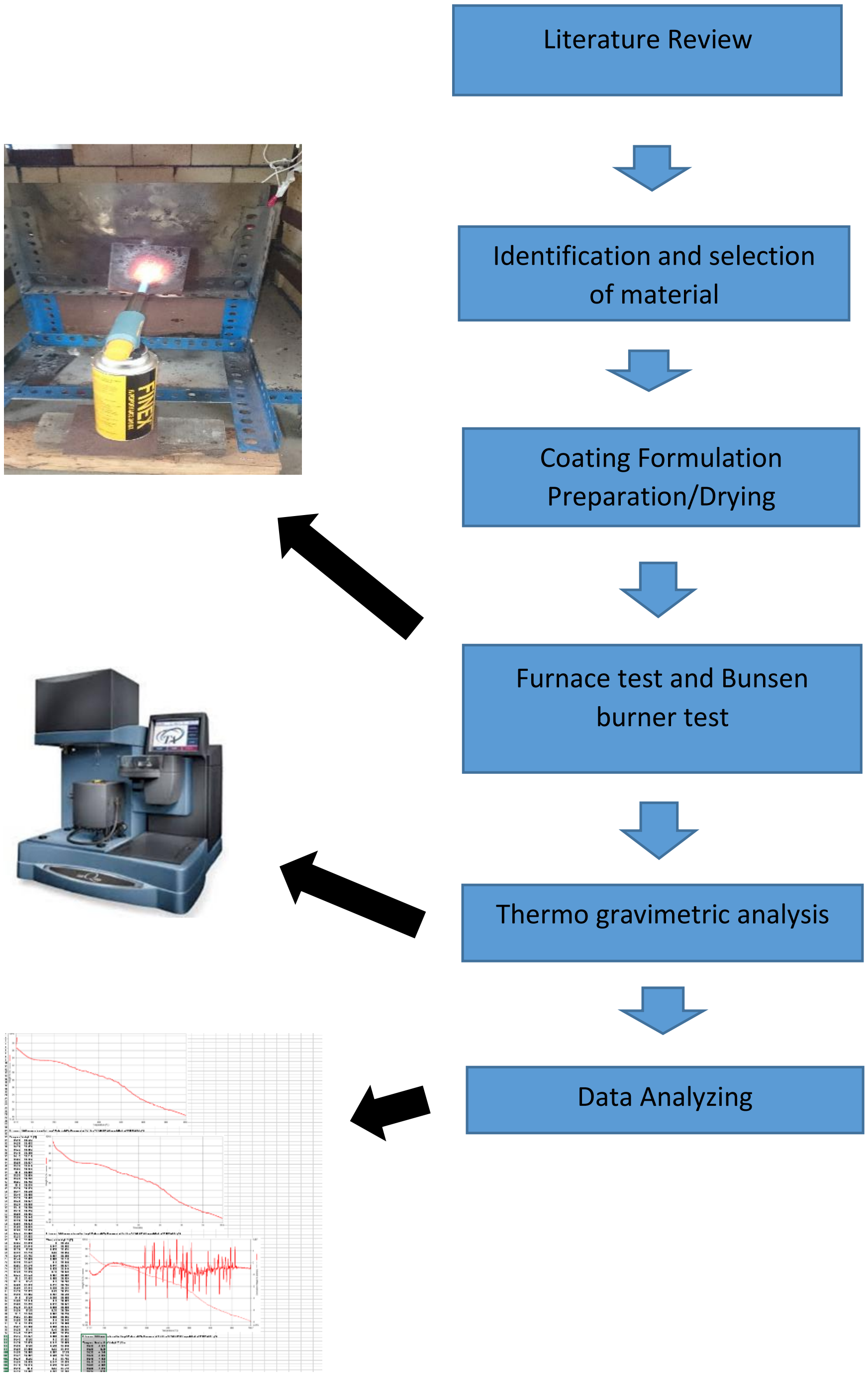
CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The study mainly concentrate on the effect of fibre reinforced towards intumescent fire coating. Furthermore, the study will compared a different fibres in terms of composition, type and length. Initially, the action taken to attain the objectives of this project is to do intensive research based on resources from internet, journals and article. Numerous journals and article were studied to obtain the necessary information on this project. Moreover, the objective of the project also need to be determined and a schedule needed to be planned well to accomplish the project. After that, the identification and selection of material are done, as well as formulations of sample. Table 3 and Table 4 shows the materials that has been used and its quantity. Coating preparation and drying are done later and the process took about 1 week. Furnace test and Bunsen burner has been conducted and results has been recorded in Table 6 and Figure 8. Then, Thermo gravimetric analysis is done and data is obtained as illustrated in Figure 10, Figure 11 and Figure 12.

3.2 General steps for project



3.3 Gantt chart and Project Milestones

Below are tasks that has been achieved throughout the project period.

