INVESTIGATION ON WATER-BORNE INTUMESCENT FIRE PROTECTIVE COATINGS FOR STEEL

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ABSTRACT

This research studies the efficiency of different water-borne intumescent formulations which incorporate chicken eggshell (CES) as a novel bio-filler, designed to protect steel in the event of a fire. The coating is based on these three flame-retardant additives: ammonium polyphosphate phase II, melamine and pentaerythritol (combination referred to as AMP). CES, silica fume (SF) and epoxy emulsion were incorporated either individually or in combination into the flame-retardant additives. The first part of the study develops and evaluates AMP, AMP+SF and AMP+SF+CES intumescent formulation systems, respectively. The best formulation produced was the AMP+SF+CES system which was subsequently selected for the next part of the study that investigates the effect of epoxy emulsion on the coating performance. The influence of (i) binder, (ii) combination of binder and filler; and (iii) combination of filler and two binders on the properties and fire-resistive performance of the coatings were investigated by using thermogravimetric analysis (TGA), scanning electron microscope (SEM), Instron microtester, field emission scanning electron microscope (FESEM), small scale Bunsen burner test and furnace test. The thermal stability of CES was compared with that of commercial calcium carbonate filler by using TGA. CES was shown to have higher thermal stability. TGA results showed that addition of CES and SF increases the residual weight and anti-oxidation of the coatings. The combination of 25 wt.% CES and 10 wt.% SF added into the flame retardant additives led to the best fire resistance performance, highest thermal stability, densest surface structure and greatest expansion, while showing improved char cohesion and sufficient adhesion to the steel substrate during fire exposure. The second part of the study attempts to investigate the effect of water-borne epoxy resin on the fire protection performance and bonding strength of the coating to the steel. Addition of 10 wt.% epoxy resulted in significant improvement in fire protection performance and foam structure of the coating. The results of Instron microtester indicated that the bonding strength of the coatings was improved with the increase of epoxy content.

ABSTRAK

Penyelidikan ini mengkaji kecekapan beberapa jenis rumusan lapisan penahan api berasaskan air yang menggunakan kulit telur ayam (CES) sebagai 'bio-filler' terkini. Lapisan penahan api ini dirumus untuk melindungi keluli apabila kebakaran berlaku dan berasaskan tiga aditif penahan api: ammonium polifosfat fasa II, melamin dan pentaeritritol (kombinasi dikenali sebagai AMP). CES, 'silica fume' (SF) dan emulsi epoksi digabung secara berasingan atau sebagai campuran ke dalam aditif penahan api. Bahagian pertama penyelidikan ini menghasil dan menilai rumusan AMP, AMP+SF dan AMP+SF+CES. Rumusan yang terbaik merupakan sistem AMP+SF+CES yang dipilih untuk bahagian penyelidikan selanjutnya yang melibatkan kajian kesan emulsi epoksi ke atas kecekapan lapisan penahan api. Pengaruh (i) 'bio-filler' (ii) kombinasi pengikat dan 'bio-filler', dan (iii) kombinasi 'bio-filler' dan dua pengikat terhadap sifat dan prestasi lapisan penahan api diuji dengan menggunakan analisis termogravimetri (TGA), 'scanning electron microscope' (SEM), 'Instron microtester', 'field emission scanning electron microscope' (FESEM), ujian penunu Bunsen skala kecil dan ujian 'furnace'. Kestabilan terma 'bio-filler' CES dibandingkan dengan filler kalsium karbonat komersil dengan menggunakan ujian TGA. CES terbukti mempunyai kestabilan terma yang lebih tinggi. Keputusan TGA menunjukkan bahawa penambahan CES dan SF meningkatkan berat baki pembakaran dan anti-pengoksidaan lapisan penahan api. Kombinasi 25 wt.% CES dan 10 wt.% SF dengan aditif penahan api menghasilkan prestasi ketahanan api terbaik, kestabilan terma yang tertinggi, struktur permukaan terpadat, pengembangan terbesar dan pada masa yang sama menunjukkan peningkatan daya lekitan 'char' dan daya lekatan pada keluli apabila didedah kepada api. Bahagian kedua penyelidikan mengkaji pengaruh resin epoksi berasaskan air terhadap prestasi menahan api dan kekuatan lekatan lapisan penahan api pada keluli. Penambahan 10 wt.% epoksi menyebabkan peningkatan kecekapan perlindungan api

dan struktur busa lapisan penahan api yang ketara. Keputusan ‘Instron microtester’ menunjukkan bahawa kekuatan lekatan lapisan penahan api pada keluli dapat ditingkatkan dengan penambahan kandungan epoksi.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Description	Unit
A	Cross section area	m^2
f_b	Bonding strength	Pa
F	Force	N
$f_{y,\theta}$	Effective yield strength	Pa
$f_{p,\theta}$	Proportional limit	Pa
$E_{a,\theta}$	Slope of the linear elastic range	Pa
$\varepsilon_{p,\theta}$	Strain at the proportional limit	-
$\varepsilon_{y,\theta}$	Yield strain	-
$\varepsilon_{t,\theta}$	Limiting strain for yield strength	-
$\varepsilon_{u,\theta}$	Ultimate strain	-
θ_a	Steel temperature	ºC
$k_{y,\theta}$	Reduction factor (relative to f_y) for effective yield strength	-
$k_{p,\theta}$	Reduction factor (relative to f_y) for proportional limit	-
$k_{E,\theta}$	Reduction factor (relative to E_a) for the slope of the linear elastic range	-

LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviation	**Compound**
AISC	American Institute of Steel Construction
Al_2O_3	Aluminum oxide
APP	Ammonium polyphosphate
ATH	Aluminum trihydroxide or aluminum trihydrate
$CaCO_3$	Calcium carbonate
CaO	Calcium oxide
CO_2	Carbon dioxide
CES	Chicken eggshell
CuO	Copper (II) oxide
e.g.	Exempli gratia (for example)
EG	Expandable graphite
et al.	et alibi (and elsewhere)
EVA	Ethylene vinyl acetate
Fe_2O_3	Iron (III) oxide
FESEM	Field emission scanning electron microscope
FTIR	Fourier transform infrared spectroscope
H_2O	Water
ISO	International Organization for Standardization
K_2O	Potassium oxide
LDPE	Low density polyethylene
MDH	Magnesium di-hydroxide
MEG	Modified expandable graphite
MEL	Melamine
MF	Melamine-formaldehyde
$MgCO_3$	Magnesium carbonate
NH_3	Ammonia
NMR	Nuclear magnetic resonance
(O)P(O)(OH)	Metaphosphoric acid
PA	Polyamide
PEG	Polyethylene glycol

LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviation	Compound
PER	Pentaerythritol
PET	Polyester
PH_3	Phosphine
rpm	Revolutions per minute
SEM	Scanning electron microscope
SF	Silica fume
SiO_2	Silicon dioxide
SnO_2	Stannous oxide
SSA	Self-crosslinked siliconeacrylate
TGA	Thermogravimetry analysis
THEIC	Tris-2-hydroxyethyl isocyanurate
TiO_2	Titanium dioxide
XRD	X-ray diffraction
XRF	X-ray fluorescence