

Zhan, Wang; Chen, Le; Gu, Zhaozhan; Jiang, Juncheng

Article

Influence of graphene on fire protection of intumescent fire retardant coating for steel structure

Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: Zhan, Wang; Chen, Le; Gu, Zhaozhan; Jiang, Juncheng (2020) : Influence of graphene on fire protection of intumescent fire retardant coating for steel structure, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 6, Iss. 2, pp. 693-697, <https://doi.org/10.1016/j.egyr.2019.11.139>

This Version is available at:

<https://hdl.handle.net/10419/243953>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

The 6th International Conference on Power and Energy Systems Engineering, CPESE 2019,
20–23 September 2019, Okinawa, Japan

Influence of graphene on fire protection of intumescent fire retardant coating for steel structure

Wang Zhan^a, Le Chen^b, Zhaozhan Gu^b, Juncheng Jiang^{a,*}

^a Jiangsu Key Laboratory of Hazardous Chemicals Safety and Control, College of Safety Science and Engineering, Nanjing Tech University, No. 30, South Puzhu Road, Pukou District, Nanjing 211800, China

^b Department of Electronic Engineering, School of Electronic Science and Engineering, Nanjing University, No. 163 Xian Lin Road, Qixia District, Nanjing 211800, China

Received 15 October 2019; accepted 23 November 2019

Abstract

Graphene (GR) was used as filler to improve the performance of fire resistance, thermal stability, smoke suppression of waterborne intumescent fire-retardant coating. The influence of graphene (GR) on the properties of the intumescent fire-retardant coating was studied by fire protection test, TGA, SEM and smoke density test. The results showed that the GR can effectively enhanced the performance of fire resistance and thermal stability of the coating. The result of SEM test indicated the coating with GR had excellent intumescent effect and enhanced foam structure. The smoke density test of the coating demonstrated the coating contain GR had excellent performance of smoke suppression.

© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering, CPESE 2019.

Keywords: Graphene; Fire resistance; Coating; Steel structure

1. Introduction

Intumescent fire retardant coatings have been widely used in the protection of buildings of steel structure [1–3]. The intumescent fire retardant coatings are composed of polymer binder, acid source, blowing agent, carbon source, fillers and other additives [4]. Specially, the filler has an important influence on expansion factor and fire retardant for the coating. The compositions of the intumescent fire retardant coating react with each other and form the foam structure. This structure of char layer can effectively isolate the flame and protect the surface of the steel plate [5].

Graphene has 2D hexagonal lattice structure and it composed only of carbon atoms with sp^2 hybridization [6–9]. This structure of graphene made coating exhibiting good performance in high thermal conductivity, electrical conductivity, high mechanical strength. In recent years, many researches on anticorrosion performance of GR have

* Corresponding author.

E-mail addresses: zw_freedom@163.com (W. Zhan), chenle26@nju.edu.cn (L. Chen), tommygu@nju.edu.cn (Z. Gu), jcjiang@njtech.edu.cn (J. Jiang).

<https://doi.org/10.1016/j.egyr.2019.11.139>

2352-4847/© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering, CPESE 2019.

showed that GR could effectively enhanced anticorrosion property of the coatings, but few studies were reported about fire resistant [10].

2. Experiment

2.1. Material

The acrylic resin emulsion was purchased from Nantong Zhenlong adhesive Co., Ltd. Ammonium polyphosphate was purchased from Shanghai Macklin Biochemical Co., Ltd. Dipentaerythritol (DPER) were purchased from Aladdin Industrial Co., Ltd. Melamine (MEL) were purchased from Shanghai Lingfeng chemical reagent Co., Ltd. Aluminum hydroxide ($\text{Al}(\text{OH})_3$) was obtained from Aladdin Industrial Co., Ltd. Titanium dioxide (TiO_2 , rutile) was taken from Aladdin Industrial Co., Ltd. Montmorillonite was purchased from Aladdin Industrial Co., Ltd. Graphene (GR) was a product from the sixth element (Changzhou) materials technology Co., Ltd.