Table 1: Gantt chart for Final Year Project I

No	Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■	■												
2	Literatures Review		■	■	■	■									
3	Submission of Extended Proposal						○								
4	Modeling the Formulation of Intumescent Coating								■	■					
5	Proposal Defense							○							
6	Identification of material					■	■	■							
7	Selection of material								■	■					
8	Modeling Experiments Execution										■	■			
9	Submission of Interim Draft Report													○	
10	Submission of Interim Report														○

Legends: ■ Project activity ○ Key Milestone

Table 2: Gantt chart for Final Year Project II

No	Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Formulation confirmation	■	■													
2	Modeled Experiments Execution and Optimization		■	■	■	■	■	■	■	■	■	■	■			
3	Submission of Progress Report							○								
4	Analyze the Result of Experiments												■	■		
5	Pre-SEDEX										○					
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

3.3 Project Activities

Initial part of the project is to identify the material selection and confirmation. Based on research on previous experiments, there are seven materials are selected. The material are listed below:

i. Ammonium polyphosphate
ii. Melamine
iii. Glass wool fibre
iv. Rockwool fibre
v. Pentaerythritol
vi. Epoxy Resin Bisphenol A
vii. Polyamide amine

After that, the formulation is determined. In this project, 11 formulations varying with fiber contents and length have been determined corresponding with project objectives. The value shown are in weight percentage unit. The formulations are stated in the table 3:

Abbreviation:

BPA	Epoxy Resin Bisphenol A
PA	Polyamide amine
APP	Ammonium polyphosphate
PER	Pentaerythritol
MEL	Melamine
GW	Glass wool
RW	Rockwool

Table 3: Intumescent fire retardant coating formulation portion

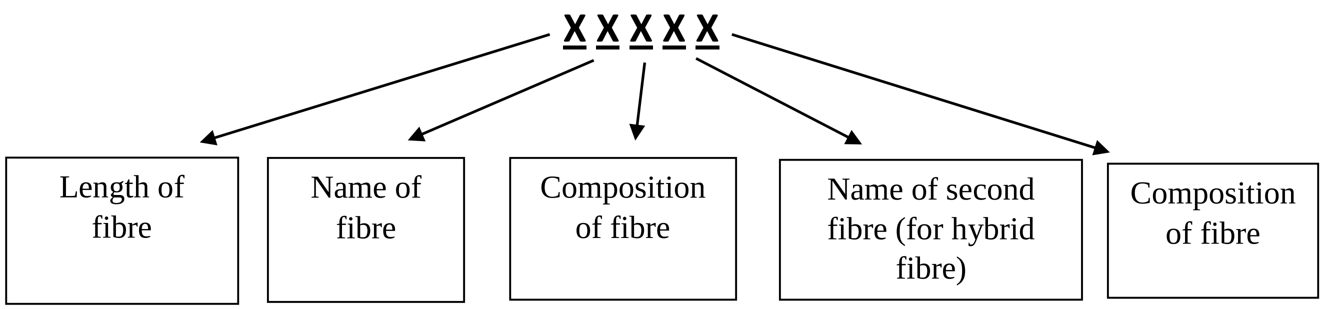
Sample No	Binder		Intumescent fire retardant				
	BPA (Epoxy) (wt.%)	PA (Hardener) (wt.%)	APP (wt. %)	PER (wt.%)	MEL (wt.%)	GW (wt.%)	RW (wt.%)
1	44.44	22.22	11.11	5.56	11.11	0	0
2	38.44	18.22	11.11	5.56	11.11	10	0
3	38.44	18.22	11.11	5.56	11.11	0	10
4	38.44	18.22	11.11	5.56	11.11	7	3
5	38.44	18.22	11.11	5.56	11.11	3	7
6	38.44	18.22	11.11	5.56	11.11	5	5
7	38.44	18.22	11.11	5.56	11.11	10	0
8	38.44	18.22	11.11	5.56	11.11	0	10
9	38.44	18.22	11.11	5.56	11.11	7	3
10	38.44	18.22	11.11	5.56	11.11	5	5
11	38.44	18.22	11.11	5.56	11.11	3	7

For each plate, 20 g of coating are applied. Therefore, based on formulation the amount of each material is determined. The table shows the quantity of material for each sample.

Table 4: Quantity of material

Sample No	Binder		Intumescent fire retardant				
	BPA (Epoxy) (g)	PA (Hardener) (g)	APP (g)	PER (g)	MEL (g)	GW (g)	RW (g)
1	8.88	4.44	2.22	1.11	2.22	0	0
2	7.69	3.64	2.22	1.11	2.22	2	0
3	7.69	3.64	2.22	1.11	2.22	0	2
4	7.69	3.64	2.22	1.11	2.22	1.4	0.6
5	7.69	3.64	2.22	1.11	2.22	0.6	1.4
6	7.69	3.64	2.22	1.11	2.22	1	1
7	7.69	3.64	2.22	1.11	2.22	2	0
8	7.69	3.64	2.22	1.11	2.22	0	2
9	7.69	3.64	2.22	1.11	2.22	1.4	0.6
10	7.69	3.64	2.22	1.11	2.22	1	1
11	7.69	3.64	2.22	1.11	2.22	0.6	1.4

After coating has been done, the sample will be labelled based on their fibre length and content. Figure below is the guide of the sample labelling:



Legend:

S: Short fibre (6 mm)

L: Long fibre (12 mm)

G: Glass wool fibre

R: Rockwool fibre

Figure 1: Sample labelling guide

For a sample without fibre content, it is labelled as C1.

3.4 Tools, Equipment and Experiment Procedure

Below are tools and equipment for creating and testing a sample:

i. Data logger
   - A data logger is an electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors. A data logger is use to record a temperature of of protected steel in Bunsen burner test.

ii. Grinder
   - Grinder is used for grinding an intumescent fire coating.

Figure 2: Grinder for grinding process

iii. Mixer

- The mixer is use to mixed an intumescent fire coating with glasswool and Rock wool fibre along with epoxy and Polyamide Amine.

Figure 3: Mixer for making a coating

iv. Thermo Gravimetric Analysis (TGA)

- TGA is a technique of thermal analysis in which changes in physical and chemical properties of materials are measured as a function of increasing temperature, or as a function of time.

