Chapter 13
Fire Retardant Coating Composition

Mohd Salahuddin Mohd Basri\textsuperscript{a,c,*}, Faizal Mustapha\textsuperscript{a,c}, Norkhairunnisa Mazlan\textsuperscript{a,b}, & Mohamad Ridzwan Ishak\textsuperscript{a,b,c}

\textit{a}Department of Aerospace Engineering, Faculty of Engineering, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
\textit{b}Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
\textit{c}Aerospace Manufacturing Research Center (AMRC), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

Abstract

Steel, while obviously a very strong material, it is not immune to the effects of fire. As fire is applied, the steel starts to lose its strength at temperatures exceeding 540°C and eventually collapses. This is the reason why all steel structures should be protected from fire and heat to maintain their strength and create adequate egress time inside the structure. Intumescent fire retardant coatings have been developed to provide protection from prolonged fire exposure. In case of a fire, such coatings will expand greatly, creating a char layer that further protects the steel structure. The char layer is considerably more effective than traditional insulating and fire retarding materials in minimizing the exposure of the underlying steel structure to rising temperatures. Innovatively, the coating is produced by using rice husk ash, an earth-friendly agricultural waste from rice production, and activated by chemicals using geopolymer technology. The uniqueness of the product is in its effective performance as fire retardant material imbued with eco-friendly, bio-degradable and non-toxic properties. Since the geopolymer coating is an intumescent coating, it is able to expand many times its thickness and form an insulating layer effective enough to protect the substrate. With the latest novel optimized formulation, the geopolymer coating is able to protect the substrate from fire and heat by delaying temperature rise and maintain it at about 350°C, well below the critical 540°C. In addition, the rates of combustion and generation of smoke are substantially reduced, increasing egress time and help maintain structural integrity.

Introduction

Steel are largely used in many areas such as in building construction, offshore structure, ships, railways, bridges and airports due to its exceptional strength. Steel, while obviously very strong, is not immune to the effects of fire. It starts to lose its strength at temperatures exceeding 540°C and eventually collapses (Jimenez, M.; Duquesne, S.; Bourbigot, S., 2006). This is why all steel structures should be protected from fire and heat to help maintain their strength and create adequate egress time for those inside the structure.

Fire retardant coating is an example of a means to shield and protect steel structures. For example, United States Publication No. 2006/0079612 A1 discloses a fire retardant coating composition comprising a resin based coating, an effective flame retarding compound selected from the group consisting of sterically hindered nitroxy stabilizers, sterically hindered hydroxylamine stabilizers and sterically hindered alkoxyamine stabilizers and at least one conventional flame retardant (US Patent No. US20060079612 A1, 2006). However, in the case of exposure to direct fire for a prolonged period of time, the fire may fully burn through the coating thus exposing the inner steel structure. Therefore, the prior art above may not be able provide adequate protection from prolonged fire exposure.

Intumescent fire retardant coatings have been developed to provide protection from prolonged fire exposure. In case of a fire, intumescent fire resistant coatings will expand greatly, creating a char layer that further protects the steel structure. The char layer is considerably more effective than traditional insulating and fire retarding materials in minimizing the exposure of the underlying steel structure to temperatures that would allow for further combustion. As a result, the rates of combustion and generation of smoke are substantially reduced, increasing egress time. In addition, the fire is usually contained to the room of origin which helps to maintain structural integrity and minimizes property damage. An example of an intumescent fire retardant coating composition is disclosed in Chinese Patent No. CN 1380368 A. This prior art discloses a fire retardant coating composition comprising acrylic resin, catalyst, char-forming agent, foaming agent, reinforced flame retardant, agents fillers,
solvent, additives and smoke suppressants (China Patent No. CN 1380368 A, 2002). However, the prior art as well as any other resin based fire retardant coatings, have low ignition temperature and contain chemicals capable of causing damage to health by inhalation of vapour or dust. Furthermore, when come into contact with skin, resin based coatings may cause irritant contact dermatitis and allergic reactions. Moreover, the combustion products emitted upon the exposure of resin based fire retardant coatings to fire may be even more harmful to humans.

Therefore there is a need for a fire retardant coating composition that addresses the abovementioned limitations of the existing fire retardant coating compositions.