2.2. Sample preparation

The components of the intumescent fire retardant coatings are listed in Table 1. First GR was dispersed in the water by ultrasonic dispersion. Then APP, DPER, MEL, TiO_2 , MMT, $\text{Al}(\text{OH})_3$ were mixed by high-speed disperse mixer. Finally the slurry with the emulsion were mixed by low-speed disperse mixer. The prepared coating was coated on steel boards (Q235 steel, 150 mm \times 100 mm \times 2 mm) and dried at room temperature. The thickness of the samples maintained 2 ± 0.1 mm.

Table 1. The components of the intumescent fire retardant coatings.

Components	SP-1	SP-2	SP-3	SP-4	SP-5
APP/DPER/MEL	15/12/10	15/12/10	15/12/10	15/12/10	15/12/10
TiO_2 /MMT/ $\text{Al}(\text{OH})_3$	2/2/1	2/2/1	2/2/1	2/2/1	2/2/1
GR	0	0.5	1	1.5	2
Water	25.5	25	24.5	24	23.5
Emulsion	30	30	30	30	30
Additives	2.5	2.5	2.5	2.5	2.5

2.3. Measurement and characterization

The fire protection test was used to study the fire resistant performance of coatings with the homemade equipment. The sample coated by the fire retardant coatings was faced to the alcohol blast burner. During the test, the temperature of backside of the sample board was recorded by the digital thermometer. The time of test was lasted for 30 min. The size of sample was 150 mm \times 100 mm \times 2 mm. The morphological structures of charring layers were observed and analyzed by SEM analysis using S-3400N II (Hitachi Co., Japan) at 20 kV. TG analysis tests were carried out under nitrogen flow by a NETZSCH STA 449F3 TG apparatus at a heating rate of 20 $^{\circ}\text{C}/\text{min}$ from room temperature to 800 $^{\circ}\text{C}$. The smoke production rate of coating was characterized using the smoke density instrument (TTech-ISO5659) with an incident flux of 25 kW m^{-2} . The size of each samples was 75 mm \times 75 mm \times 1 mm.

3. Result and discussion

3.1. Fire resistant test

During the fire resistant test, the data of the backside temperature was recorded by the data acquisition instrument and plotted as a curve in Fig. 1. And the residual carbon photographs of coatings after fire test were shown in Fig. 2. Before the first 500s, the curves of temperature increased rapidly. Then the rate of the temperature increased slowly. After the test, the finally backside temperatures of Q235 steel plate were 420 $^{\circ}\text{C}$, 319.3 $^{\circ}\text{C}$, 302.2 $^{\circ}\text{C}$, 284.5 $^{\circ}\text{C}$, 275.3 $^{\circ}\text{C}$, respectively. The results indicated that the coatings with the filler of GR can decrease the temperature of the steel plate effectively and SP-5 had the best performance of the fire resistant. As the images shown in Fig. 2, the GR dispersed well in the coatings and formed the barrier and prevented the flame and heat reached the surface of the steel plate [11].

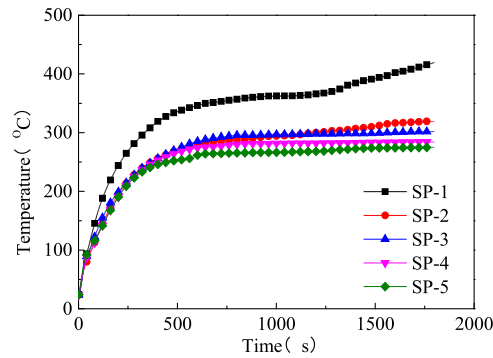


Fig. 1. The backside temperature of Q235 steel plate.