Procedure:

1. The flow rates of inert and oxidative gas are set at 20 mL/min.
2. The temperature is started at 30°C and reach maximum temperature 790°C with heat rate 20°C/min.
3. The test material is place in the specimen holder and raise the furnace. The initial weight reading is set to 100%, then the heating program is initiated. The gas environment is preselected for thermal-oxidative combination.

v. Bunsen burner test

- In this project, a Bunsen burner test will be used to evaluate the performance of fire coating. The purpose of Bunsen burner test is to record for temperature of back of the steel to analyze for the thermal properties of the coating.

Procedure:

1. The Bunsen burner flame is set to a known and constant height of 10 mm ± 1 mm and applied to the end of the splint - angle at 20 °.
2. The flame is moved to the centre of the horizontally orientated splint. Observations such as extent of flame spread, ignition of sample or substrate, extent and nature of intumescence, adhesion of coating and char are recorded and compared between samples.
3. Experimentation is carried out in duplicate to ensure repeatable results. The fire protection test was carried out using a Bunsen burner by applying high temperature to plates.
4. The distance between the plate and Bunsen burner was fixed to 7 cm and the samples were exposed to fire vertically for 1 h. During the fire test, measurement of the temperature of backside of board was recorded by a data logger and the temperature of backside was drawn as the function of time.

vi. Furnace test

- Furnace test is used to test the char expansion of fire coating when applied to high temperature. The higher expansion produce a better fire resistance performance.

Procedure:

1. The samples are put into the furnace and the cover is closed.

2. The furnace is set up where the starting temperature is 30°C. The temperature is raised to 400°C in 1 hour and the temperature is maintain for about 10 minutes.
3. The temperature is lowered to 30°C in 1 hour and the samples are left to be cooled for 10 hours.
4. The thickness of each sample is taken after the furnace test.

3.5 Preparation of Sample

1. The process is starting with the measure of APP, Melamine and Pentaerythritol based on the formulation portion.
2. All of them are mixed together and the mixture powder is grinded in grinder.
3. Glass wool or/and Rockwool fibres then added into the grinded mixture powder and will be mixed them together manually until uniformly dispersed.
4. Prepare the epoxy and hardener based on the formulation portion and stir via mixer until a white milk layer is produced.
5. Powder and fiber 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 is left to dry at room temperature for about 1 week

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:-

Figure 4: Sample of intumescent coating for 10 cm x 10 cm

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

4.2 Experiment Results

All of the samples have been labeled as below:

Table 5: Samples labelling description

Formulation	Test Pieces	Glasswool composition (%)	Rockwool composition (%)	Length (mm)
1	C1-1 C12-2	0	0	0
2	SG10-1 SG10-2	10	0	6
3	SR10-1 SR10-2	0	10	6
4	SG7R3-1 SG7R3-2	7	3	6
5	SG3R7-1 SG3R7-2	3	7	6
6	SG5R5-1 SG5R5-2	5	5	6
7	LG10-1 LG10-2	10	0	12
8	LR10-1 LR10-2	0	10	12
9	LG7R3-1 LG7R3-2	7	3	12
10	LG10-1 LG10-2	3	7	12
11	LG5R5-1 LG5R5-2	5	5	12

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 a week to have a fully cured intumescent coating that ready for any test or experiment. Eleven formulations of sample have been leave in room temperature environment for curing process.

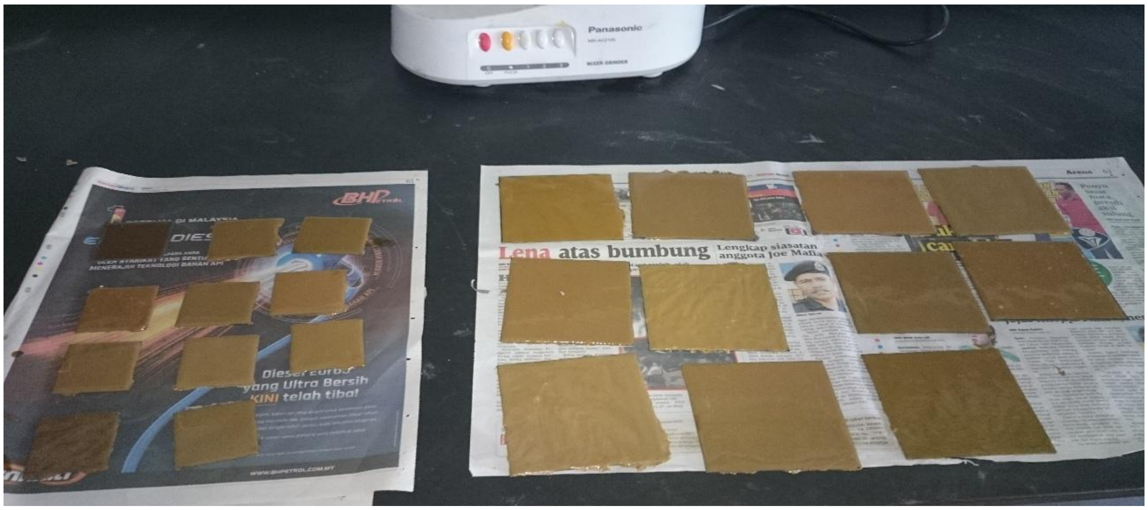


Figure 5: Intumescent coating after fully cured

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 shows the comparison of expansion between each sample.

