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Formulating 2K High Performance, High Build, Solvent-Free Epoxy-Based Green Intumescent Coating.

Dr. Pankaj M. Vyas

Chemical Engineering Department - Birla Institute of Technology & Science, Pilani - Dubai Campus

Spraytek Coatings – Technical Manager -Head of R&D, https://www.spraytek-me.com/ P. O. Box 27356, Dubai - UAE.

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ABSTRACT

Traditional, epoxy passive fire-fighting intumescent or reactive coatings have been used by the industry for a very long time. They are used to safeguard expensive industrial assets like storage tank farms, onshore and offshore oil drilling platform rigs, LPG (Liquified Petroleum Gas) installations, pipelines carrying highly flammable materials, steel buildings, refineries, petrochemical processing facilities, and chemical and fertilizer manufacturing facilities. These conventional coatings are less effective at preventing fires and emit more VOCs (volatile organic compounds), which limits their ability to successfully protect these expensive assets. The demand for products produced by the oil, gas, and petrochemical industries is soaring. These products need to be stored according to strict fire safety regulations since they are so highly flammable. Here, an effort is made to develop a green intumescent coating that is epoxy-based. In order to produce a synergistically better performance in the coating, we integrate innovative inorganic minerals and nanofillers, additives like graphene, CNTs (Carbon Nano Tubes), and embedded carbon fiber mats in our studies. By using, heavy duty priming, base coats such as 2K inorganic zinc silicate and epoxy zinc phosphate, this is improved even more. These coatings systems offer steel surfaces barrier protection against hydrocarbon and jet fires that are common in petrochemical sectors, as well as thermal insulation. One of the new experimental items that was created, which included embedded C (Carbon)-fiber matt and CNTs, produced significantly better results in terms of both char generation and bare steel protection. In numerous experiments, it was determined to be the best.

Keywords: 2K, two components - Base and Hardner, high build, "green" -pollution-free, VOC-volatile organic contents, intumescent coating, hydrocarbon fire, jet fire, synergist (interaction of two or more chemical agents to generate a combined effect greater than the sum of their separate effects).

INTRODUCTION

The application of intumescent coating technology goes back more than 50 years. As a result of developments in the technologies of resins, polymer composites and additives, nanofillers,

inorganic functional mineral fillers, etc., new products on acrylic, silicone, epoxy, and other materials are offering good services [1,2,3]. Our primary goal is to protect extremely valuable and significant steel structures and industrial assets, such as factories that make chemicals and fertilizers, refineries, petrochemical processing plants, storage tank farms, onshore and offshore oil drilling platform rigs, nuclear power plants, LPG installations, and pipelines that transport highly flammable liquids. Three important formulating criteria considered are:

(a) A high volume of solids, low VOC-volatile organic content with low pollution, and solvent-free (SF) green coatings are some of the most important green coatings formulation characteristics.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

(b) High build (HB), non-drip coatings with the ability to apply at high film thickness are more cost-effective since fewer coats are needed to achieve the appropriate DFTs (Dry Film Thickness) and performance.

(c) To produce synergistically better performance coatings, novel additives, nanofillers, functional inorganic mineral fillers, chopped fibers, and carbon fiber matting, among others, are made use of. [4,5,6,7].

An intumescent coating can be compared to a carefully prepared chemical mixture that expands excessively beyond its initially applied thickness when exposed to fire and heat. As a result, the density falls while the volume rises [8,9]. Heat exposure causes a range of chemical and physical processes in the case of flame retardants that lead to a tumescent condition. What distinguishes this state from others is its fire-resistant insulating foam. The foam extinguishes the flames by severing heat and oxygen from the fuel. They typically contain a variety of ingredients, including mineral fillers, pigments, and resinous binders, as well as functional additives like catalysts, dehydrating agents, and carbonizing agents (APP, Ammonium Poly Phosphate), sources of carbon (Penta or Dipentaerithritol), a blowing agent (Melamine), and flame-retardant fillers (ATH, Aluminium Tri Hydrate, and other additives). [1-5]. Below is a summary of this in Figure 1:

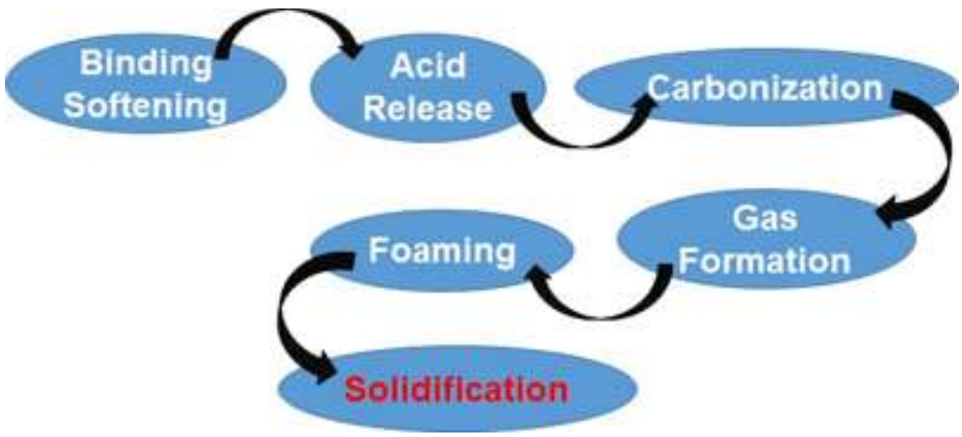

Figure 1. Schematic diagram showing the sequence of steps / mechanism of its action and performance in an Intumescent passive fire protection system.

Recent developments in this area have improved char cell structure, char height creation, and strength through the use of chopped carbon and glass fibres, inserted carbon matt, and other techniques, resulting in less weight loss and more char production. The temperature rise of steel surfaces is limited because carbon fiber and embedded matt do not degrade and steel structures are particularly effectively insulated. The fundamental idea behind an intumescent coating is that it expands when exposed to heat, and the enlarged char's low thermal conductivity creates a thermal insulating barrier effect. Hence, numerical data about both of these factors can be useful for designing and creating new coatings. It carries out the main duties, such as controlling the spread and escalation of fire, preventing steel from reaching higher temperatures to prevent structural failure and collapse, giving inmates enough time to flee to safety, safeguarding the highly flammable chemicals kept in tank farms, etc. [6, 10, 11].

The hydrocarbon fires sometimes referred to as jet fires, 2K epoxy intumescent coatings are crucial fire protection options for steel structural elements there. The intumescent coatings must endure extremely high heat fluxes and highly abrasive forces from ignited pressurized gases.

Thus, continuous fiber reinforcement is added during installation to the thick epoxy coating to protect the fragile intumesced char's integrity during fire exposure. Under normal service circumstances, a fiber-reinforced intumescent coating (FRIC) is essentially a weakly fiber-reinforced polymer (FRP) composite material because the typical form of this reinforcement is a bidirectional carbon and/or glass fiber mesh. [12-15]

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

Historical facts show that the Piper Alpha was an oil production platform in the North Sea operated by Occidental Petroleum (Caledonia) Limited. On July 6, 1988, it was the site of the world's deadliest offshore accident. A platform explosion and the ensuing oil and gas fires destroyed it, killing 167 people, including two crew members of a rescue vessel. At the time of the catastrophe, the platform was producing 10% of the oil and gas from the North Sea, and the total insured loss was close to $3.4 billion. This catastrophe has highlighted the need for in-depth knowledge as well as improvements in the understanding of fire dangers and protection in offshore constructions. Through several industry-sponsored programs, significant new knowledge has been gained on how fires begin, spread, and escalate. These initiatives have also shown how to limit and reduce fire threats through smart design and efficient protection. Interim Guidance Notes, which offer information to operators on how to assess jet fire threats, were produced as a result of a major push by the offshore oil and gas industry operators. It includes tabulated data and easy computation methods for estimating the risks of jet fires. [16,17,18]

One of two common types of fire may occur in a hydrocarbon processing plant [19]. The first kind of fire, known as a pool fire, occurs when a flammable liquid seeps from a container or pipeline to create a fluid reservoir. Temperatures up to 1100 °C and heat fluxes of roughly 150 kW/m2 are possible as a result of a hydrocarbon pool fire. Three main passive fire prevention product types are frequently used in hydrocarbon processing facilities. Cementitious goods, intumescent coatings that are typically epoxy-based and applied by spray or hand, and items with blanket systems comprised of man-made fibres that use insulation as their principal fire protection mechanism are a few examples. A pressurized vessel or gas line breaking can result in a jet fire, which is the second and potentially dangerous type. A jet fire may cause the temperature to climb equally, even though it may produce twice as much heat as a pool fire.

Serious accidents on offshore sites provide a risk that heavily involves jet flames. The behavior of jet flames is influenced by the fuel mixture, release conditions, release rate, release geometry, direction, and ambient wind conditions. In terms of laziness, wind effect, buoyancy, soot, and radiative intensity, low-velocity two-phase discharges of condensate material can produce flames that are similar to pool fires. Natural gas emissions that are audible can result in relatively fast fires that are significantly less buoyant, sootier, and therefore less radiative. [20].

Information on commercial testing is available from [21], using various industry-specific standard specifications like:

- Jet Fire Testing by ISO 22899-1-which evaluates the flame resistance of passive fire-protection materials intended for use on components such as tanks, pipes, valves, etc. The material is subjected to a constant jet fire during this test.

- The Jet Fire and Hydrocarbon Curve Tests (EN 13381-4 and EN 13381-8), to be used in conjunction with in-furnace hydrocarbon curve tests, to evaluate passive fire-protection systems to be applied to structural elements.

- Jet Fire Tests for Other Elements as per ISO 22899 also describe the kinds of testing necessary on items and systems intended to safeguard various components of a facility.

- The size of the global market for intumescent coatings, which was estimated at USD 1,100.79 million in 2021 and is expected to increase at a CAGR of 5.5% from 2022 to 2030, is important to note [11]. Due to strict restrictions and an increase in exploration operations worldwide, the oil and gas sector's high product demand is expected to drive market expansion. Moreover, during the anticipated period, demand from the construction sector is anticipated to drive market expansion.

- A set of Recent References is added [Ref; 61-69]- to engage with recent advances in Intumescent Coatings from 2020 onwards.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

MATERIALS AND METHODS

Materials

The coatings to be formulated are 2K, high performance, high build, solvent-free epoxy-based green intumescent coatings with very high performance against exposure to fire. They exhibit protection to steel plant structures for a long time, have ease of manufacturing and access to raw materials, economic considerations, ease of finished product offering that includes packing, simple mixing ratios, ease of handling and application, adequate working time, early setting, proper curing, strength, control of film formation after application, etc. They satisfy the parameters (a), (b), and (c) noted in the introduction were also taken into account. To achieve better performance, different formulations of epoxy intumescent coatings were tested, including those with different ratios of boric acid, borax decahydrate, zinc borate, engineered mineral fibres, and specially treated rockwool fibrous powder for increasing char strength and reinforcing properties, hollow Cenosphere effects, and minerals like ATH/Mg $(OH)_2$/ Hunite-Hydromagnesite/vermiculite, among others. The effects of reacting APP, Dipentaerithritol, and Melamine at weight ratios of 2:1:1 was investigated. Researchers examined the effects of

cutting-edge carbon materials like graphene, CNTs, and embedded carbon matt in coating films. [22-26]. Further information on the source and grades of some of the significant raw materials utilized in the experiments is provided in [59] as Annexure -A at the end under the reference section.

Classification of the raw materials

Based on their specialized roles in the formulations of the coatings, the raw materials used were separated into various classes. Further information on the source and grades of some of the significant raw materials utilized in the experiments is provided [59], as Annexure -A at the end under the reference section. These Groups are:

Table 1 Raw Material Groups

Groups	Raw Material
Group A:	Epoxy resin binder/reactive diluent:
Group B:	Pigments -Minerals:
Group C:	Silica-based minerals:
Group D:	Fire retardant Pigments, Chemicals:
Group E:	Intumescent Pigments/ Minerals:
Group F:	Additives:
Group G:	Hardner -Curing Agent:

Designing of Experimental Compositions:

- Three different formulations of 2K SFHB (Solvent Free High Build) Epoxy Intumescent coatings were tried as per formulation scheme shown in Table 2. They are labelled as E1, E2, E3. Also, a standard reference of conventional Intumescent coating of other (non-Epoxy) type, was included for comparison, with experiment ref. E4.
- The above Paints were tested on two sets of primers, P1-2K Epoxy zinc Phosphate Primer and P2- 2K Inorganic Zinc Silicate Primer, after sand blasting and priming with them.
- Experiments Nos. II and III (E2, E3), were tried with Graphene and CNTs respectively along with Expandable Graphite in all experiments.
- An experiment was designed by embedding Carbon fiber matt in one of the coating experiments, ref. P2E2CM.
- Various experiments tried are labelled as: P1 Series-P1E1, P1E2, P1E3, P1E4 and P2-Series P2E1, P2E2, P2E2CM, P2E3, P2E4.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

Table 2 - showing the composition for the coating formulas.

Materials from group	Experiment References					
	E1		E2		E3	
	Components of E1		Components of E2		Components of E3	
	Comp.E1-A	Comp.E1-B	Comp.E2-A	Comp.E2-B	Comp.E3-A	Comp.E3-B
A	46.00	00.00	46.00	00.00	46.00	00.00
B	10.00	10.00	10.00	10.00	8.00	13.00
C	0.30	19.00	0.30	20.00	12.90	26.00
D	24.70	-	24.70	-	16.00	-
E	14.00	18.00	14.00	18.00	13.30	10.00
F	5.00	3.00	5.00	2.00	3.80	5.00
G	-	50.00	-	50.00	-	46.00
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00
Important Characteristics						
1. Sp.Gr.	1.55		1.51		1.47	
2. % Pigment by Weight:	52.60%		52.60%		53.80%	
3. % Binder Solids by Weight:	47.40%		47.40%		46.20%	
4. % Solids by Volume:	100.00%		100.00%		100.00%	

Mixing Ratios: Component A: Component B: 2: 1 By Weight

Consistency: Viscous-Thixotropic Paste

Equipment used and test preparations:

A list of other Test Equipment is:

- Humidity test chamber - ASTM -117, F2129- and similar other standards.
- UV-exposure weathering test chamber- AST M G154- and similar other standards
- Salt spray test chamber - ASTM B117 and similar other standards.
- Adhesion tester- Posi Test AT-A-Automatic Adhesion Tester- ASTM D4541/D7234,

and similar other standards, these are available from various sources like CME- CM Envirosystems- https://www.cmenvirosystems.com/ product-details/salt-spray-chamber etc.