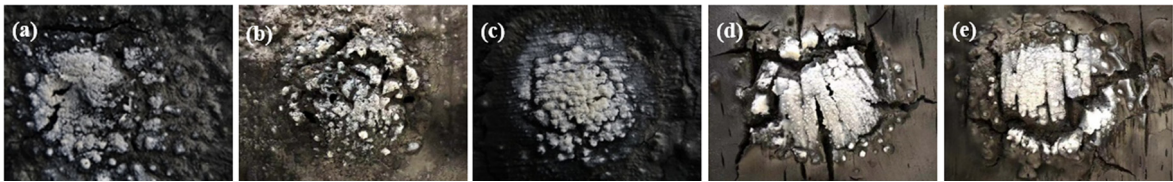


Fig. 2. The residual carbon photographs of coatings after fire test.

3.2. Scanning electron microscopy analysis

The Scanning electron microscopy images of the residual carbon are shown in Fig. 3. The coating of SP-1 formed the uneven foam structure and blank space. This structure led the poor performance of fire resistance. The structure of SP-3 was shown in Fig. 3c. This foam structure demonstrated that GR had a uniform distribution in the coating and could isolate steel plate from flame and heating, reaching a better properties of fire resistant [12].

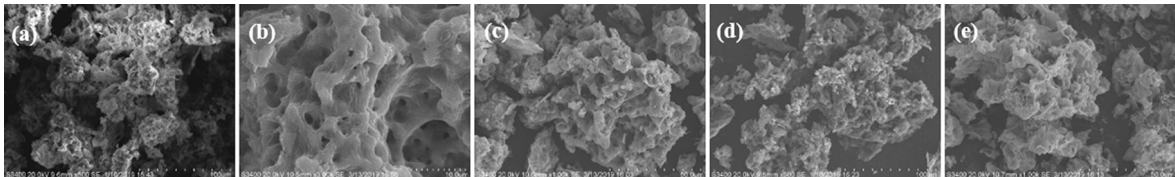


Fig. 3. SEM images of the residual carbon.

3.3. TG-DSC analysis

Thermal stability is an important index of evaluating coatings [13]. Fig. 4 shows the TGA curves of all samples. The weight residue of all samples showed that SP-1, SP-2, SP-3, SP-4 and SP-5 have a weight residue of 28.12%, 35.55%, 39.52%, 39.99% and 40.12% at 800 °C. The result indicated that the filler of GR can effectively increase the residual weight of carbon layer. This is because the GR has thermal stability even at a high temperature. But when the mass fraction of GR over 1%, the thermal stabilization effect is not obvious.

3.4. Smoke density test

To investigate the smoke suppression performance of coatings, smoke density test was carried out at a flux of 25 kW m⁻². The specific optical density (D_s) curves of the coatings were shown in Fig. 5. The results demonstrated that the D_s values of SP-1 was higher than other samples and the GR could effectively suppress the smoke production. The D_s values indicated that SP-3 had the best effect of smoke suppression. Because the GR can form foam structure

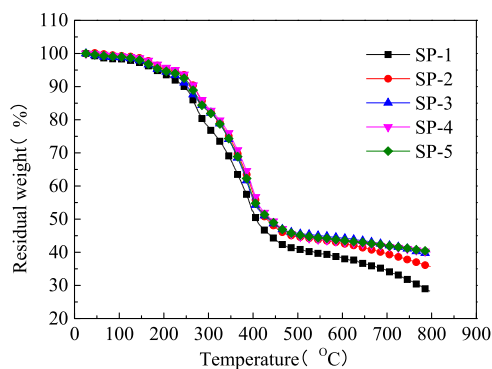


Fig. 4. TGA curves of the coatings.

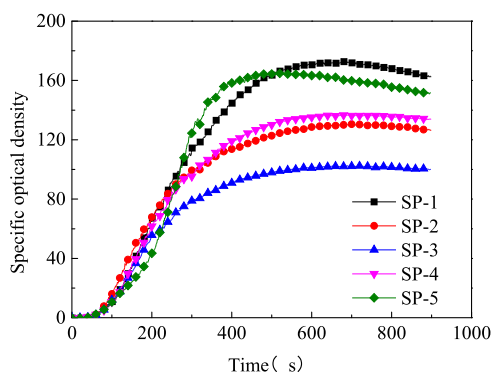


Fig. 5. Specific optical density curves of the coatings.

to absorb the smoke and suppress the smoke during the combustion process [8,9,14,15]. Moreover, the GR also can react with oxygen and product the smoke. And the SP-3 had the excellent performance of smoke suppression.