Figure 6 : Intumescent coating after furnace test

Table 6: Result of intumescent coating reinforced in furnace test

Sample	Temperature (°C)	Thickness (mm)		Expansion (mm)
		Before	After	
Formulation without fibre reinforced – C1	**400 Degree Celsius**	2.05	3.19	1.14
Formulation 10% Glass wool of 6mm length – SG10		2.57	6.05	3.48
Formulation 10% Rockwool of 6mm length – SR10		2.97	5.24	2.27
Formulation 7% Glass wool 3% Rockwool of 6mm length – SG7R3		2.99	5.36	2.35
Formulation 3% Glass wool 7% Rockwool of 6mm length – SG3R7		2.3	5.45	3.15
Formulation 5% Glass wool 5% Rockwool of 6mm length – SG5R5		2.96	6.08	3.12
Formulation 10% Glass wool of 12mm length – LG10		2.69	4.74	2.05
Formulation 10% Rockwool 12mm – LR10		2.67	4.71	2.04
Formulation 7% Glass wool 3% Rockwool of12mm length – LG7R3		2.5	3.46	0.96
Formulation 3% Glass wool 7% Rockwool 12mm length – LG3R7		2.68	5.23	2.55
Formulation 5% Glass wool 5% Rockwool of 12mm length – LG5R5		2.70	4.67	1.97

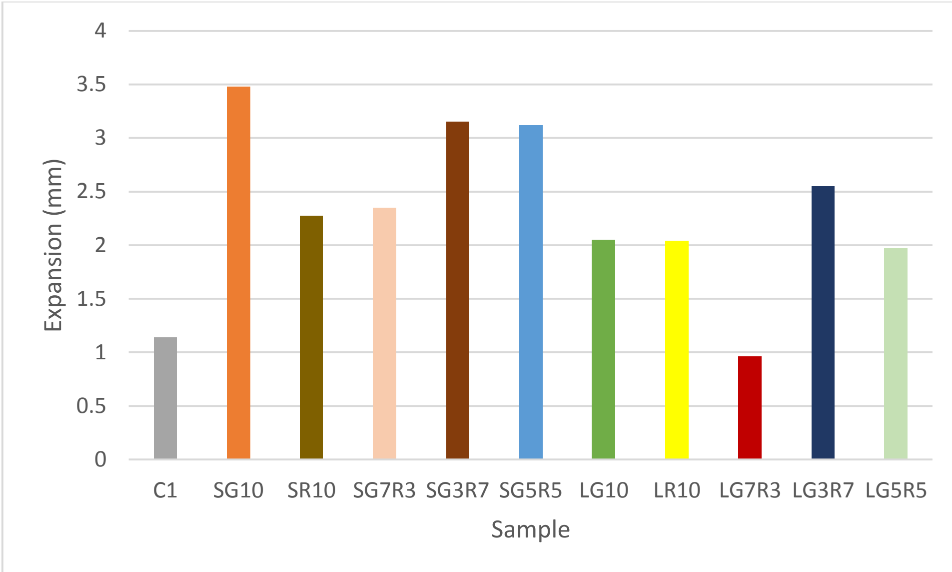


Figure 7 : Expansion of coating for each sample

Based on the result of furnace test at 400°C, the intumescent coating samples that showed the highest expansion are Sample SG10 followed by SG3R7 and SG5R5. Sample SG10 recorded an expansion of 3.48mm, SG3R7 with 3.15 mm and SG5R5with 3.12 mm. The char observed to have a rough crumbly surface and sufficiently attached to the steel substrate.

1.2.3 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 analyzed 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.