- Fire Test Box with Temperature indicator screen of each side were recorded at intervals of 2.50 minutes or 150 seconds, as shown in observation Table 3A and Table 3B. The Time-temperature graphs were plotted, Figure 10 and Figure 11, from the recorded observation table. The Fire test was conducted in a specially designed, Fire Box. The Firebox can raise the temperature of the test panel within 20 minutes to 1000 deg. C. It has an arrangement of attaching thermocouples on both sides of the panel (the painted side and bare steel on the back side), and temperatures

The samples of Intumescent ash after each fire test were collected and sent for characterization tests like -Raman and XRD spectral analysis as well as SEM at various magnifications.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

Figure. 2 Figure 3 Figure 4



Furnace pictures were taken after fire testing.

The temperature indicating screen in Fig #2 and 4, on the left and right sides of screen, indicates the temperature for the Painted side (seen as 1000 Deg. C) and the right-side screen indicates the back side/bare steel temperature (seen as 665 deg. C).

Specimen Panel preparation, actual fire exposure testing:

- Steel panels of size 150 X 100 X 2 mm thickness were used after sand blasting to SA2.50 and priming with two sets of primers:

1- P1-2K Inorganic Zinc Silicate Primer

2- P2-2K Epoxy zinc Phosphate Primer

- Panels were applied with finishing coat of experiments E1, E2, E3 and reference standard E4, as mentioned earlier. Panels for fire exposure test were coated on one side only, leaving back side as unpainted, bare steel metal. Both sides of panel have thermocouple attachment device which records the temperature of each side.

  - The panels made were labelled with following references: P1E1, P1E2, P1E3, P1E4 for P1-series primer and
  - P2E1, P2E2, P2E2CM, P2E3, P2E4 for P2-series primer.
  - On a P2 primed panel, a coat of experimental paint EII was applied and on its wet surface, a carbon matt was placed, pressed and a full coat of EII was applied to cover up the matt, was allowed to dry. This was labelled as ref. P2E2CM.

- These panels were allowed to dry and cure at ambient temperature for 7 days before subjecting to various tests as indicated in Table 2. Dry film thickness for each panel were recorded.

- Panels were applied at Thickness of 1.30-1.50 mm with an approximate Application Rates of 2.00 -2.20 kgs per Sq. mts. (Kgs/M2)

A List of Equipment used and test preparations / Test Standards-:

- Humidity test chamber – ASTM -117, F2129- and similar other standards.
- UV-exposure weathering test chamber- AST M G154- and Adhesion similar other standards
- Salt spray test chamber – ASTM B117 and similar other standards.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

- Adhesion tester- Posi Test AT-A-Automatic Adhesion Tester- ASTM D4541/D7234, and similar other standards, these are available from various sources like CME- CM Envirosystems- https://www.cmenvirosystems.com/ product-details/salt-spray-chamber etc.

- The Fire test was conducted in a specially designed, Fire Box as shown in the Figures. – 2/3/4 above. The Firebox can raise the temperature of the test panel within 20 minutes to 1000 deg. C. It has an arrangement of attaching thermocouples on both the sides of the panel (the painted side and bare steel on the back side), and temperatures of each side were recorded at intervals of 2.50 minutes or 150 seconds, as shown in observation Table 3A and Table 3B. The Time-temperature graphs were plotted, Figure 10 and Figure 11, from the recorded observation table. The samples of Intumescent ash after each fire test were collected and sent for characterization tests like -Raman and XRD spectral analysis as well as SEM at various magnifications.

- The Price Factor: As on 02-2023

Category Description	Category Ref.	Price in Dhs. Per kg	Price in US$ per kg
Formulating advanced 2K high performance, high build, solvent-free epoxy-based green intumescent coatings.	E-1 E-II, E-III	10.50 12.00 10.90	2.90 3.30 3.00

- The Time -Temperature graphs were plotted from the recorded observation table.

- The samples of Intumescent ash after each fire test were collected and sent for characterization tests like -Raman and XRD spectral analysis as well as SEM at various magnifications.

- Direct fire exposure tests were also conducted on I- Beams, sand blasted to SA 2.50 and painted with experimental systems. See Figure 8.

- P1-2K Epoxy Zinc Phosphate / P2- 2K Zinc Silicate - primed panels and I-Beam are shown in Figure 5 and Figure 6.

Figure 5

Figure 6

Figure 7 (a/b/c/d /e/f)-Shows Painted Panels of experiments tried:

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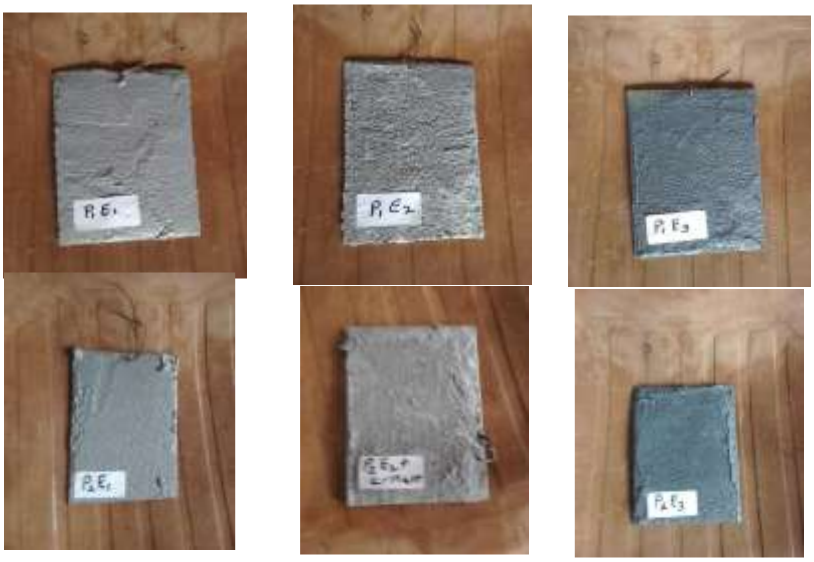
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

a. P1E1-Panel b. P1E2 – Panel c. P1E3-Panel



d. P2E1-Panel e P2E2 + CM Matt Panel f. P2E3-Panel

Figure 8 (a/b/c/d) -shows Painted I-Beams of various experiments conducted: a-I-Beam Painted with P1E2 and P1E3 / b.- I-Beam Painted with P1E1 and P1E4 / c-I-Beam Painted with P2E2 and P2E3 d - I-Beam Painted with P2E1 and P2E4.

a b c d

Figure 8 (a /b/c/d)

Test Results and Observations

Table 3, shows the results and observations of various tests performed for each of the experiments tried.

Table 3: Performance Tests Results:

		E1	E2		E3	E4
1	Fire Exposure Test in Fire Box	Detailed Results available in Tables: 3(A) and 3(B)				
2	I C E F	P1E1	P1E2		P1E3	P1E4
	ICEF (mm)	31.50	27.00		28.50	16.70
	DFTs (mm)	1.40	1.30		1.23	1.20
		P2E1	P2E2	P2E2CM	P2E3	P2E4
	ICEF (mm)	32.20	30.00	31.20	32.80	18.40
	DFTs (mm)	1.43	1.30	1.60	1.22	1.20

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

3	Corrosion- as per ASTM -B-117 for 1000 hours	All experiments pass test satisfactorily			
4	Salt spray - as per ASTM-B-117 for 1000 hours	All experiments pass test satisfactorily			
5	Accelerated UV weathering -as per ASTM G-154 for 1000 hours	All experiments pass test satisfactorily			
6	Adhesion Test values	P1E1 4.14	P1E2 4.14	P1E3 4.04	P1E4
		P2E1 4.80	P2E2 4.40	P2E3 4.93	P2E4

Figure 9. Adhesion Tested Panels

Fire Test Observations- and graphical presentations of test results:

1-. Fire exposure test results: The Time-Temperature readings for Jet Fire Test Curves for an initial 10 mts. of fire exposure and a further 15 mts. of fire exposure are shown in Table 3. (A) and Table 3. (B).

Table 3. (A): Initial 10 mts. from start

Sr. No	Time In Mins	P1 – Series Experiments – Temp (°C) On 2K Epoxy Zinc Phosphate Primer								P2 – Series Experiments – Temp (°C) On 2K Inorganic Zinc Silicate Primer									
		Coated Side Temp (°C)				Bare steel side Temp (°C)				Coated Side Temp (°C)					Bare steel side Temp (°C)				
		E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E2 CM	E3	E4	E1	E2	E2 CM	E3	E4
1	0	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
2	2.5	245	224	220	204	125	115	105	108	421	262	285	322	174	221	145	172	195	155
3	5	385	451	408	560	179	196	196	232	442	604	440	491	321	226	229	229	248	204
4	7.5	575	592	593	814	217	230	235	304	643	765	621	671	762	331	316	252	337	326
5	10	678	690	711	924	287	297	315	398	768	885	803	803	885	421	438	341	443	427

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

Comments:

- The above **Table 3.(A),** shows that within initial 10 mts. of fire test started, the maximum Coated side temperatures for different experiments quickly reaches from 678 deg. C (for experiment P1E1) to 885,885 and 924 deg. C. (for experiments P2E2, P2E4 and P1E4) as shown in yellow highlights.

- As against this, the maximum back side -bare steel temperatures reached for both of P1 and P2 series of experiments are well under control and below the critical steel failure temperatures of 450 deg. C. This is as shown in blue highlights in above observation table.

- From both P1 and P2 experimental series, experiments P1E1, P1E2 and P2E2CM with bare side steel temperatures of 287 deg. C, 297deg. C and 341deg. C are the best minimum of all experiments tried.

- In general, the P1-Serise with 2K Epoxy Zinc Phosphate primer shows better results and lower bare steel -back side temperatures than P2-2K Inorganic Zinc Silicate Primer.

- Experiment with CNTs (experiment P1E2) performs better than Graphene (experiment P2E3).

Table 3(B) Observations –for the fire exposure test - continued further for another15 mts.

Sr. No	Time In Mins	P1 – Series Experiments – Temp (°C) On 2K Epoxy Zinc Phosphate Primer								P2 – Series Experiments – Temp (°C) On 2K Inorganic Zinc Silicate Primer									
		Coated Side Temp (°C)				Bare steel side Temp (°C)				Coated Side Temp (°C)					Bare steel side Temp (°C)				
		E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E2 CM	E3	E4	E1	E2	E2 CM	E3	E4
6	12.5	768	790	808	1000	399	396	410	506	847	952	890	891	981	506	535	444	545	532
7	15	837	865	876	1000	529	492	497	580	896	1000	930	954	954	525	647	525	629	629
8	17.5	901	921	939	1000	624	573	583	642	865	1000	969	997	997	611	702	585	698	698
9	20	947	962	979	1000	675	641	650	680	899	1000	992	1000	1000	636	739	636	742	742
10	22.5	995	996	999	1000	715	695	705	715	972	1000	998	1000	1000	688	767	672	775	775
11	25	1000	1000	1000	1000	748	727	723	738	1000	1000	1000	1000	1000	730	785	699	798	798

Comments:

- This series of observations establishes the better protection offered by embedded carbon matt introduced in one of the experiment- P2E2CM with CNTs. followed by P1E3 as shown in yellow highlight.
- The Fire test box has some limitations of its own, as it is very small, compact in size with no enough air circulation, very high heating rates from front, but no heat dissipation. The coatings in general, protects steel very well much beyond 1000 deg. C, but poor heat dissipation leads to increase in the bare steel temperatures at faster rates in a closed, compact fire box.
- The test conducted in open air, for one of the experiments gives much better results than in compact, closed fire box.
- The combined overall Time – Temperature relations for both experimental series P1 and P2 were plotted graphically.

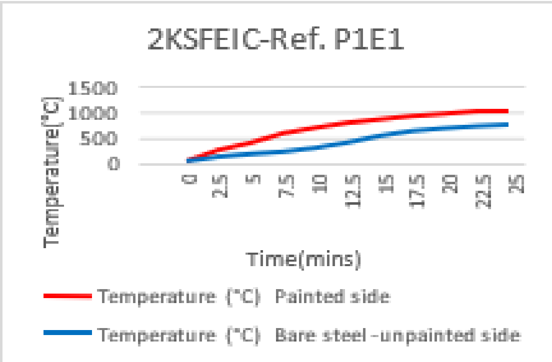
Graphical presentation of Individual and Superimposed Graphs for experiments: Using observations recorded in Table – 3(A) and Table -3(B) above, graphs were plotted. The combined overall, Time – Temperature

INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

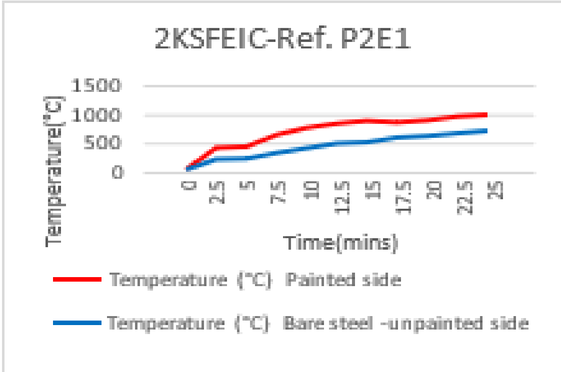
relations for both experimental series: P1 series (P1E1/P1E2/P1E3/P1E4) and P2 series(P2E1/P2E2/P2E2CM/P2E3/P2E4). are plotted graphically as shown in Figure 10, Graphs: 1 to 9 and superimposed Graphs are shown in Figure 11, graphs :10 to 13. Term 2KSFEIC used in Graphs -indicates: Two Component Solvent Free Epoxy Intumescent Coating.

