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Environmentally friendly intumescent coatings formulated with vegetable compounds

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ABSTRACT

Intumescent coatings have been presented as a great choice for the protection of steel structures against fire due to their ability to provide thermal insulation of the metal substrate by the formation of a protective carbonaceous layer. The carbon source is one of the main components of the intumescent system and usually it comes from non-renewable sources. Therefore, the development of more environmentally friendly alternatives is essential. In this work, epoxy resin coatings were prepared with vegetable compounds (ginger powder and coffee husk) to act as a carbon source in the intumescent system. In addition, the possibility of using zinc phosphate (ZnP) and triphenyl phosphate (TPP) as flame retardants has been verified. The characterization of the coatings was performed through a fire resistance test, thermogravimetric analysis (TGA), Fourier transform infrared (FTIR), X-ray diffraction (XRD) and pyrolysis gas chromatography mass spectrometry (Py-GC–MS). Both vegetable compounds showed potential for application as a carbon source, decreasing the temperature of the substrate when compared to the blank condition. Coatings containing TPP show better behaviour as flame retardants and better expansion than ZnP. Py-GC–MS analysis shows the absence of toxic gases such as CN^- and phosphine.

1. Introduction

Steel is the most commonly used metal alloy in everyday life, with several applications. Structural steel is applied in construction and in various industrial sectors, which include petrochemical refineries and offshore oil and gas platforms, where accidental fires may cause degradation of the steel properties, causing catastrophic failure [1–3]. Steel structures lose their structural properties (mechanical strength) when subjected to high temperatures (over 500 °C) [3]. Thus, the importance of the development and improvement of flame retardant and thermal isolation coatings is clear.

An intumescent coating is an alternative that has been gaining prominence in the protection of metallic structures against fire. The intumescent system consists of three main components: acid source, carbon source and expansion agent [4,5]. In contact with heat, the surface of the intumescent coating melts in the form of a highly viscous liquid and inert gases are produced due to the occurrence of chemical reactions [6]. The formation of ester occurs from the reaction of the acid with the carbon source, which will form a residue and inert gases [7,8]. The protective carbonaceous layer appears through the expansion of the coating, which, due to the retention of inert gases formed in the reactions within the highly viscous liquid, generates bubbles [6–8]. Protection of the metallic substrate is provided by the thermal insulation between it and the flame provided by the carbonaceous layer formed [6].

The carbon source of an intumescent coating is essential for the formation of the carbonaceous layer and performance of the coating in the protection of the metallic substrate against fire. Currently, non-renewable sources are the main raw materials used as carbon sources, such as pentaerythriol, but their processing is harmful to the environment, which makes it necessary to study and develop new and more ecologically correct alternatives [9]. Cellulose and lignin are the most abundant natural resources, with lignin being the only aromatic renewable resource present in nature [10]. Jiao et al. [10] proposed replacing the pentaerythriol with alkaline lignin as the carbon source. The use of alkaline lignin in polymers provided an improvement in the flame retardant behaviour [10].

Lignin and cellulose are present in the composition of many

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Table 1
Formulation of intumescent coatings.

Coatings	Resin (%)	Vegetable Compound[a] (%)	Melamine (%)	Boric acid (%)	TPP (%)	TiO_2 (%)	ZnP (%)
BlankTPP	77.99	–	6.19	6.19	3.43	6.20	–
GgpTPP	71.80	6.19	6.19	6.19	3.43	6.20	–
ChkTPP	71.80	6.19	6.19	6.19	3.43	6.20	–
BlankZnP	77.99	–	6.19	6.19	–	–	9.63
GgpZnP	71.80	6.19	6.19	6.19	–	–	9.63
ChkZnP	71.80	6.19	6.19	6.19	–	–	9.63

Percentages are given in dry mass.
[a] Ggp: Ginger powder; Chk: Coffee husk.

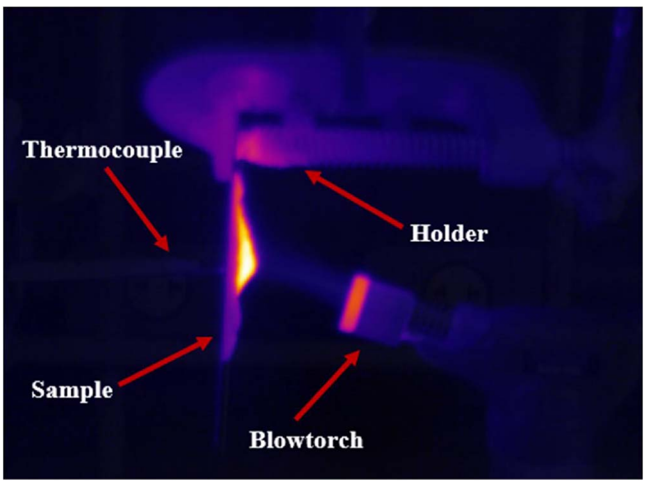

Fig. 1. Operation of the fire resistant test.