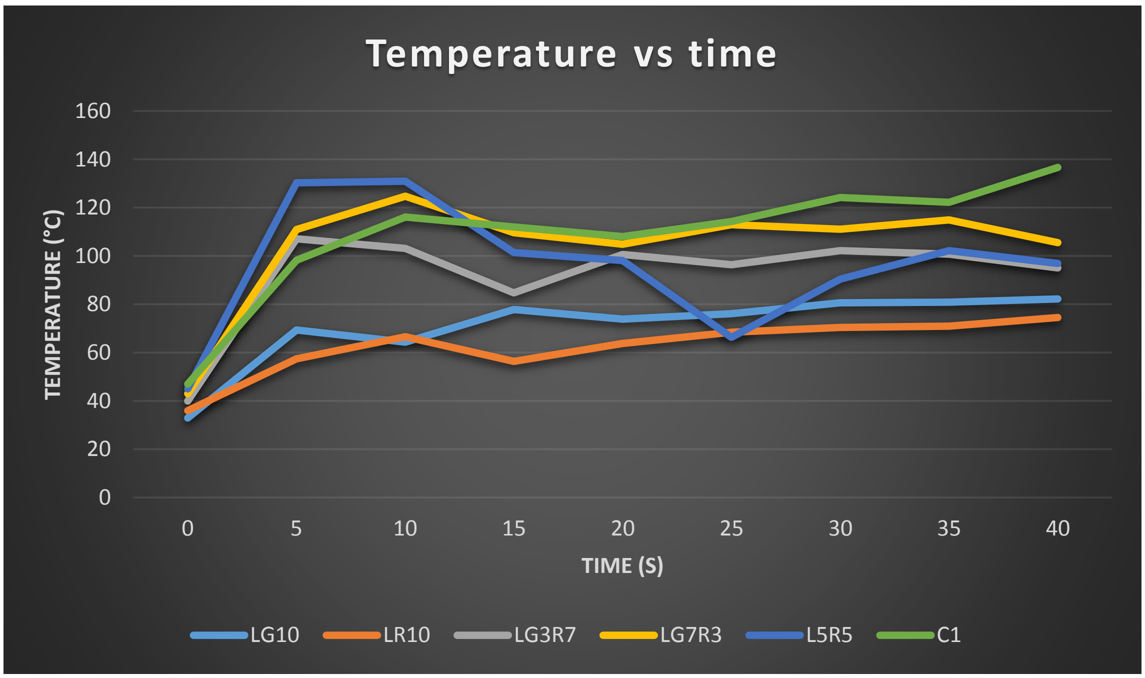


Figure 8: Graph of Temperature vs. Time of Tested Samples

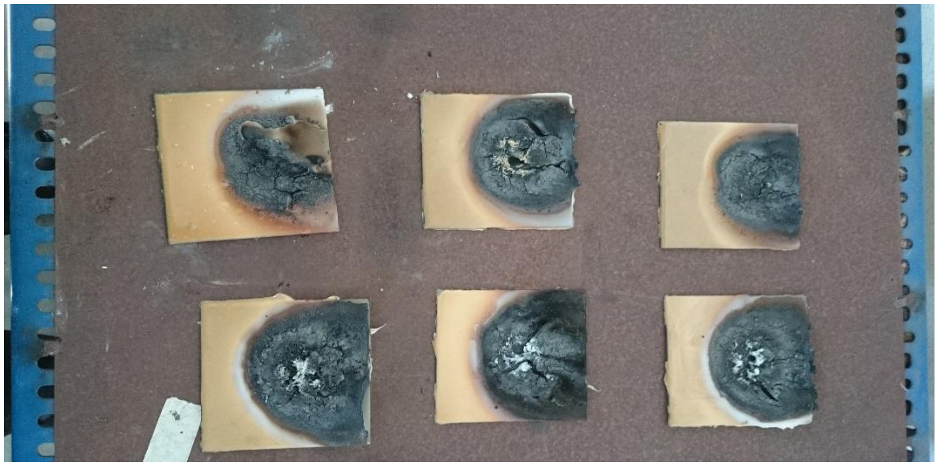


Figure 9: Sample char formation after Bunsen burner test

Sample LR10 which is coating reinforced and 10% Rockwool composition recorded the lowest temperature after 60 minutes of exposure. It can be concluded that the content of fiber 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. However, the hybrid fibre recorded a higher temperature compared to single fibre. From the observation, the single fibre produced a bigger crack compared to hybrid fibre.

1.2.4 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.