Figure 10 - for Table -3(A), 3(B) observations- individual graphs- 1 to 9

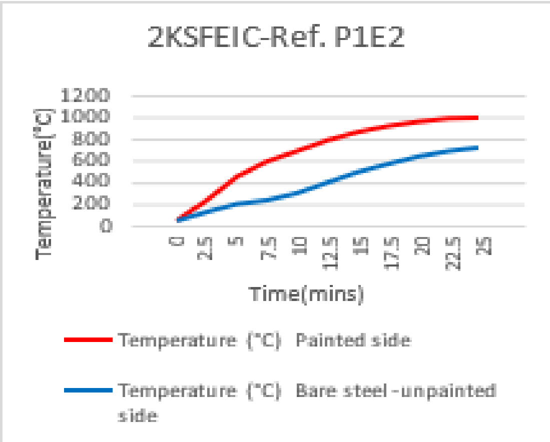
Graph-1 for Experiment Ref. P1E1



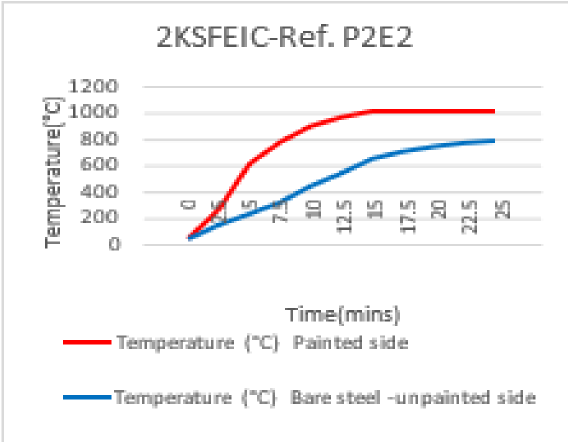
Graph-2 for Experiment Ref. P2E1



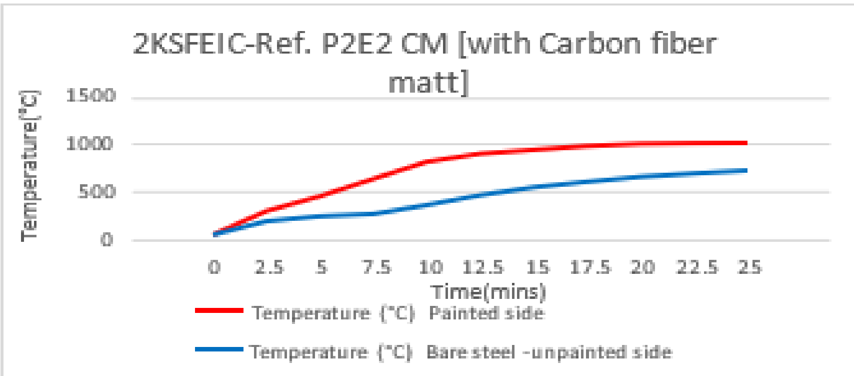
Graph-3 for Experiment Ref. P1E2



Graph- 4 for Experiment Ref. P2E2

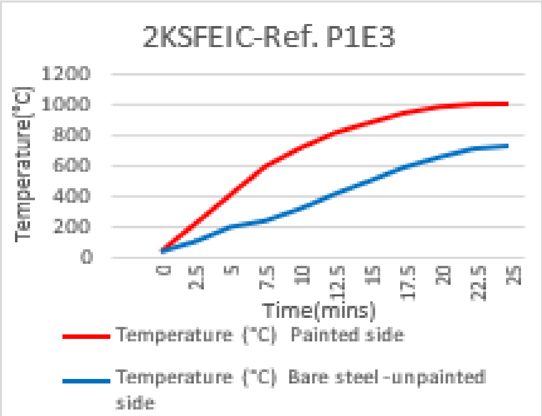


Graph-5 for Experiment Ref. P2E2 CM-With C-Matt

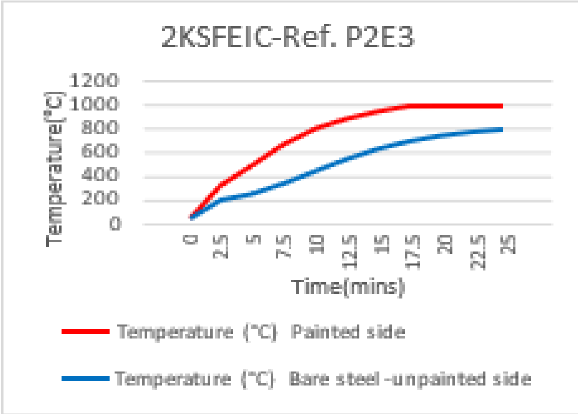


INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

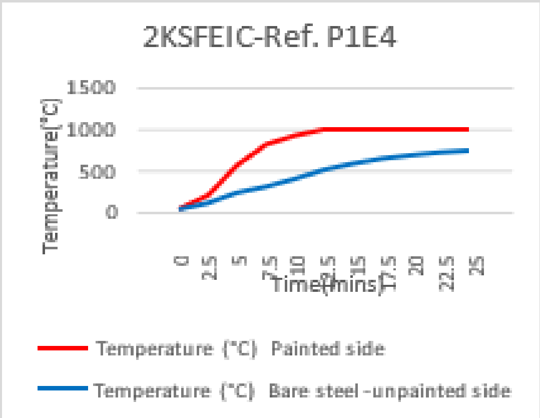
Graph -6 for Experiment Ref. P1E3



Graph -7 for Experiment Ref. P2E3



Graph-8 for Experiment Ref. P1E4



Graph-9 for Experiment Ref. P2E4

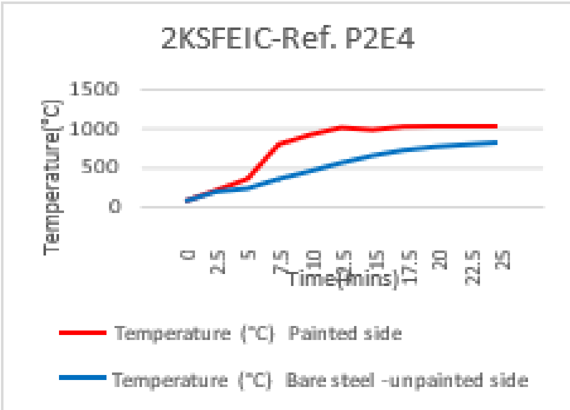
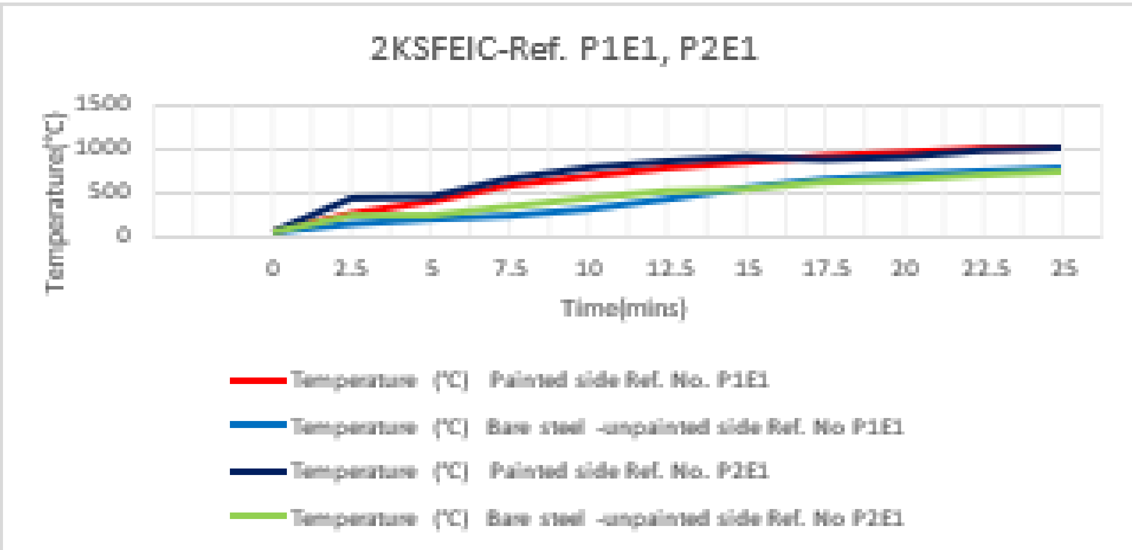


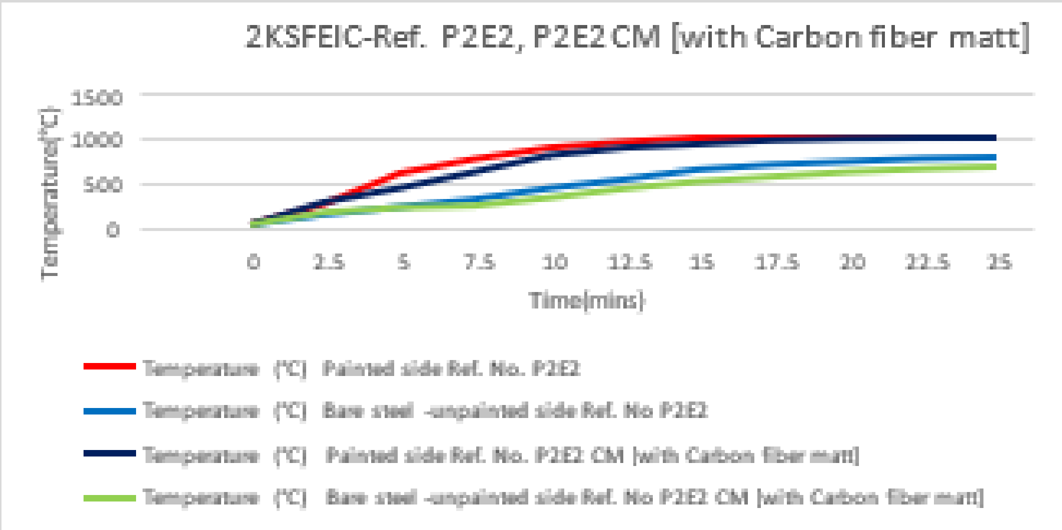
Figure 11 - for Table -3(A), 3(B) observations- super imposed graphs- 10 to 13.

Graph -10- Super imposed graph for Experiment Ref. # P1E1 and P2E1

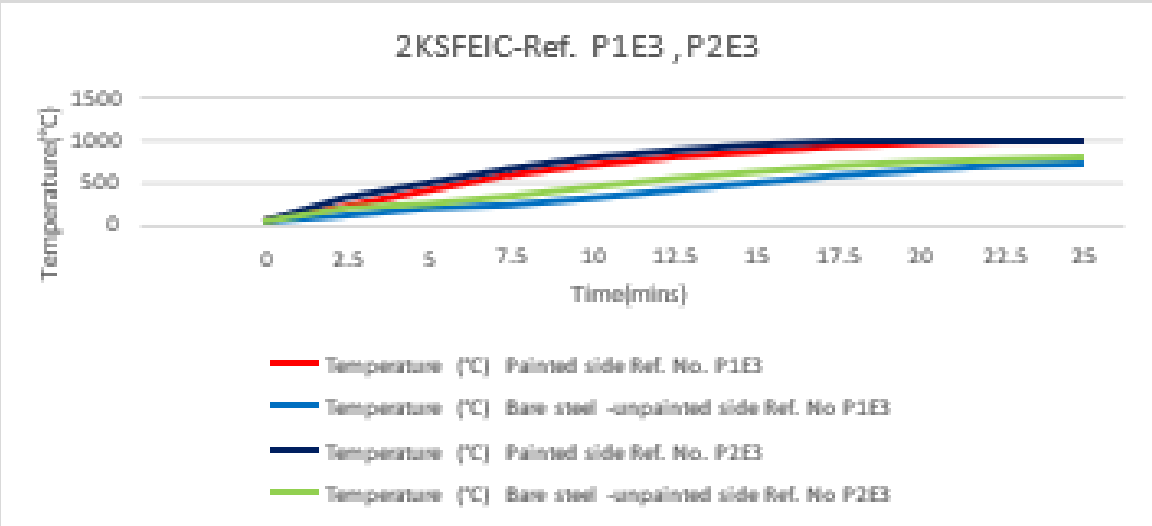


ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

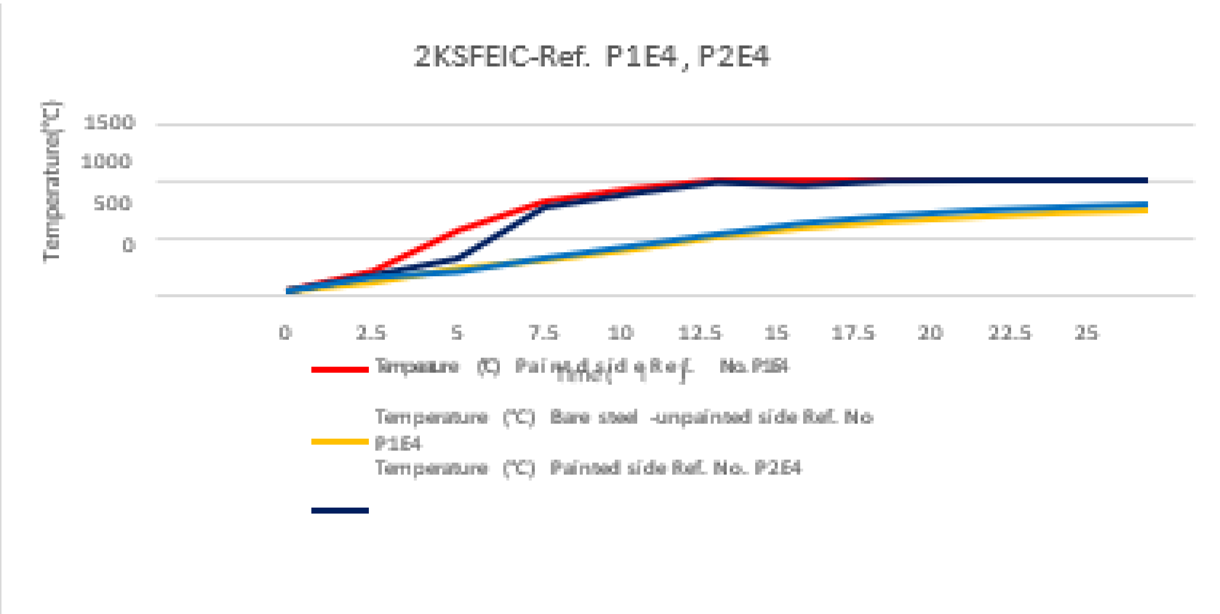
Graph -11- Super imposed graph for Experiment Ref. # P2E2 and P2E2 CM [with Carbon fiber matt]



Graph -12.- Super imposed graph for Experiment Ref. # P1E3 and P2E3



Graph -13- Super imposed graph for Experiment Ref. # P1E4 and P2E4



ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

Test Results for -I C E F

The term ICEF stands for Intumescent Char Efficiency Factor. Amount of char formation during fire test is an important criterion of intumescent coating, indicating its effectiveness in terms of performance. The Intumescent expansion of coating also known as Intumescent char expansion factor-ICEF, is measured by simple formula as explained below.

The, metal panel of thickness say T1 mm is selected.

- The Coating is applied and allowed to dry and thickness of coating after drying is measured, Say T2 mm.
- The painted panel is subjected to fire testing and upon cooling, very accurately the thickness of char formed is measured very precisely, say T3 mm.
- The ICEF is calculated using simple formula as below:

ICEF = T3-T1 / T2-T1 or also Simply = T3/T2 is used more practically.

Epoxy Intumescent Coatings- with char layer photographs:

Figure 12: Epoxy Intumescent Coatings- with char layer photograph:

Table 4.3 ICEF values in mm for series P1 and P2

Experiment Name	ICEF (mm)	DFT (mm)
P1E1	31.5	1.40
P1E2	27.0	1.30
P1E3	28.5	1.23
P1E4	16.7	1.20
P2E1	32.2	1.43
P2E2	30.0	1.30
P2E2CM	31.2	1.60
P2E3	32.8	1.22
P2E4	18.4	1.20

The above figure shows an Epoxy Intumescent Paint panel tested by fire-heated from the backside. See the thickness of the charred layer- it was thick, about 25-35 times the applied film Thickness. The white line is the Steel Panel Surface on which the coating was applied.