vegetable compounds, are derived from renewable sources, and have a lower cost than petroleum derivatives. Therefore, vegetable compounds can be considered a good possible carbon source to be used in intumescent coatings. Ginger (*Zingiber officinale*) is a vegetable compound belonging to the family *Zingiberaceae*. It is an important root spice that can be used in fresh or dried form and has India as its main producer [11]. Fouda et al. [12] used ginger extract as a green corrosion inhibitor for steel protection. Ginger has several chemical structures that have an aromatic ring, which is advantageous for its use as a carbon source in intumescent coatings. Some of the chemical structures of ginger are: ar-turmerone, α-turmerone, β-turmerone, curlone, zingiberene, curcumene and gingerol [12]. Coffee husk is a solid waste from coffee processing [13]. It has been used as a bioprocess raw material for the production of biogas, enzymes, mushroom and compost [14–16]. Pandey et al. [14] showed that coffee husk is rich in cellulose, hemicellulose, pectin and lignin. In addition, coffee husk presented nitrogen and potassium in its composition [14]. Other components present in this solid waste from coffee processing are caffeine and tannins [13]. Due to the presence of lignin and other aromatic components, coffee husk also has potential for application as a carbon source.

Halogenated flame retardants are the most efficient and well known in the industry. However, during the combustion of these compounds, they release toxic elements that are harmful to the environment and human health [8,17,18]. Thus, non-halogenated flame retardants have been used in place of the halogenates, among which phosphorous compounds are the most popular alternative. There is no release of toxic gases during the combustion of phosphorous flame retardants and the phosphorus is usually retained within the char. Triphenyl phosphate (TPP) is a flame retardant widely used in intumescent systems and also acts as a plasticizer in coatings. As a flame retardant, TPP acts by eliminating the hydrogen radicals of the flame, blocking the chain reactions and preventing flame propagation [19]. In addition, flame suffocation occurs with the formation of a char layer [20]. Zinc phosphate (ZnP) pigment is a phosphorous compound very well known in the protection against corrosion. It is a non-toxic anti-corrosive pigment used as a replacement for chromium-based pigments [21]. The total amount of phosphorus in the zinc phosphate pigment pentahydrate is greater than the amount present in TPP.

This work aims to test the efficacy of two vegetable compounds (ginger and coffee husk) as a carbon source and two phosphorous compounds (ZnP and TPP) as flame retardant. Thus, six intumescent

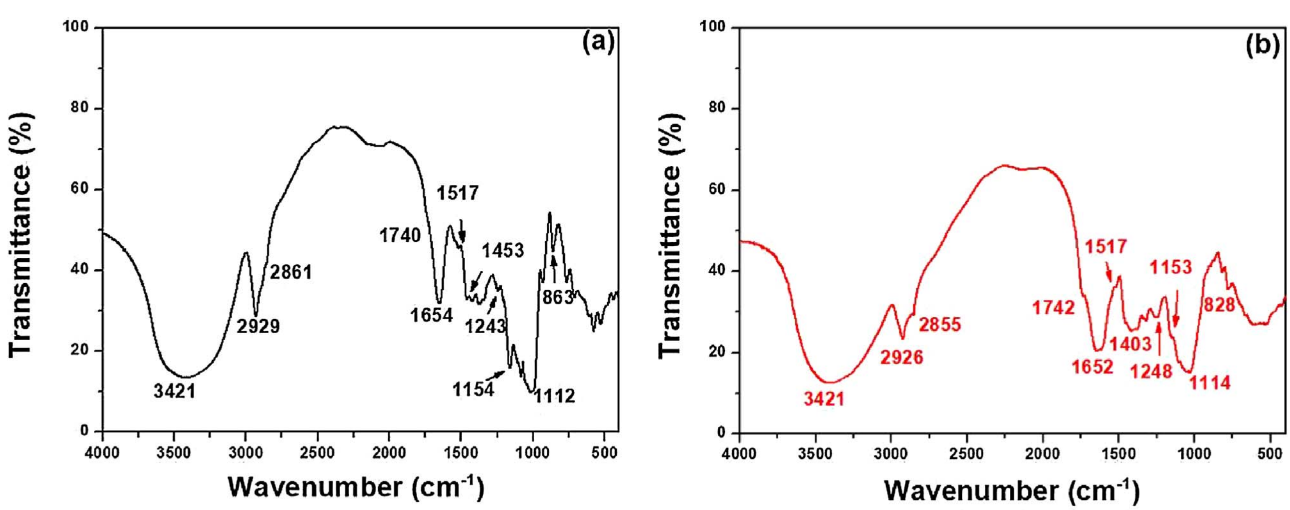

Fig. 2. FTIR spectra of (a) ginger powder and (b) coffee husk.