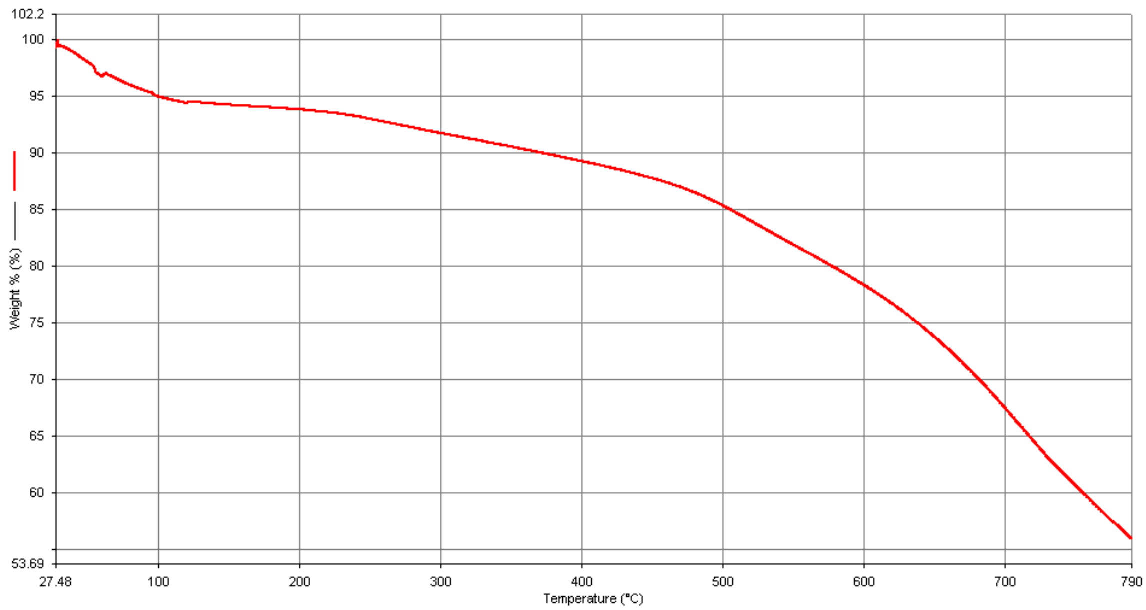


Figure 10: TGA result for C1

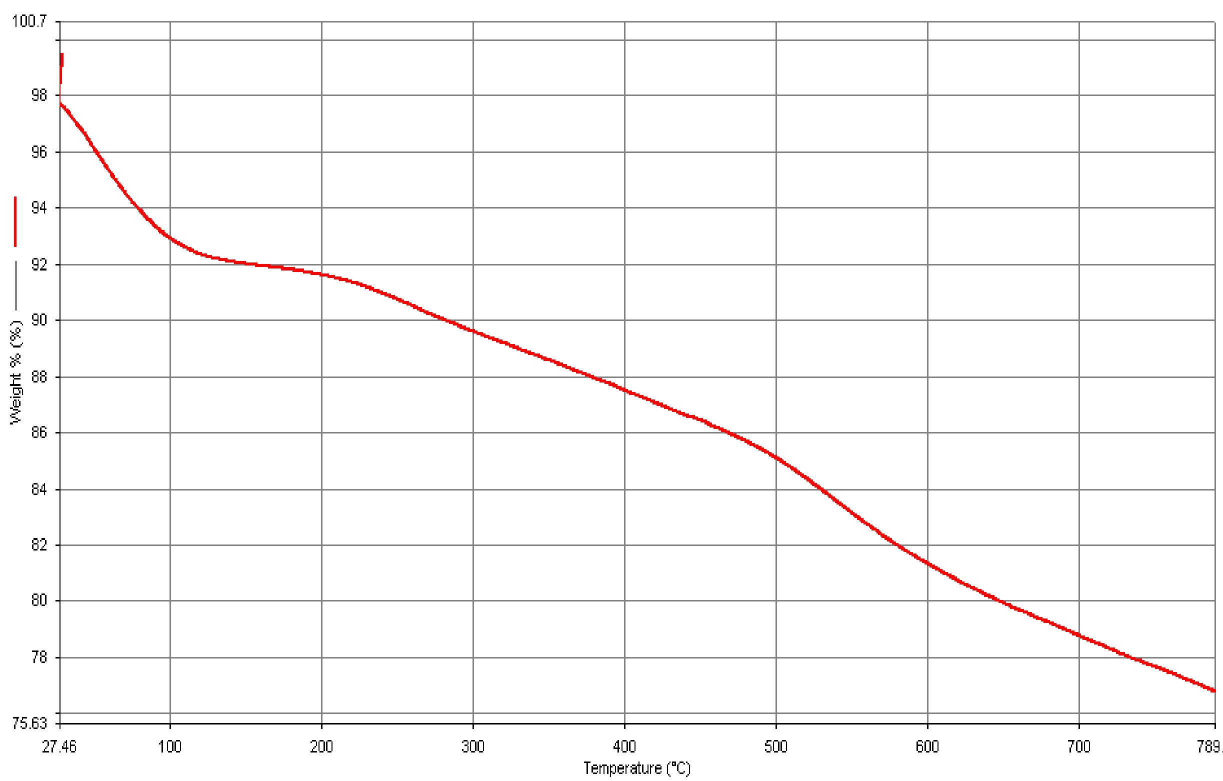


Figure 11: TGA result for SG3R7

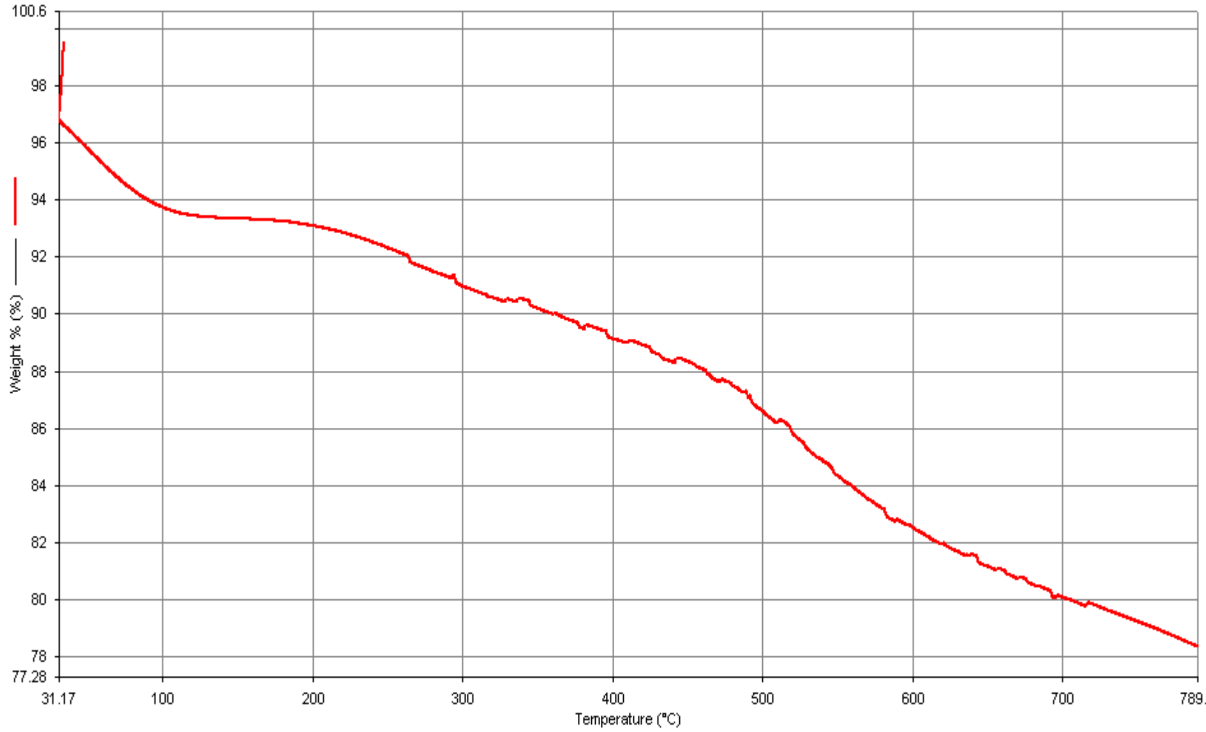


Figure 12: TGA result for SR10

Figure 10, 11, and 12 show the results of TGA for control sample, C1 (0% fibre), SG3R7 (3% glass wool 7% Rockwool) and SR10 (10% Rockwool). The residual weight is plotted against temperature to analyze for the effectiveness of intumescent coating during the burning process. Based on the figure 7,8 and 9,it is also shown that the weight loss of the coating is 1% at the beginning of the experiment, the moment is mostly due to fraction substance and resin decomposing, rudimental solvent and other volatilization vaporizing (Gu, Jun wei et al, 2007). When the temperature exceeded 290°C, the TGA curves of the coatings became slightly different from each other. From Yew M.C (2014), the residual weight from three samples (sample X, Y and Z) at 750°C were 28.07 wt. %, 27.70 wt. % and 26.98 wt. %, respectively. From this experiment, the residual weight obtain from samples C1, SG3R7, and SR10 were 60.62 wt %, 77.06 wt % and 79.21 wt %. At maximum TGA temperature of 790°C, the results shows that sample C1 left 56 wt %, SG3R7 left 76 wt %, and SR10 left 78 wt % residual weight.