For industrial applications, where large steel structures with very high thicknesses of substrates like-I Beams, Girders, Thick plates, etc., and with thin films of applied coatings below 2000 to 3000 microns (2-3 mm), many times very simply the ICEF calculations are done without considering the substrate thickness. Simply, the ratio

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

of the expanded char layer after the fire test to applied DFTs is considered and, ICEF = Expanded char layer after fire test ÷ Applied DFT of coating on substrates, for various experiments are displayed in Figure – 13.

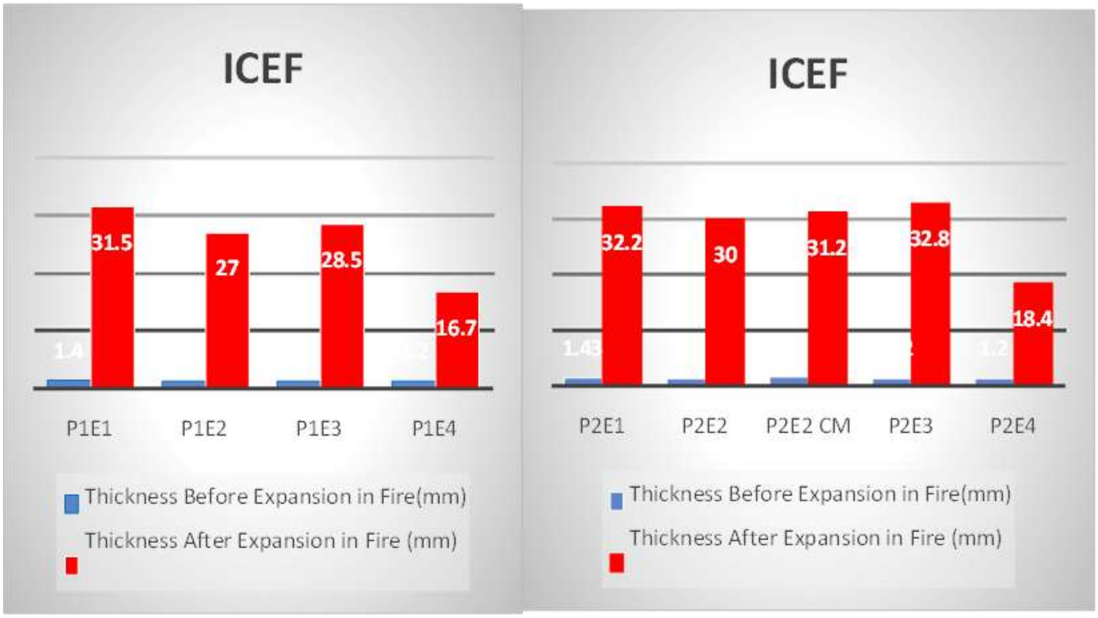


Figure 13: I C E F – Intumescent Char Efficiency Factor – Bar Chart for P1 and P2 Series of Experiments:

Panels after Fire exposure testing:

Figure .14 :(a/b/c) - Panels of some of the various experiments after fire exposure testing

a.P2E2- after fire exposure b. P2E2CM – after fire exposure c. P2E3-after fire exposure

Figure 15 (a/b) - I -Beams of various experiments after and during fire exposure testing

a) I -Beam P2E1 -after fire exposure test

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

b) I- Beam P1E3 – after fire exposure test

Figure 16: (a/b/c/d) I-Beams during direct fire exposure testing.

a. P1E1 - fire exposure test

b. P1E2 - fire exposure test, sides of I-Beam

c. P2E2-P2E3 - fire exposure test, sides of I-Beam

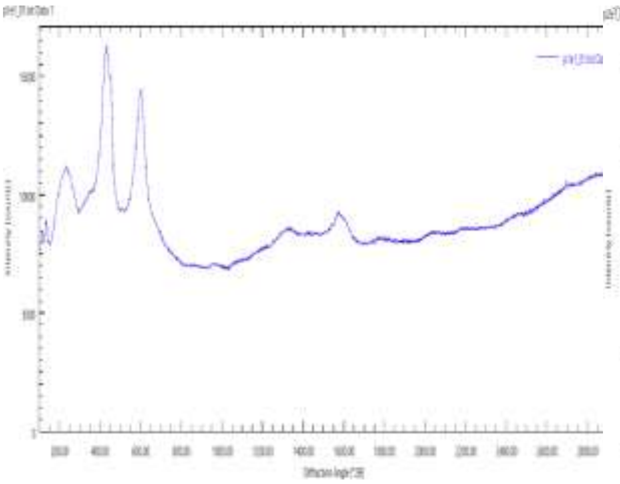
d. P2E3 - fire exposure test, I-Beam

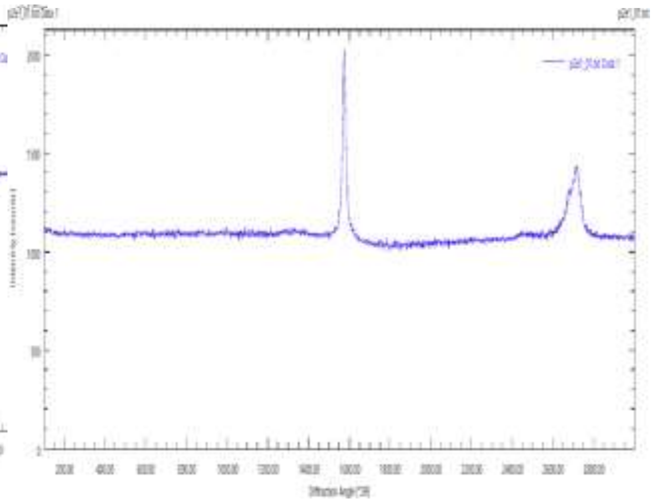
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

Characterization Test Results:

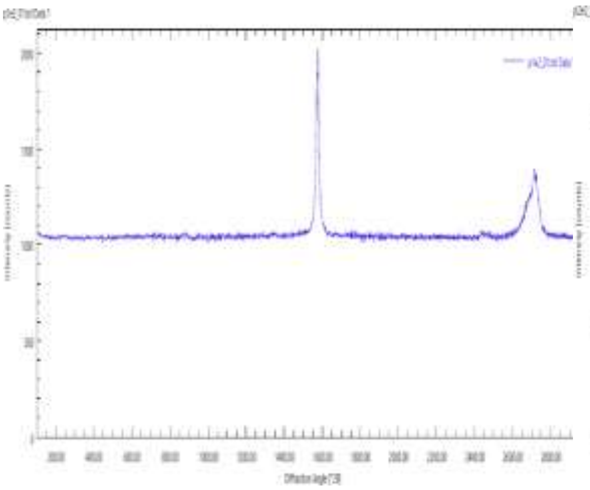
Raman Spectra- Figure 17:

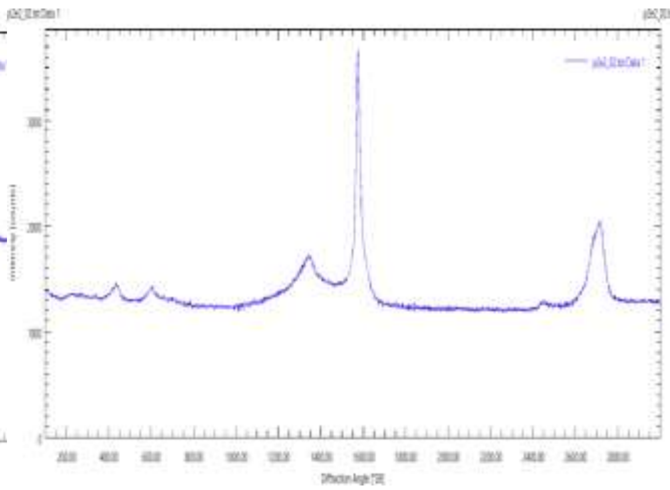
P1E1 P2E1





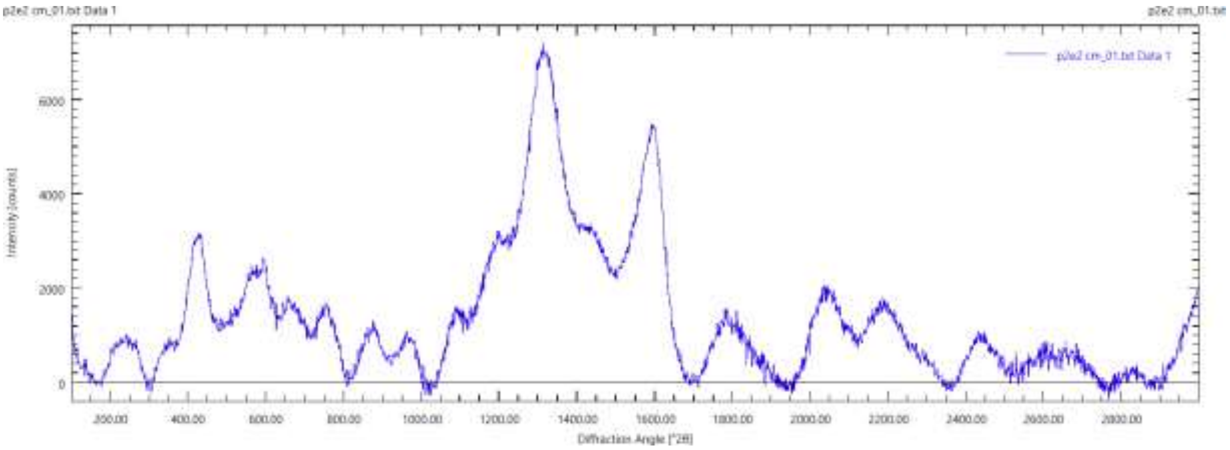
P1E2 P2E2



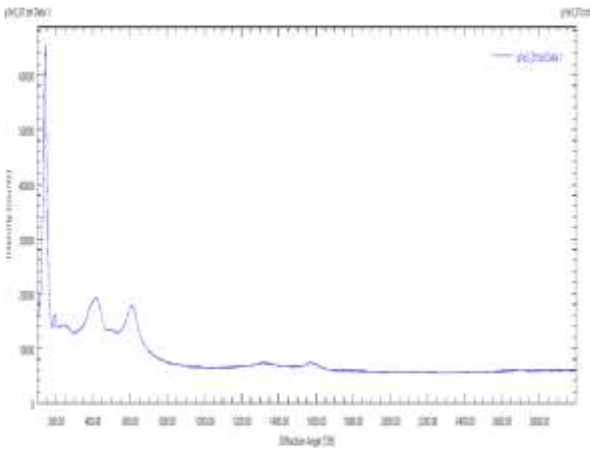


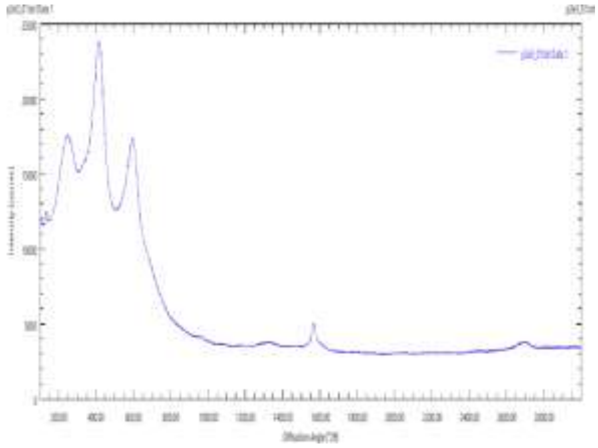
P2E2CM

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

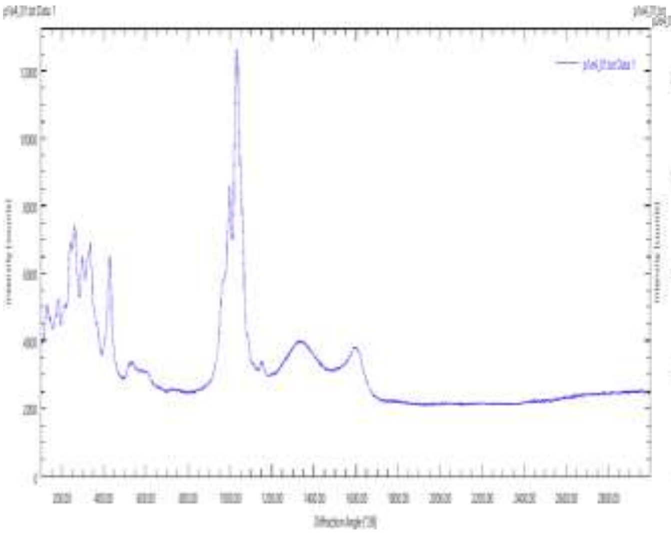


P1E3 P2E3





P1E4 P2E4



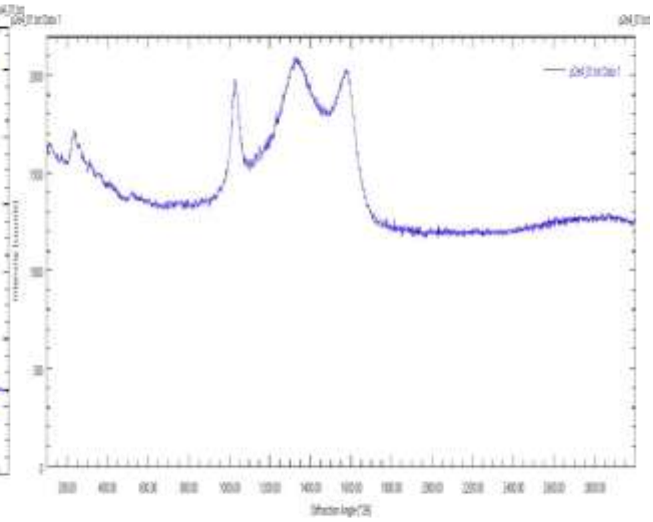
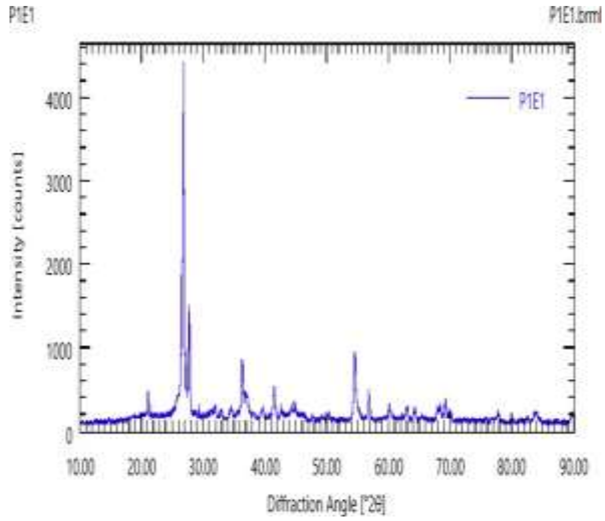
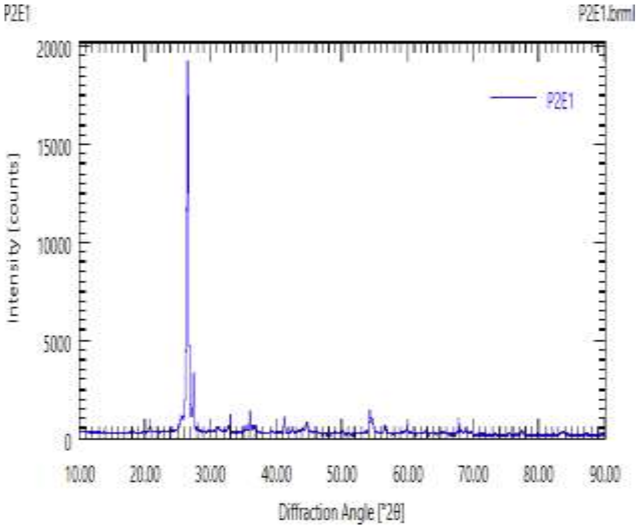
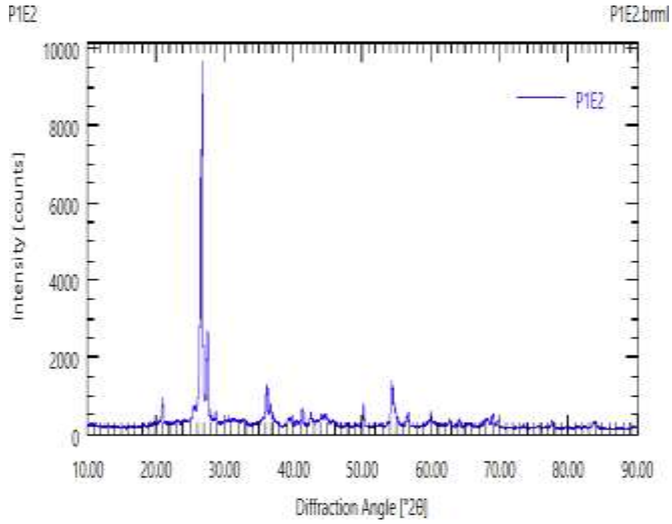


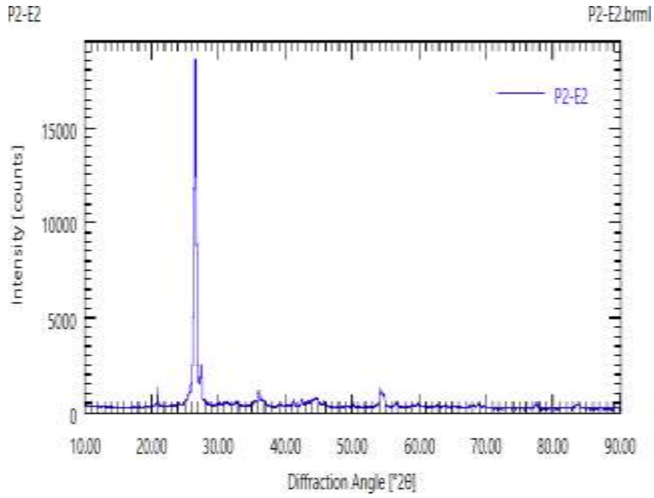
Figure - 17: Raman Spectras

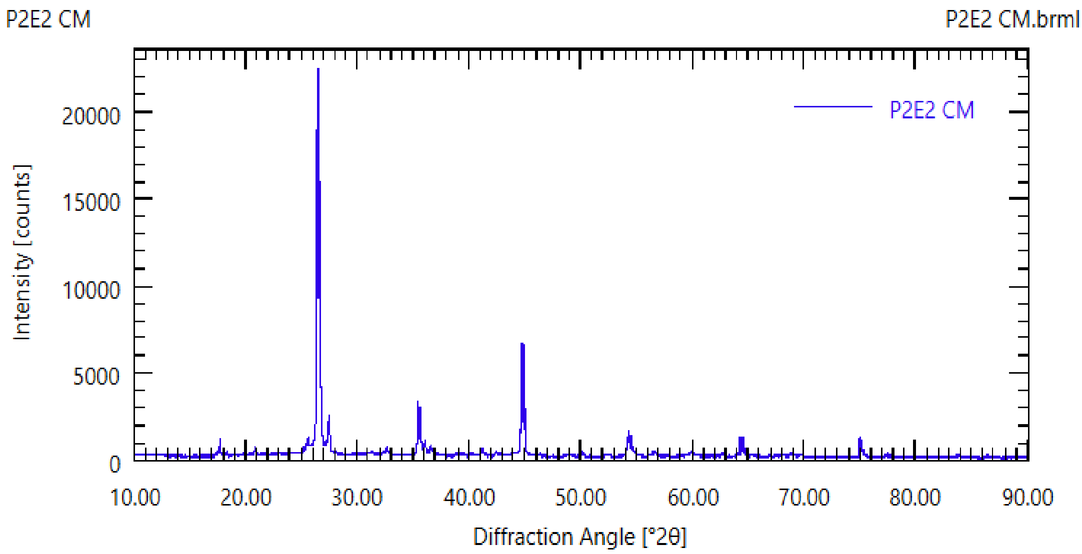
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026











INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

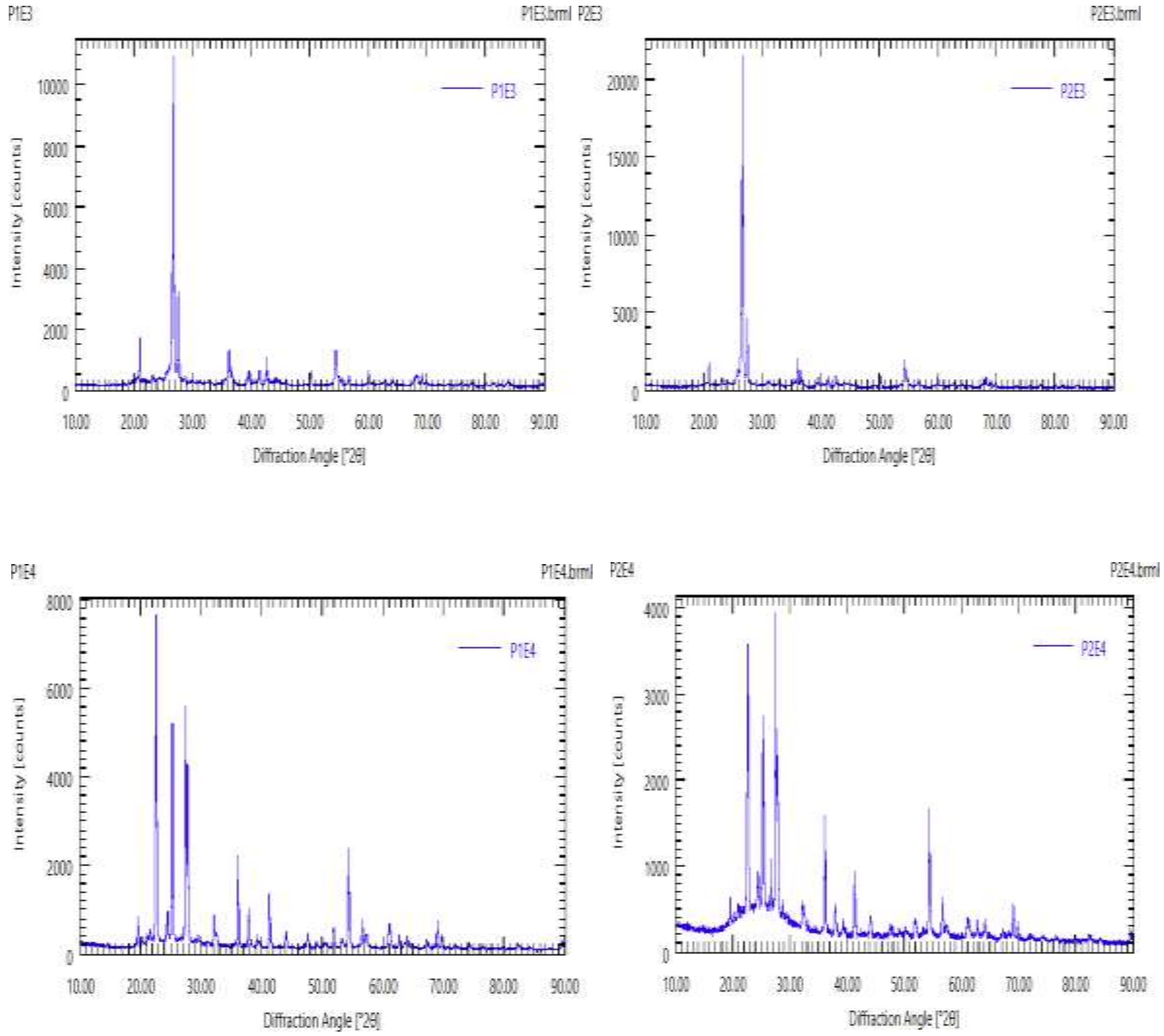


Figure 18: XRD Spectra.

Comments: - RAMAN/ XRDs

- Raman spectra for P1E2, P2E2 shows distinct graphene C- peaks and the same for P2E2CM shows peaks and profiles of spin coated graphene on mica.[12]

- The experimental Raman Spectra can be best analysed further using data from

[13] which discuss the Raman spectra for Epoxy resin – Amine hardner curing reactions with a detailed tabular display of various Raman bands (cm -1) at a particular intensity with various chemical bonds like C-H aromatic/aliphatic, Epoxy ring breathing, aromatic ring stretching etc.

- Raman spectra of some of the standard heat resisting minerals like muscovite mica, graphite, vermiculite, nano / micro silica, MAS- Mg, Al, Si glass ceramic, quartz etc. have very complex, broad and diffused patterns, which are similar to patterns as seen in experimental curves. These patterns, reflects in terms of better heat and fire resisting performance to these coatings [27,28,29,30].

- Standard X-ray diffraction spectra of pure graphite and synthesized graphene oxide shows deviation of XRD peak at $2\theta = 26.5°$, seen in all experimental XRDs.

INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

• The XRD patterns for various experimental samples after fire -heat testing above 1,050 ◦C for long time, are showing some flattening tendency, indicating the formation of more stable (metastable) refractory minerals silicon oxide, quartz etc. as seen in XRD, which is reflected in their performance.

• The crystalline nature of minerals, which gives very sharp peaks in XRD curves and as the experimental compositions are heat tested, at high temperatures, phase changes may be occurring at various increasing temperatures. The minerals in the composition start reacting and transforming into more stable amorphous compositions, which are responsible for providing excellent thermal stability. [31-36]

The high intensity peaks in XRD curves are characteristics of crystalline minerals whereas in amorphous phase, rays are scattered in many directions leading to a large bump distributed in a wide range (2Theta) instead of high intensity narrower peaks. Upon further heating the amorphous, metastable mineral phase, with increase in temperature, it begins to form a melt with some crystalline phase still remaining.

This suggests crossing into a peritectic region. If continued to increase the temperature further, it may cross over into other peritectic regions with different crystalline phases in equilibrium with the melt before finally going into a fully liquid phase. Also, in DTA/DSC tests the amorphous structure will show up as a peak since it is an exothermic transition. The transition at higher temperature from crystalline to liquid + crystalline will show a dip since this is an endothermic transition [33,37,38].

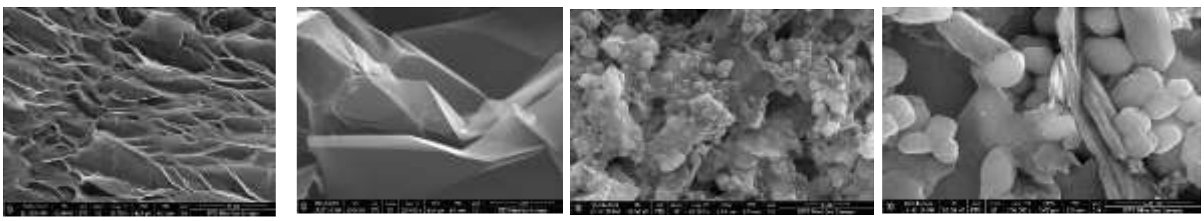
• XRDs for both P1 and P2 series of experiments shows prominent peaks in general views at around angle 25◦ -30◦ (2 Theta) X-axis, which compares well as shown in [12], The mechanisms involved in flame retardants are physical effects including(i) cooling effect, (ii) fuel dilution, or (iii) via formation of a protective layer (shielding), and the chemical effects containing (i) gaseous and (ii) condensed phase. The char layer as condensed phase involved in Intumescent Flame-Retardant coatings mainly undergoes reaction processes like: gaseous evolution from the decomposition reaction and expansion of the coating into highly porous char. Four important zones have been identified in the combustion process: They are flaming zone, char layer, molten polymer, and underlying polymer. Char layer is known as the most critical zone which mainly governs the heat and mass transfer phenomena.[5]

S E M Images: [12-13-39 to 58]

• SEM -IMAGES-P1E1-(a) X-10,000, (b) X-100,000 shows a continuous, smooth char formation giving good char strength and better heat insulating properties. The scattered, reinforcing fibers are seen in SEMs-P1E1(d) X-200,000 distributed randomly- giving better char strength and heat-insulating characteristics. Images-(c) X-60,000 shows Titanium dioxide particles and graphite platelets. Images(d) X-200,000 shows Titanium dioxide particles, graphite platelets, zinc particles, and zinc phosphate presence in these SEMs. [52,55]

Figure 19: SEM -IMAGES- P1E1 (a/b/c/d)

1E1-(a) X-10,000 (b)X-100,000 (c) X-60,000 (d) X-200,000



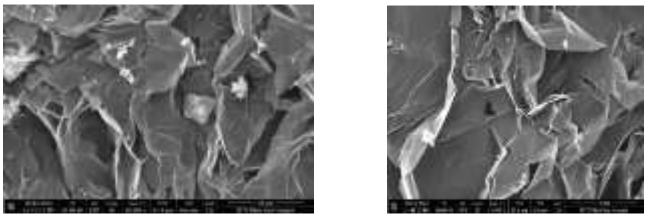
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

• SEM -IMAGES-P1E2-(a) X-10,000, (b) X-25,000, (c) X-50,000 shows uniform,

compact char formation indicating better char strength and efficient heat insulating characteristics. The randomly scattered fibers, Titanium dioxide and Graphite layers are also visible, indicating reinforcement and better char morphology with better heat insulation, char strength.