### Content

The fire retardant coating was first prepared by mixing sodium hydroxide (NaOH) solution and sodium silicate (Na$_2$SiO$_3$) solution at various ratio to produce an alkaline activator (AA) solution. Sieved RHA was added to the AA solution and the mixture was gently stirred by hand for 30 seconds and by mechanical stirrer for an additional 30 minutes. The obtained slurry mixture was poured directly onto a mild steel plate substrate having a width of 10 cm, length of 10 cm and a thickness of 0.1 cm. The fire retardant test was conducted using a non-contact method involving an infrared camera and a blow torch. A total of 32 samples of coated substrates were exposed to fire for at least 20 minutes or until equilibrium temperature was reached. Temperature on the back of the coated substrate was plotted as a function of time.

Based on the results from fire resistant test, sample with the best fire retardant performance achieved an equilibrium temperature at about 398°C, which is well below mild steel’s failure temperature, after about 25 minutes. The equilibrium temperature is expected to remain unchanged for at least one hour. Figure 1 shows real image of sample with the best fire retardant performance after the fire retardant test.

![Fig. 1 Sample with the best fire retardant performance after fire retardant test](image1)

Figure 2 shows the microstructure images of the sample after further analysed using SEM. Wide and deep cracks are observed following exposure of the sample to fire at approximately 950°C for more than 30 minutes. The cracks are a result of additional removal of hydrogen bonded water. A closed up view of sample after exposure to fire exhibit a surface morphology covered with small and large needle-like structures (Mohd Salahuddin, M. B.; Faizal, M.; Norkhairunnisa, M.; Mohamad Ridzwan, I.;, 2016). The presence of such crystalline structures indicate that more oligomers are generated as a result of fire exposure. The generated oligomers trigger the release of more reactive Si- and Al-tetrahedra. The formation of crystalline structures, which indicates a high degree of geopolymerization in the fire retardant coating, provided the improved fire retardant performance (Zhang, M.; El-Korchi, T.; Zhang, G.; Liang, J.; Tao, M., 2014).

![Fig. 2 SEM micrographs of the geopolymer coating based on RHA after exposure to fire](image2)
Taking into consideration the results of the coating composition, an alternative coating composition was formulated as in Table 5.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of Sodium silicate to Sodium hydroxide (AA)</td>
<td>4.5 to 5.5</td>
</tr>
<tr>
<td>Ratio of Rice husk ash to AA</td>
<td>0.40 to 0.55</td>
</tr>
<tr>
<td>Curing temperature</td>
<td>≤ 50°C</td>
</tr>
<tr>
<td>Curing period</td>
<td>1 to 7 days</td>
</tr>
<tr>
<td>NaOH concentration</td>
<td>8 to 10M</td>
</tr>
<tr>
<td>Rice husk ash particle size</td>
<td>3.4 to 59.5 µm</td>
</tr>
</tbody>
</table>

The alternative coating composition was coated on mild steel substrate using a similar preparation method as the previous experiment. However, the thickness of the air cured fire retardant coat of the alternative coating composition was varied to be 1 mm and 10 mm thick. Coating with 10 mm thickness only reached equilibrium at approximately 87 °C after 4000 seconds. On the other hand, coating with 1 mm thickness reached equilibrium much faster after 1800 seconds at around 340 °C.

Both samples showed outstanding fire retardant performances. Moreover, both samples exhibited intumescent behaviour with an optimum expansion. The samples only expanded between 3 to 5 times its original thicknesses. The thermal images obtained from the test proved that the heat did not spread to another parts of the coating which resulted in the expansion of only the central part of the coating. It shows that the alternative coating composition has a lower thermal diffusivity. This is one of the main characters of good intumescent material which is able to block heat from spreading to the other parts of the material.

**Conclusion**

The optimized coating composition proved to provide an effective fire retardant performance and able to protect substrate from fire and heat. Geopolymer coating has huge potential as green technology product for commercialization in particular as manufacturing coating, insulation and fire retardant materials. The fabrication technique is simple and low cost. Geopolymer coating may be applied in many applications including but not limited to construction, transportation, aviation and ship-building. It provide an excellent protection for a long time and able to produce versatile product such as panel and composite.

**References**