1.3 Result Discussion

Result showed that sample with shorter length have a higher char expansion compare to the samples with longer length. As an example, in 400°C furnace test experiment, the sample reinforced with 3 mm glasswool and 8% contents of glasswool have an expansion of 3.48 mm while the sample with same percent of content (10%) but with longer length of 12 mm have lower expansion of 2.05 mm. This showed that the shorter of fiber glass length has increased the char expansion that increases the performance of intumescent coating in high temperature.

Based on Bunsen burner test result, Sample LR10 which is coating reinforced and 10% Rockwool composition recorded the lowest temperature after 60 minutes of exposure. It can be concluded that the content of fiber 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. However, the hybrid fibre recorded a higher temperature compared to single fibre. From the observation, the single fibre produced a bigger crack compared to hybrid fibre. This shows that hybrid fibre has higher strength than single fibre.

For Thermo Gravimetric Analysis (TGA), the samples that recorded higher residual weight have a better performance. Previous 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. 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 10% of single fibre Rockwool. Results also show that residual weight increased due to increasing of composition percentage Rockwool fibre that provide a better protection for the coating.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The purpose of this project was focused on the study of effect of glasswool and Rockwool hybrid fibre content on the performance of intumescent coating. 6mm and 12mm length of chopped fiberglass and various contents of fiberglass ranging from 3% to 10% were added into the basic intumescent coating formulations. Sample SG10 (10% of 6 mm fiberglass) recorded the best expansion when tested in furnace test. In Bunsen Burner Test, LR10 recorded to have lowest back steel temperature which was lower than 100°C during an hour test. A sample with highest Rockwool fibre content also recorded the highest residual weight when analyzed with TGA. Based on this result, the residual weight of sample is increase with the increasing of content of Rockwool in the intumescent coating. Thus, it can be concluded that the single fibre has increase the performance of the coating better than hybrid fibre and helps to enhance the thermal characteristics of the coating to provide better protection for the substrate steel. However, the strength of hybrid fibre is higher than single fibre.

This project has obtained the objectives as 11 varying formulation of intumescent coating reinforced with glasswool and Rockwool 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 6 mm and 12 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.

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.

Analysis of mechanical properties

- Mechanical test can be to study more the properties of single and hybrid fibre.