4. Conclusion

In this study, fire resistance, structure of the carbon layer, thermal stability, smoke suppression were investigated. The GR has an important influence on the properties of the fire retardant coating. The results shown that the fire retardant coating with the filler of GR can decrease the backside temperature and had lower D_s . The effect of GR in the fire retardant coating will be study in the future work. The material of GR has many excellent properties and deserves further study in fire retardant coating.

Acknowledgments

The authors gratefully acknowledge the financial support from the key project of National Natural Science Foundation of China under Grant No. 21436006, and key project of National Natural Science Foundation of China under Grant No. 51834007.

References

- [1] Morys M, Illerhaus B, Sturm H, et al. Variation of intumescent coatings revealing different modes of action for good protection performance. *Fire Technol* 2017;53(4):1569–87.
- [2] Puri RG, Khanna AS. Intumescent coatings: A review on recent progress. *J Coat Technol Res* 2017;14(1):1–20.
- [3] Zhitian, Liu MDYZ. Preparation and performances of novel waterborne intumescent fire retardant coatings. *Prog Org Coat* 2016;95:100–6.
- [4] Qiu S, Wang X, Yu B, et al. Flame-retardant-wrapped polyphosphazene nanotubes: A novel strategy for enhancing the flame retardancy and smoke toxicity suppression of epoxy resins. *J Hard Mater* 2017;325:327–39.

- [5] Puri RG, Khanna AS. Effect of cenospheres on the char formation and fire protective performance of water-based intumescent coatings on structural steel. *Prog Org Coat* 2016;92:8–15.
- [6] Wang N, Zhang M, Kang P, et al. Synergistic effect of graphene oxide and mesoporous structure on flame retardancy of nature Rubber/IFR composites. *Material* 2018;11(6):1005.
- [7] Wei H, Zhu Z, Sun H, et al. Graphene and poly(ionic liquid) modified polyurethane sponges with enhanced flame-retardant properties. *J Appl Polym Sci* 2017;134(44):45477.
- [8] Zhang X, Shen Q, Zhang X, et al. Graphene oxide-filled multilayer coating to improve flame-retardant and smoke suppression properties of flexible polyurethane foam. *J Mater Sci* 2016;51(23):10361–74.
- [9] Zhang F, Chen P, Wang Y, et al. Smoke suppression and synergistic flame retardancy properties of zinc borate and diantimony trioxide in epoxy-based intumescent fire-retardant coating. *J Therm Anal Calorim* 2016;123(2):1319–27.
- [10] Md JN, Martin AC, Diana NHT, et al. Graphene: a multipurpose material for protective coatings. *J Mater Chem A* 2015;(3):12580–602.
- [11] Yuan B, Sun Y, Chen X, et al. Poorly-/well-dispersed graphene: Abnormal influence on flammability and fire behavior of intumescent flame retardant. *Composites A* 2018;109:345–54.
- [12] Wang J, Wang G. Influences of montmorillonite on fire protection, water and corrosion resistance of waterborne intumescent fire retardant coating for steel structure. *Surf Coat Technol* 2014;239:177–84.
- [13] Jiang W, Hao J, Han Z. Study on the thermal degradation of mixtures of ammonium polyphosphate and a novel caged bicyclic phosphate and their flame retardant effect in polypropylene. *Polym Degrad Stab* 2012;97(4):632–7.
- [14] Chen P, Zhang F, Li S, et al. Smoke suppression properties of epoxy crosslinked structure and intumescent fire retardant in epoxy-based intumescent fire-retardant coating. *J Appl Polym Sci* 2016;133(36):43912.
- [15] Chen C, Zhao X, Shi C, et al. Synergistic effect between carbon nanoparticle and intumescent flame retardant on flammability and smoke suppression of copolymer thermoplastic polyurethane. *J Mater Sci* 2018;53(8):6053–64.