Figure 20: SEM -IMAGES-P1E2 (a/b/c):

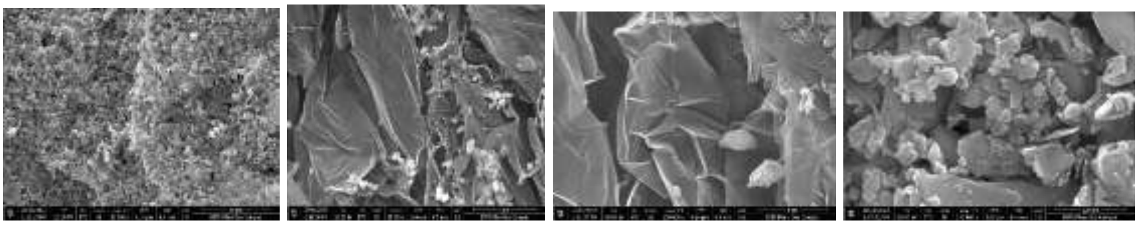
P1E2-(a) X-10,000 **P1E2**-(b) X-25,000 **P1E2**- (c) X-50,000



• SEM Images-P1E3- (a) X-10,000 shows Titanium dioxide nanoparticles and P1E3- (b) X-25,000, (c) X-100,000 shows both Titanium dioxide and Graphite platelets after high heat exposure test. SEM images for experiments P1E3 (a), (c), and (d) show the presence of CNTs. [56,57,58]

Figure 21: SEM-IMAGES P1E3- (a /b/c/d)):

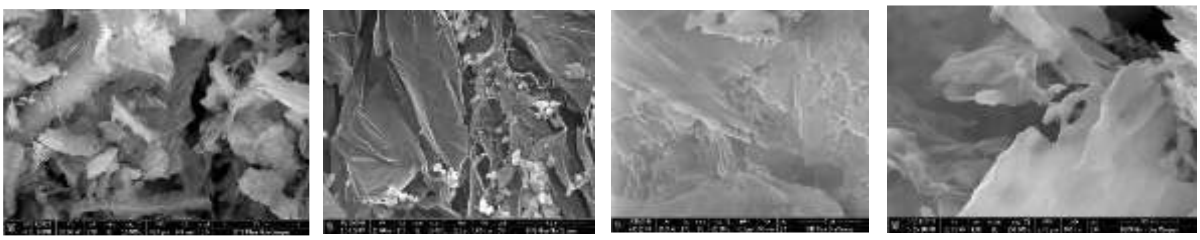
P1E3- (a) X-10,000 - (b) X-25,000 -(c) X-100,000- (d) X-200,000



• SEM -IMAGES-P1E4- (a) X-10,000, (b) X-25,000 shows scattered fibers, which helps in better binding and overall better heat shielding and char strength. Images P1E4-(c) X-100,000 and P1E4-(d) X-150,000 shows uniform, very smooth layers indicating better heat insulation and better binding characteristics.

Figure 22: SEM -IMAGES P1E4- (a/b/c/d):

P1E4- (a) X-10,000 -(b) X-25,000 - (c) X-100,00 -(d) X-150,000

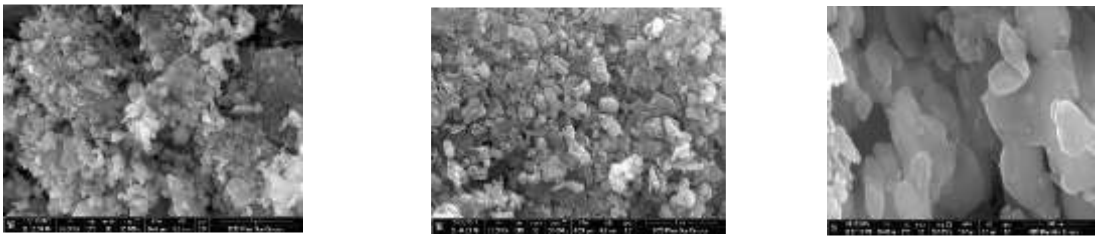


SEM -IMAGES-P2E1-(a) X-25,000, (b) X-50,000 shows compact binding and Titanium dioxide and Graphite platelets. Image (c) X-200,000 shows smooth, uniform char layer which imparts better performance and char strength. Also, these images reveal the presence of zinc silicate formed by heat during fire test. [52,55]

Figure 23: SEM- IMAGES-P2E1(a/b/c):

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

P2E1-(a) X-25,000 -(b) X-50,000 -(c) X-200,000

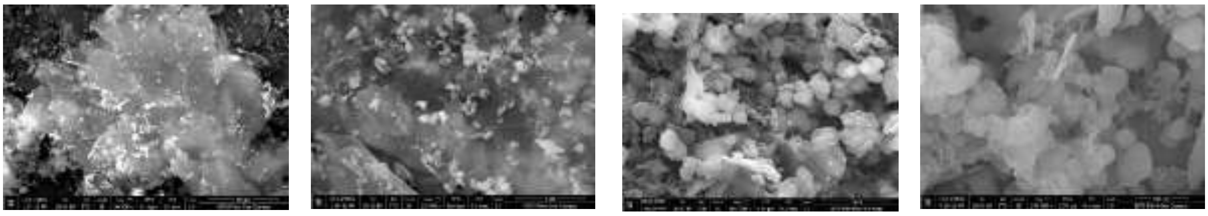


- SEM -IMAGES-P2E2- (a) X-10,000-(b) X-25,000 shows a compact, well bound continuous morphology, with no pores- indicating better heat insulation and barrier to steel surface against heat. It also indicates synergistic characteristics imparted by graphene inclusion. Randomly scattered fibers are seen in (a) X-10,000 (b)X-25,000, (c) X- 100,000,

(d) X-150,000 providing better char strength and superior heat insulating, shielding and reinforcing characteristics.[54]

Figure 24: SEM IMAGES--P2E2 (a/b/c/d):

P2E2-(a) X-10,000 -(b) X-25,000 - (c) X-100,000 -(d)-X-150,000

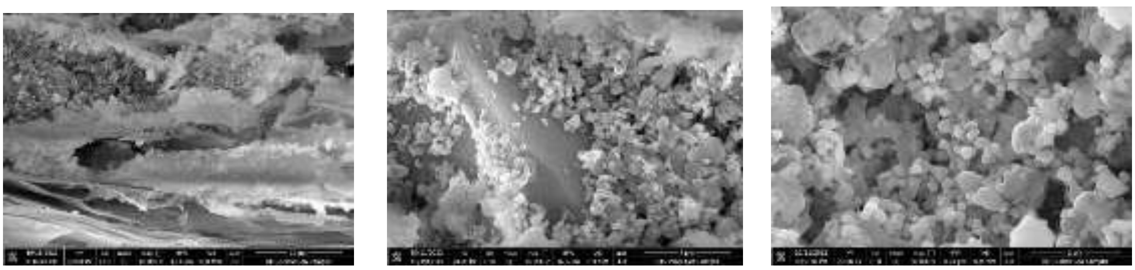


- SEM -IMAGES-P2E2CM- (a)X-10,000, (b)X-25,000, (c) X-50,000 and (e) X-150,000

shows carbon fiber matt images clearly as compared with carbon fiber matt manufacturer SEM Data. [50,54]- Images –(a) X-10,000, (d) X-100,000 ad (f) X-200,000 shows uniform layers of carbon fiber matt, giving excellent heat insulation and protection against heat from fire to bare steel structure.

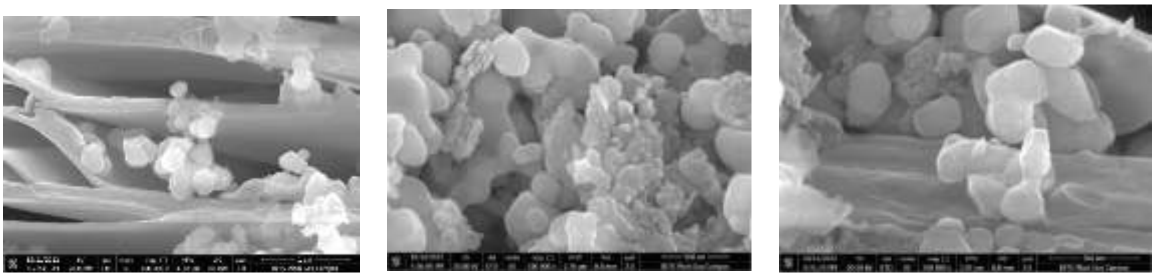
Figure 25: SEM-IMAGES- P2E2CM (a/b/c/d/e/f):

P2E2CM-(a) X-10,000 -(b) X-25,000 - (c) X-50,000



P2E2CM- (d) X-100,000 - (e) X-150,000 - (f) X-200,000

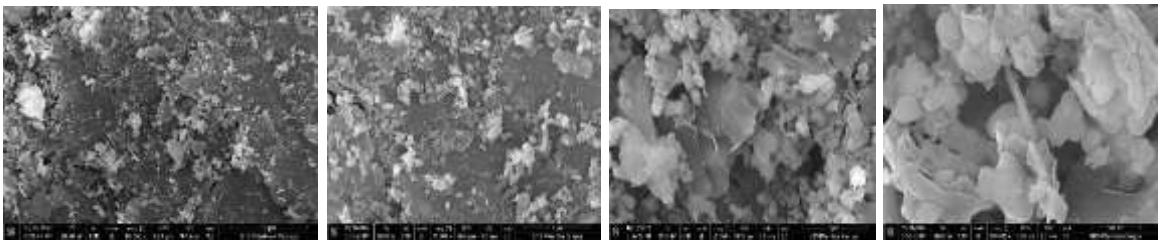
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026



SEM -IMAGES-P2E3- (a) X-10,000, (b) X-25,000 shows compact, dense structure indicating better heat resisting and shielding, stronger char formation with better char strength, synergistically upgrading overall properties by Graphene. SEM images for experiments P2E3(b), (c), and (d) shows presence of CNTs [57]

Figure 26: SEM IMAGES--P2E3 (a/b/c/d):

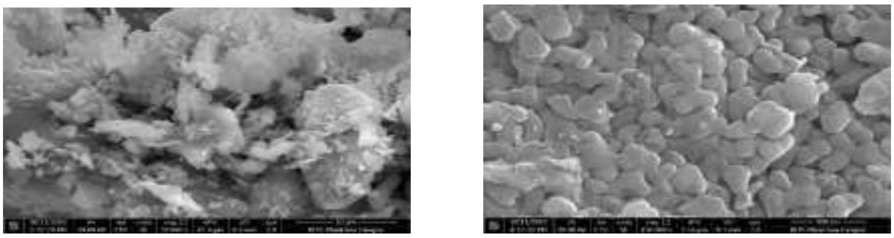
P2E3- (a) X-10,000 - (b) X-25,000 - (c) X-50 ,000-(d) X-150,000



• SEM IMAGES - P2E4- The bigger char pores as seen in (b) X-150,000. The large pores are an indication that it might have been exposed at high temperatures for longer time. This also shows zinc silicate coating with zinc, silica particles. P2E4- (a) X-10,000 also shows compact and uniform layers with fibers indicating better char strength and heat insulation characteristics. [54,58]

Figure 27: SEM IMAGES

P2E4(a/b): **P2E4**- (a) X-10,000 - (b) X – 150,000



Some general observations on SEM images are summarized here:

• SEM images for experiments P1E3 (a), (d) and P2E3(b), (c), and (d) shows presence of CNTs.[57]

• SEM Images of both of our experimental Series P1 and P2 shows presence of graphite, like as seen in P1E1(a), P1E2(a), P1E3(b), P1E4(b), P2E3(c). They compare and show a good match to the images shown in [12,51].

• SEM images of our experiments like P1E3(a), P2E1(a), (b), P2E2(a), (d), P2E2CM(a), (b), (c), P2E3(a), etc. shows rough surface and large no. of tiny holes of different sizes. These could be due to the evolution of gases produced during combustion/ fire testing above 1000◦C from epoxy resin. [13,39,52,56].

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

- Conclusions: SEM images for experiments P2E2CM (a), (d), (f) clearly show the graphene and carbon cloth /matt. It shows a fairly uniform distribution of graphene on carbon cloth. It has been concluded in this [4], that graphene reduced the internal resistance. [40,54,58]

- SEM images for experiments P1E3 (a), (d) and P2E3(b), (c), and (d) shows presence of CNTs.[57]

- SEM Images of experimental series P2- all experiments show the presence of zinc dust from base coat zinc silicate primer, in the char formation after extensive fire exposure test for above 1000◦ C. It can be seen in P2E1-(a), / P2E2- (d), P2E2CM-(b), (c), (d), (e), (f)/P2E3--(b), (c), /P2E4- (b). [53,56]

CONCLUSIONS

- The experiments tried on 2 K Epoxy, high performance, high build -solvent free intumescent green coatings gives excellent heat shielding and insulating char formation characteristics as seen in the observations and data presented above. The high build nature of coatings, allows the application at high film thickness in a single coat, with reduced VOCs and with better coating performance.
- The P1-2K epoxy zinc phosphate primer series in general gave better performance as far as back side, bare metal protection and the P2-2K inorganic zinc silicate primer series gave better adhesion characteristics as well as better char formation as seen in ICEF-Intumescent Char Efficiency Factor charts.
- The experiments E2-based on CNTs and E3- based on Graphene, gave synergistically improved characteristics to coatings, with CNTs showing better comparative results in terms of back side bare steel temperature. The experiment P2E2CM, with embedded C-fiber matt and with CNTs, gave much better results on char formation as well as bare steel protection. It was found to be the best in different experiments tried.