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APPENDICES

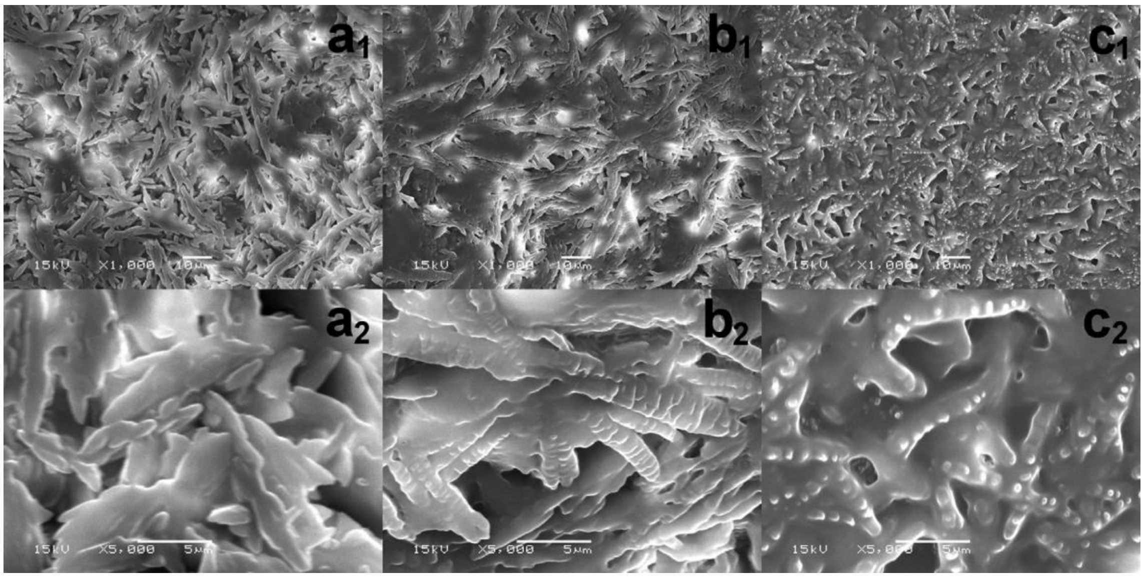

Figure 13: Scanning Electron Microscope photo

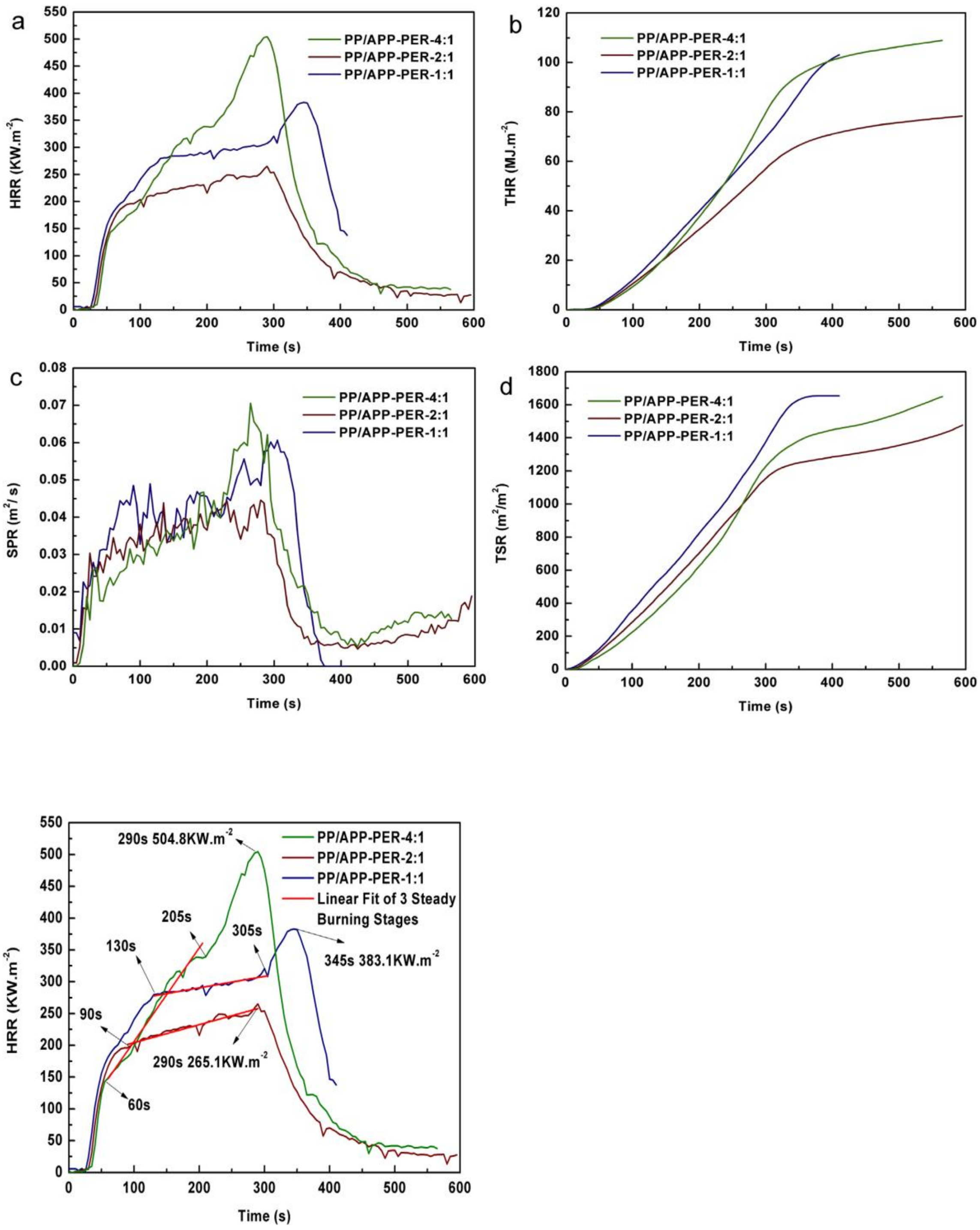

Figure 14: Xia Y et al experiment result

Figure 15: Fire intumescent coating after furnace test

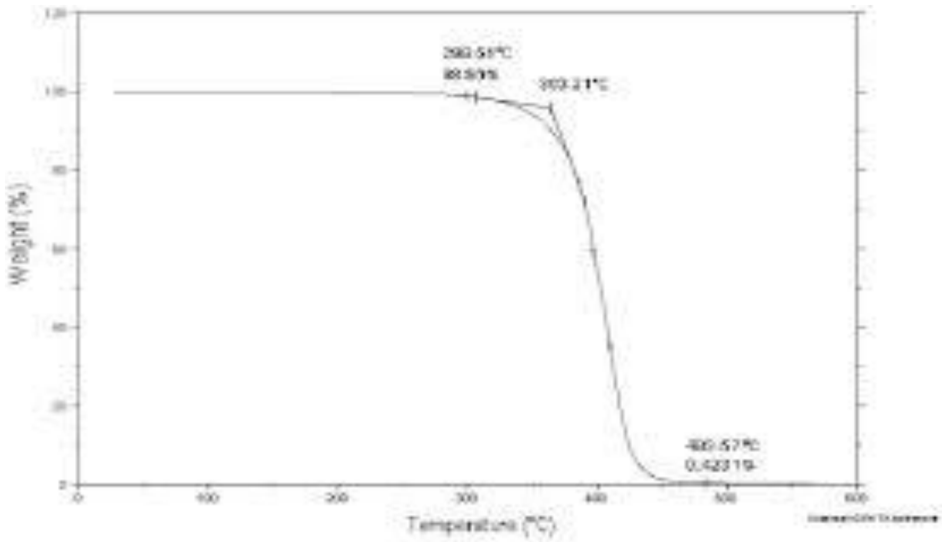

Figure 16: Thermo gravimetric analysis

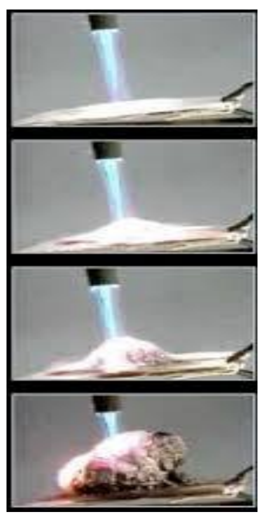

Figure 17: Bunsen burner test