REFRERENCES

1. Thirumal Mariappan, Recent developments of intumescent fire protection coatings for structural steel: A review, Journal of Fire Sciences 1–44, Reprints and permissions: sagepub.co.uk/journalsPermissions.nav jfs.sagepub.com vol. 34 – Issue -34. https://doi.org/10.1177/0734904115626720
2. Thirumal Mariappan, New Technologies in Protective Coatings - Fire Retardant Coatings - Chapter-6, FROM THE EDITED VOLUME -New Technologies in Protective Coatings, Edited by Carlos Giudice and Guadalupe Canos https://www.intechopen.com/books/5827, http://dx.doi.org/10.5772/67675
3. Aggie Lotz, An Overview of Intumescent Coatings- Highlights from IPPIC's (The International Paint and Printing Ink Council), Publication, Global market analysis for Paint and Coatings Industry (2015-2020), The ChemQuesat Group Inc. Coatings Tech I 2018. https://www.paint.org/coatingstech-magazine/articles/overview-intumescent-coatings/
4. Ravindra G. Puri & A. S. Khanna, Intumescent coatings: A review on recent progress-Journal of Coatings Technology and Research Volume 14, pages1–20 (2017) DOI-https://doi.org/10.1007/s11998-016-9815-3
5. Pestereva, L., et al. "Intumescent Type Fire Retardant Epoxy Coating." Materials Science Forum, vol. 992, Trans Tech Publications, Ltd., May 2020, pp. 605–609. https://doi.org/10.4028/www.scientific.net/MSF.992.605
6. A-PhD. Thesis Report by Jermy CIRET to University Lille-I Science & Technologies. Investigation of Intumescent Coatings for Fire protection- Application to Jet Fire- A-PhD. Thesis Report by Jermy CIRET to University Lille-I Science & Technologies
7. Michael Aamodt, Alan Guy, and Raouf Kattan, Solvent-Free Epoxy Coatings—A Common Universal definition- Solvent-Free Epoxy Coatings—A Common Universal Definition (materialsperformance.com)

8. Lucherini A. and Maluk C. “Intumescent coatings used for the fire-safe design of steel structures: A review”. Journal of Constructional Steel Research, vol. 162, no. 105712, 2019. https://doi.org/10.1016/j.jcsr.2019.105712 https://www.sciencedirect.com/science/article/abs/pii/S0143974X19301099
9. Allen Zielnik, Atlas Material Testing Technology LLC, Fighting Fire with Fire Protectives, Modern intumescent have advanced significantly in both fire performance and aesthetics. From an ebook, FIRE RESISTIVE COATINGS, D+D Technology Publishing Company 2100 Wharton Street, Suite 310 Pittsburgh, PA 15203
10. Matt Ghiji, Paul Joseph, Maurice Guerrieri, Some recent developments and testing strategies relating to the passive fire protection of concrete using intumescent coatings: a review-, Journal of Structural Fire Engineering, https://doi.org/10.1108/JSFE-11-2021-0069
11. A Report by Technology (Water-based, Solvent-based, Epoxy-based), By Application (Hydrocarbon, Cellulosic), By End-Use (Construction), By Region And Segment Forecasts, 2022 – 2030. Intumescent Coatings Market Size, Share and Trends Analysis, Report ID: 978-1-68038-475-8 /Number of Pages: 159 /Format: Electronic (PDF).- https://lnkd.in/dcB2mkVj https://www.linkedin.com/pulse/epoxy-coating-market-size-share-industry-trends-forecast-khatode/:
12. N. Amir, F. Ahmad and P.S.M. Megat- Yusoff-Study on the Fiber Reinforced Epoxy-based Intumescent Coating Formulations and their Char Characteristics- Jjournal of Applied Sciences, 11: 1678-1687. DOI: 10.3923/jas.2011.1678.1687 URL: https://scialert.net/abstract/?doi=jas.2011.1678.1687
13. N. Amir, W.M.S.W. Othman, and F. Ahmad, - Fire Resistance Properties of Ceramic Wool Fiber Reinforced Intumescent Coatings, Citation: AIP Conference Proceedings 1669, 020062 (2015); Published by the American Institute of Physics: AIP Conference Proceedings 1669, 020062 (2015); https://doi.org/10.1063/1.4919200
14. Triantafyllidis, Zafeirios, Structural enhancements with fibre- reinforced epoxy intumescent coatings- URI – http://hdl.handle.net/1842/29514
15. Balbinder K. Kandola, Piyanuch Luangtriratana, Sophie Duquesne and Serge Bourbigot- The Effects of Thermophysical Properties and Environmental Conditions on Fire Performance of Intumescent Coatings on Glass Fibre-Reinforced Epoxy Composites (mdpi.com)- doi:10.3390/ma8085216 Materials 2015, 8, 5216-5237; doi:10.3390/ma8085216
16. PUBLISHED -JULY 5, 2018 2:30 AM BY THE MARITIME EXECUTIVE – THE
17. INTELLECTUAL CAPITAL FOR LEADERS-https://www.maritime-executive.com/article/july-6-1988-the-piper-alpha-disasterJuly 6, 1988: The Piper Alpha Disaster (maritime-executive.com)
18. G. A. Chamberlain, Shell Global Solutions, OTC 14132 Controlling Hydrocarbon Fires in Offshore Structures G. A. Chamberlain, Shell Global Solutions, Copyright 2002, Offshore Technology Conference held in Houston, Texas U.S.A., 6–9 May 2002.
19. The world’s worst offshore oil rig disasters -1 June 2019 (Last Updated December 10th, 2020 04:42) https://www.offshore-technology.com/features/feature-the-worlds-deadliest-offshore-oil-rig-disasters-4149812/Deadliest Fires or Explosions in the World – Excluding bombings and wartime attacks -NFPA-Report
20. https://www.nfpa.org/News-and-Research/Data-research-and-tools/US-Fire-Problem/Catastrophic-multiple-death-fires/Deadliest-fires-or-explosions-in-the-world
21. Sources: C:\Users\user\Desktop\FIRE STATISICS- DATA-Pictures- Videos- New folder\Topic 10_ ONGC Mumbai High Accident (July 27, 2005 @ West Coast of India) _ iMechanica.html- Mumbai High Field - Offshore Technology (offshore-technology.com) https://www.offshore-technology.com/features/the-leading-causes-of-drilling-rig-disasters/
22. Hydrocarbon EAPFP- European Association for Passive Fire Protection - https://eapfp.com/hydrocarbon/#:~:text
23. Health and Safety Executive-H S E, Offshore Oil and Gas, Jet Fires https://www.hse.gov.uk/offshore/strategy/jet.htm

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

24. Laboratories – Jet Fire Testing https://www.appluslaboratories.com/global/en/what-we-do/service-sheet/jet-fire-testing
25. Jing Han Beh, Ming Chian Yew, Lip Huat Saw and Ming Kun Yew, Article Fire Resistance and Mechanical Properties of Intumescent Coating Using Novel Bio Ash for Steel - Coatings 2020, 10, 1117; doi:10.3390/coatings1011111 coatings-10-01117-v2 (5).pdf
26. A.I. Arogundade, F. Ahmad, A.H. Bhat, Q.F. Gillani, P.S.M.B. Megat- Yuso Investigating the Synergistic Effect of Bauxsol™ in an Epoxy Intumescent, Coating System., Procedia Engineering 148 (2016) 223 – 227, ScienceDirect, Elsevier https://doi.org/10.1016/j.proeng.2016.06.579
27. M.Jimenez, S. Duquesne, Bourbigot- Characterization of the performance of an intumescent fire protective coating, Surface and Coatings Technology, Volume 201, Issues 3–4, 5 October 2006, Pages 979-987, ELSEVIER, https://doi.org/10.1016/j.surfcoat.2006.01.026
28. Sami Ullah, Faiz Ahmad, Abdullah G. Al-Sehemi, Mohammed Ali Assiri, Muhammad Rafi Raza, Ahmad Irfan, Effect of expandable graphite and ammonium polyphosphate on the thermal degradation and weathering of intumescent fire-retardant coating, , Journal of Applied Polymer Science Volume138, Issue17, May 5, 2021 – 50310 https://doi.org/10.1002/app.50310
29. Donatella de Silva, Iolanda Nuzzo, Emidio Nigro and Antonio Occhiuzzi- Review Intumescent Coatings for Fire Resistance of Steel Structures: Current Approaches for Qualification and Design, Coatings 2022, 12, 696. -MDPI -, https://doi.org/10.3390/coatings12050696
30. RRUFF Project - Department of Geosciences, University of Arizona, 1040 E 4th, Tucson, AZ, USA.85721-0077 RRUFF Project https://rruff.info/about/about_general.php https://rruff.info/
31. Rios, Carlos & Williams, Craig. (2010). Hydrothermal transformation of kaolinite in the system K2O-SiO2-Al2O3-H2O. Dyna. 77. no.163 Medellin July/ Sept. (2010). (PDF) Hydrothermal transformation of kaolinite in the system K2O-SiO2-Al2O3-H2O (researchgate.net)
32. Leandro Fernandes, Rafael Salomãoa, Preparation and Characterization of Mullite-Alumina Structures Formed "In Situ" from Calcined Alumina and Different Grades of Synthetic Amorphous Silica, Materials Research. 2018; 21(3). https://doi.org/10.1590/1980-5373-MR-2017-0783
33. Niraj Singh Mehta, Praveen Kumar Sahu, Pankaj Tripathi, Ram Pyare, Manas R. Majhia, Influence of alumina and silica addition on the physico-mechanical and dielectric behavior of ceramic porcelain insulator at high sintering temperature, Spanish Society of Ceramics and Glass, Volume 57, Issue 4, July–August 2018, pp 151-159. DOI: 10.1016/j.bsecv.2017.11.002
34. R. St. C. Smart, Minerals, Ceramics and Glasses: Chapter- In Surface Analysis Methods in Materials Science [second edition], Springer Series in Surface Sciences book series (SSSUR, volume 23), pp377-403. https://link.springer.com/chapter/10.1007/978-3-662-05227-3_16 DOI: 10.1007/978-3-662-05227-3_16
35. Raimonda Kubiliute, Rimvydas Kaminskas, The Pozzolanic Activity of Calcined Clay - Silica Gel Composites, Materials Science, Vol. 19, No. 4. 2013. https://doi.org/10.5755/j01.ms.19.4.2300
36. The Quartz Page: The Silica Group, Overview of Silica Polymorphs, http://www.quartzpage.de/, Accessed 21 Feb.2021.
37. B. D. Cullity, Elements of X-RAY DIFFRACTION, Second edition, 1978, Addison-Wesley Publishing Company Inc. https://archive.org/details/elementsofxraydi030864mbp/page/n7/mode/2up
38. Gwénaël Gouadec and Philippe Colomban, Raman Spectroscopy of Nanomaterials: How Spectra Relate to Disorder, Particle Size and Mechanical properties-https://doi.org/10.1016/j.pcrysgrow.2007.01.001
39. Brittani D. McNamee and Mickey E. Gunter, Mineralogy and Optical Mineralogy Laboratory Manual, Published by Mineralogical Society of America, 2014. https://msaweb.org/mineralogy-and-optical/ https://msaweb.org/wp-content/uploads/2022/06/McNamee_Gunter_Lab_Manual.pdf
40. Zhen Hua Sun, Huiquan Li, Weijun Bao, ChenyeWang, Mineral phase transition of desilicated high alumina fly ash with alumina extraction in mixed alkali solution, Elsevier, International Journal of Mineral Processing-Volume 153, 10 August 2016, pp 109-117. https://doi.org/10.1016/j.minpro.2016.05.004

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

41. Mullite Ceramic Properties, ACCURATUS Ceramic Corporation, New Jersey, USA, https://www.accuratus.com/mullite.html, Accessed 21 Feb. (2022).
42. Chen Ling, Rudong Zhou, et al, Solvent-free flexible epoxy intumescent fire-retardant coatings, J. Coat. Technol. Res., 21 (5) 1591–1603, 2024, https://doi.org/10.1007/s11998-024-00918-3
43. Prasan Chaisaenrith, Phoomphat Taksakulvith, Sorapong Pavasupree, Effect of nano titanium dioxide in intumescent fireproof coating on thermal performance and char morphology, Materials Today: Proceedings 47 (2021) 3462–3467, https://doi.org/10.1016/j.matpr.2021.03.461, ELSEVIER, ScienceDirect.
44. Kaur Jesbains, Ahmad Faiz, Yussof Megat P.S.M and Ullah Sami-Mechanical Engineering Department, University Technology PETRONAS, Bandar Sri Iskandar, The Study of Bonding Mechanism of Expandable Graphite based Intumescent Coating, Research Journal of Chemistry and Environment, Vol.15 (2) June (2011) file:///C:/Users/techn/Desktop/401-405_ThestudyofBonding.pdf
45. Ullah Sami, Ahmad Faiz and Megat-Yusoff P.S.M., The Effect on Expansion and Thermal degradation of 63um Expandable Graphite on Intumescent fire-retardant coating composition, Research Journal of Chemistry and Environment, Vol.15 (2) June (2011) https://www.researchgate.net/publication/277305993_The_Effect_on_Expansion_and_Thermal_degradation_of_63um_Expandable_Graphite_on_Intumescent_fire_retardant_coating http://scholars.utp.edu.my/id/eprint/6182
46. Zhao, Wei Ling et al. "Synthesis of a novel PEPA-substituted polyphosphoramide with high char residues and its performance as an intumescent flame retardant for epoxy resins." Polymer Degradation and Stability 118 (2015): 120-129. journal homepage: www.elsevier.com/locate/polydegstab http://dx.doi.org/10.1016/j.polymdegradstab.2015.04.02
47. Lianghui Ai, Shanshan Chen, Jinming Zeng, Liu Yang, and Ping Liu, Synergistic Flame Retardant Effect of an Intumescent Flame Retardant Containing Boron and Magnesium Hydroxide, ACS Omega 2019, 4, 3314−3321, DOI: 10.1021/acsomega.8b03333
48. Tentu Nageswara Rao, Imad Hussain, Ji Eun Lee, Akshay Kumar and Bon Heun Koo, Enhanced Thermal Properties of Zirconia Nanoparticles and Chitosan-Based Intumescent Flame Retardant Coatings, Appl. Sci. 2019, 9, 3464; doi:10.3390/app9173464, https://www.mdpi.com/journal/applsci
49. Nana Tiana, Jiang Gonga, b, Xin Wena, Kun Yaoa, b and TaoTanga , Synthesis and characterization of a novel organophosphorus oligomer and its application in improving flame retardancy of epoxy resin ,Royal Society of Chemistry , RSC Advances DOI: 10.1039/c0xx00000x C4RA01525H (rsc.org)
50. W. Farhan M., Faiz Ahmad, Sami Ullah, Effects of inorganic fillers on Thermal performance and char morphology of Intumescent fire-retardant coating, Asian Journal of Scientific Research-2013, ISSN 1992-1454, DOI: 10.3923/ajsr.2013.263.271
51. Sami Ullah| Faiz Ahmad | Abdullah G. Al-Sehemi | Mohammed Ali Assiri | Muhammad Rafi Raza | Ahmad Irfan, Effect of expandable graphite and ammonium polyphosphate on the thermal degradation and weathering of intumescent fire-retardant coating – J Appl Polym Sci. 2020; e50310. wileyonlinelibrary.com/journal/app © 2020 Wiley Periodicals LLC 1 of 16 https://doi.org/10.1002/
52. Sami Ullah , Faiz Ahmad -Effects of zirconium silicate reinforcement on expandable graphite based intumescent fire retardant coating , Polymer Degradation and Stability 103 (2014) 49- 62, www.elsevier.com/locate/polydegstab - http://dx.doi.org/10.1016/j.polymdegradstab.2014.02.01
53. Harri Junaedi , Muneer Baig , Abdulsattar Dawood , Essam Albahkali and Abdulhakim Almajid-Mechanical and Physical Properties of Short Carbon Fiber and Nanofiller-Reinforced Polypropylene Hybrid Nanocomposites , Polymers 2020, 12, 2851; doi:10.3390/polym12122851, www.mdpi.com/journal/polpolymers
54. Muting WuORCID, Wei Song, Yuzhang Wu and Wei Qu ,Preparation and Characterization of the Flame Retardant Decorated Plywood Based on the Intumescent Flame Retardant Adhesive, Materials 2020, 13(3), 676; https://doi.org/10.3390/ma13030676

55. P F – PRODUCTS FINISHING-Phosphate Conversion Coatings -Published 9/29/2011,Types of phosphate conversion coatings, how to apply them, and their specific functions. #basics, https://www.pfonline.com/articles/phosphate-conversion-coatings
56. Jiang-Jhy Chang, Wei-Chung Yeih, Kuo-Lien Chen, Maochieh Chi - ZINC-RICH LITHIUM SILICATE COATINGS FOR CORROSION PREVENTION IN STEELS (ntou.edu.tw)- - Journal of Marine Science and Technology, Vol. 25, No. 3, pp. 259-267 (2017)-DOI: 10.6119/JMST-016-1214-1
57. Meng Low, Hani Manssor Albetran, Michael Degiorgio, Structural Characterization of Commercial Graphite and Graphene Materials, Journal of Nanotechnology and Nanomaterials- Research Article-DOI: https://doi.org/10.33696/Nanotechnol.1.005 https://www.scientificarchives.com/journal/journal-of-nanotechnology-and-nanomaterials
58. Hana Vaškova, Vojtěch Křesalek, Quasi real-time monitoring of epoxy resin crosslinking via Raman microscopy, INTERNATIONAL JOURNAL OF MATHEMATICAL MODELS AND METHODS IN APPLIED SCIENCES, Issue 7, Volume 5, 2011 www.researchgate.net/publication/228901440_Raman_spectroscopy_as_an_innovative_method_for_material_identification file:///C:/Users/techn/Downloads/17-120.pdf
59. Minghui Fang, Jun Qian, Xuezhi Wang, Zhong Chen, Ruilin Guo, and Yifeng Shi, Synthesis of a Novel Flame Retardant Containing Phosphorus, Nitrogen, and Silicon and Its Application in Epoxy Resin, ACS Omega 2021, 6, 7094−7105, https://dx.doi.org/10.1021/acsomega.1c00076
60. Hung-Yin Tsai, Wei-Hsuan Hsu, and Ying-Chen Huang, Characterization of Carbon Nanotube/Graphene on Carbon Cloth as an Electrode for Air-Cathode Microbial Fuel Cells, Journal of Nanomaterials, Volume 2015, Article ID 686891, 7 pages, Hindawi Publishing Corporation, http://dx.doi.org/10.1155/2015/686891
61. YaChao Wang, Gongfan Tang, JiangPing Zhao, Yujiu Han, Effect of flaky graphite with different particle sizes on flame resistance of intumescent flame-retardant coating, Results in Materials -Volume 5, March 2020, 100061 -https://doi.org/10.1016/j.rinma.2020.100061:
62. Annexure -A - Information on the source and grades of some of the significant raw materials utilized in the experiments

Ref. [59] : An Annexure to some of the important Raw materials - their Grades and Sources- used in the experiments: -

Annexure: The following is a list of some of the important raw materials – their grades and sources -used in the experiments.

Group A: Epoxy resin binder/reactive diluent:

- Solvent-free liquid Epoxy resin: Epoxide equivalent 180-190

- Reactive diluent: Low viscosity, long chain aliphatic mono epoxide reactive diluent based on C12-C14 alcohol.

Group-B: Pigments -Minerals:

- Titanium Dioxide -Rutile: TiO_2-R, dry brilliant white powder, sp.gr. 4.20, Refractive Index 2

Refractive Index: -2.73. Residue on 325 Mesh-below5.00

- Ordinary China clay, kaolinite: $Al_2Si_2O_5(OH)_4$ and Montmorillonite hydrated Na-Ca-Al-Mg- silicate hydroxide (Na, Ca) $0.33(Al, Mg)\ 2(Si_4O_{10})\ (OH)\ 2$n H_2O, average particle size of 5-6 microns, Density of 2.70-2.80 g/cm3.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

Group-C: Silica based minerals:

• Cenosphere: Light grey, Alumino silicate hollow-glass spheres, Particle size – 100 % below 500 microns. 50%, 150-300 microns, 5 % below 50 microns, sp.gr. 0.85-o.95.Petra Build Care Products- FILLIT 500L – www.indiacenosphere.com

• Fine amorphous Silica- Fume Silica: Minimum SiO2 content in the range of 85 - 90%, with residue on 325 mesh,1.50 % maximum, Density 2.20-2.23 g/cm3.

• Cab-o-Sil-CABOT-https://www.cabotcorp.com/solutions/products-plus/fumed-metal-oxides

• Perlite: Volcanic glass/ 76 % SiO2 and 14% Al2o3, White- Light weight –Granular, size 0-1.18 mm., Sp. Gr - 2.20-2.40 / Bulk Density: - 70-80 Kgs/cu. Mt. GULF PERLITE - PERLITE – FINE GRADE [0 – 1 mm] - Web: www.uaeperlite.com - www.gulfperlite.ae

Group-D: Fire retardant Pigments, Chemicals:

• A T H -Aluminium Trihydrate, white crystalline powder AI2O3•3H2O -ATH M 10B-Source- LKAB Minerals Product, www.lkabminerals.com

• Borax -decahydrate: Na2B4O7.10H2O-White crystalline solid- Chemiebor 36 RAJBORAX-https://rajborax.com/Images/chemeibor%2036.pdf

• Zinc Borate: Zn3B2O6, white amorphous powder- Medshield India-https://www.indiamart.com/medshield-india/products.html#1375971533 Zinc borate Firebrake ZB* (2ZnO·3 B2O3·3.5H2O), CAS number 138265-88-0 ,generally used.

• Magnesium filler- UltraCarb 1290- a white, finely milled natural inorganic product consisting of two minerals: huntite- Mg3Ca (CO3) 4 (a platy magnesium calcium carbonate) and hydromagnesite- Mg5 (CO3) 4 (OH)2 .4H2 O (hydrated magnesium carbonate). Source- LKAB Minerals Product, www.lkabminerals.com

• A P P: Ammonium Polyphosphate- an excellent flame retardant in dry powder form free of halogens. Chemically [NH4PO3)] n, n > 1000-Exolit AP-422 -a Clariant Product- www.clariant.com

• Dipentaerythritol: CA 126-58-9S-chemical formula: (CH2OH)3CCH2OCH2C(CH2OH)3-Supplier-Parchem https://www.parchem.com/chemical-

• Melamine: An acid donor and a blowing agent. Melamine Orthophosphate (14.5% P,37% N), of relatively low-temperature decomposition. Commercial Product AFLAMMIT® PMN 185- THOR Products-

https://www.thor.com/flameretardantsintumescentsystems.html

Group – E: Intumescent Pigments/ Minerals:

• Graphite: Expandable/Intumescent graphite- grade -3721 - ASBURY CARBON-www.asbury.com - Chemical formula C, dry -black-flaky-hexagonal, flake size > 300 microns, C-content- ≥ 98, expansion ratio (cc/gm), 300:1., Sp.gr. 1.90 – 2.30,

• Graphene - A perfect two-dimensional carbon nanostructure, ACS Material, consisting of a monolayer of graphite carbon atoms arranged in a hexagonal lattice, with sp2 hybridization. Graphene can be in the range of diameters of one nanometer, while their length can reach several micrometers. It is an allotrope of carbon in the structure of a plane of sp2-bonded atoms with a molecule bond length of 0.142 Nanometres. It is the thinnest and lightest element known at one atom. Grey-black, greenish fine powder of diameter 1-15-micron, thickness-

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

0.8-1.2 nm, specific surface area 5-10 m2/gm, chemical composition CxOyHz, sp.gr. 1.80.www.acsmaterial.com-

• CNTs: Carbon Nanotubes - are allotropes of carbon with a cylindrical shape and with diameters of an order of a nanometer (nm) which have superior electrical,

thermal, and mechanical properties. The tubes averaged a height of 380 nm and a mass density of 1.6 gms/cm3.: Carbon Nanotubes - LG Chem CNT (Carbon Nanotube) Products | https://www.lgchem.com/product/product

• Exfoliated Vermiculite - Name derived from Latin vermicularis (worm-like), a hydrated laminar magnesium aluminum iron silicate mineral which resembles mica in appearance with composition- (Mg, Fe++, Al)3(Al, Si)4O10(OH)2•4(H2O) Ramamurthi Vermiculite -Mines- Chennai-India- www.ramamaruthi.co.in , dry, soft. brown-bronze lustrous, platy. Specific Gravity: - 2.50 / Bulk Density: - 64 -160 kg/m3,

• Mica Flakes: Muscovite Mica- KAl2 (Si3AlO10) (OH) 2, Phlogopite, biotite, etc. – KMg3 (AlSi3O10) (OH) 2, Bronze gold, platy flakes-Dry, off-white powder,platy, Flakes, with silky lustrous - flat six-sided monoclinic crystals, Sp.gr.- 2.85 PD900-https://additives.ulprospector.com/datasheet/e257866/phlogopite-mica-pd900

Group –F: Additives:

• Soya lecithin: A red brown, viscous liquid, rich in phospholipids derived from soybeans, used as a wetting and dispersion aid, Acetone insoluble: 55-60 %, Acid value :32-35 mgs KOH/ gm solid.

• Bentone Thickener: A rheological additive, derivative of a bentonite clay-designed for use in moderate to high polarity systems containing solvents such a ketone, esters, glycol ethers and alcohols, including polar systems with some aromatic solvents. Very light cream, finely divided powder Density 1.62 g/cm3, Particle size (dispersed) less than 1 micron

• Rockwool fibers: Solid, highly stable, grey green fibers. Fiber density of approx. 2.90gms/cm3, non-flammable, MP above 1300 oC, Rockwool loose wool- Fujairah Rockwool Factory-grade-FRF250.: www.rockwoolfujairah.ae

• Lapinus fibers: Lapinus® MS610- a green, high quality, engineered mineral fibre for coating applications, are highly stable and there is no reactivity between both components up to 1000 °C. Shot content >125 µm Max 1.0 wt.% TV316 (internal method) Fibre length -weighted average 230 ± 50 µm, it provides dimensional stability, and heat resistance.Lapinus Fibres BV - www.lapinus.com

Group G: Hardner -Curing Agent:

• Curing Agent: Reactive Cycloaliphatic Amine, Amine Value: 300-350 mgs KOH/gm

ADDITIONAL-RECENT-NEW REFERENCES

[60] New Products from INTERNATIONAL: [https://www.international-pc.com/en/products/chartek-one

Boron-free Chartek 8E provides exceptional pool fire performance with up to 30% lower installed weight compared to alternative PFP products, allowing for greater flexibility in structural design. It improves coating efficiency through reduced number of coats and no mesh requirement for up to 60 minutes pool fire duration.

A self-reinforced epoxy coating, Chartek 7E simplifies application giving the oil and gas industry more choice and greater efficiency than ever before. Chartek 7E offers outstanding pool and jet fire resistance for up to two hours and a significant reduction in installed weight against other PFP products in the market.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

Chartek 2218 is our latest epoxy PFP system for installations requiring certification to the UL 1709 standard. Using patented technology, it offers our lowest certified thickness for longer duration fires. Boron-free Chartek 2218 is certified for up to four hours pool fire protection in addition to being jet fire tested. Simplified installation and unique rapid cure, even at low temperatures, enable faster application, imp

Chartek 8823 is a high performance, patented, boron free, modified epoxy intumescent fire protection solution.

Chartek ONE is our latest mesh-free epoxy PFP system for installations meeting industry's highest standards, including NORSOK M-501:2022, ISO 20902, IMO Res MSC307(88-(2010)), ISO 22899, and UL 1709 Edition 5, ensuring reliability and safety. Using patented technology, Chartek ONE is effective across all fire types with allowance for high operating temperature operations. Boron-free Chartek ONE can provide protection for up to three hours pool fire protection in addition to being tested for high heat flux jet fires up to 60 minutes tested. Simplified installation and unique rapid cure, even at low temperatures, enable faster application, improve production rates and reduce overall installed costs.

With an unrivalled track record spanning more than 20 years, Chartek 7 provides exceptional protection for long duration pool and jet fires, and proven long term corrosion resistance. It is the most widely certified epoxy intumescent in the world and has protected over six million square meters of steel globally.

Part of our UL 1709 product offer, boron-free Chartek 1709 provides long term corrosion and fire protection in a single system. Having covered millions of square meters over a period of 10 years, Chartek 1709 can be used with confidence for pool fires up to four hours, jet fires and vessel protection. Its low installed weight and excellent application properties make Chartek 1709 the ideal choice for modular construction or site application.

[61] A new range of Coatings from -IRIS Coatings-for Steel and Concrete fire protection is available. https://www.iriscoatings.it/reactive-coatings
[62] Sikagard®-831 is a new -solvent-free 2-pack modified epoxy-based intumescent fire-protection coating for internally or externally exposed aluminum or steel surfaces. https://industry.sika.com/en/home/transportation/bus-and-coach/fire-protection-coatings/sikagard-831.html
[63] Fireshield® Structural Steel Fire Rated Coatings are water-based and 2K epoxy intumescent coatings that provide up to 120 minutes of fire resistance for interior and exterior structural steel. https://fireshieldcoatings.com/.../structural-steel-fire.../ #Fireshield #StructuralSteelFireRatedCoatings #FireSafety #BuildingProtection
[64] Intumescent, Epoxy-Based Flame-Retardant Coatings Based on Poly (acrylic acid) Compositions BY : Erik J. Price - James Covello -- Andrew Tuchler - Gary E. Wnek ACS Applied Materials & Interfaces- Vol 12/Issue 16-RESEARCH ARTICLE-March 31, 2020
[65] Intumescent Coatings for Steel-SHERWIN-WILLIAMS. https://protectiveeu.sherwin-williams.com/en
[66] AARONITE ITALIA GROUP – www.aaronite.it- INTUMESCENT COATINGS REACT TO HEAT BY SWELLING IN A CONTROLLED MANNER TO MANY TIMES THEIR ORIGINAL THICKNESS.
[67]Research Article-Thermal performance of hybrid fibers reinforced epoxy based intumescent coating for fire resistance of steel structures- Muhammad Yasir and Fiaz Ahmad Materials Research Innovations Volume 27, 2023 - Issue 5- https://doi.org/10.1080/14328917.2022.2160540
[68] TECHNICAL PAPER -Balancing the Performance and Robustness of Epoxy Intumescent Coatings - Ingrid Vee; James Irving; Muhammad Ahsan Bashir; Zuzanna Wierzba- Paper No: C2024-20661, pp. 1-10; 10 pages https://doi.org/10.5006/C2024-20661 -Published Online: March 03 2024- AMPP -ANNUAL EXPO-
[69] Intumescent Coatings for Hydrocarbon Fire. - htps:// www.shreepaintcoating.com / intumescent-coatings.php htps://www.shreepaintcoating.com/intumescent-coatings.php