5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The aim of this work was to investigate the efficiency of different intumescent coating formulations, designed for the protection of steel in the event of a fire. The effects of flame retardant components on the performance of intumescent coatings in terms of sticking ability, fire protection, thermal degradation and stability, surface morphologies as well as bonding strength were investigated.

The initial part of the study investigated the thermal stability of formulations with different composition ratios of flame retardant additives (AMP). The TGA curves of the AMP systems showed similar profiles. Sample A2 which had the highest residual weight was also found to be the formulation with the highest anti-oxidation and thermal stability.

The thermal stability of CES as a bio-filler was compared with that of commercial $CaCO_3$ filler using TGA test. CES decomposed completely at about 907°C whereas commercial $CaCO_3$ at about 850°C, proving that CES had better thermal stability compared to commercial $CaCO_3$.

TGA experiments were also carried out to study the decarbonation and recarbonation of CES. The mass loss is attributed to the decarbonation of CES into CaO and CO_2. The release of non-flammable molecules (CO_2) dilutes combustible gases and also promotes the formation of a protective vitreous layer. CES acts as an additional blowing agent when exposed to temperatures above 790°C. CES was also found to have a direct physical flame retardant action because it decomposes endothermically during heating and therefore absorbs energy. During the cooling phase, partial recarbonation of CaO resulted in mass increase. The results show that CES as a bio-filler reduces negative impact on the environment due to its ability to absorb CO_2 from the air during partial recarbonation. Thus, CES is a good candidate as a bio-filler due to its availability in bulk quantity, cost-effectiveness, excellent fire protection performance as well as having environmentally friendly properties.

The optimal combination of A2+10 wt.% SF+25 wt.% CES formulation led to the best fire resistance performance, highest thermal stability, densest surface structure and greatest expansion, while showing improved char cohesion and sufficient adhesion for remaining in place during fire exposure.

Temperature variations of the protected and unprotected steel plates obtained from the small scale furnace test during heating and cooling phases were compared with the Eurocode parametric standard time-temperature fire curve. The protected steel plate coated with A2+10 wt.% SF+25 wt.% CES formulation experienced a lower rate of initial temperature rise than the unprotected steel plate. Also, the temperature difference between the protected and unprotected steel plate increased to almost 450°C after about 22 minutes. The furnace test results indicated that the steel plate with fire protection coating could maintain its integrity and properties because the coating protected the steel from continuous temperature increase. As expected, the unprotected steel became deformed due to degradation of the steel’s structure and properties.

Fire protection performance depends strongly on the surface structure of the coating. Addition of SF and CES resulted in the formation of a more uniform, dense surface structure that reduced surface cracking. This surface structure effectively forms a barrier that isolates the steel substrate from fire and thus provides better fire protection.

In the second part of this research study, the effects of different epoxy binder compositions on the fire protection performance, char surface morphology, thermal stability and bonding strength of the coating samples were investigated. The fire protection performance and foam structure of the coating was significantly improved by adding 10 wt.% water-borne epoxy resin which produced the thickest char layer in the AMP+SF+CES+ER system. In addition, the TGA results showed that the residual weight of sample D2 (10 wt.% epoxy) was higher than sample D3 (15 wt.% epoxy). This indicates that sample D2 had better anti-oxidation and thermal stability due to the optimal combination and composition of epoxy, flame retardant additives and filler. The results of Instron microtester indicate that the bonding strength of the coatings was improved with the increase of epoxy content without much reduction in fire protection performance.

As a conclusion, although fire protective coatings are mainly based on intumescent systems, research in this field has great potential and many parameters in the formulation process can be further developed to improve the fire protection performance. Mixing different compositions of fillers, binders and flame retardant additives uncover a new range of flame retardant properties. The optimization of the formulation as well as the characterization of its performance in terms of fire protection, surface morphology, thermal conductivity, sticking ability, bonding strength as well as thermal stability should be determined for specific fire protection requirements. Therefore, depending on the substrate used, tailored flame retardant materials can be developed.

5.2 Recommendations

- Experiments investigating the combination of magnesium hydroxide and titanium dioxide should be performed to determine and characterize the effect of flame retardant fillers in synergistic combination.
- Further research can be done to determine the heat release and ignitability of the intumescent coatings by using the cone calorimeter.
- The water resistance and anti-corrosion of solvent-based intumescent coatings should be studied in the future work.
- Further work can be carried out by adding modified expandable graphite into existing intumescent coating formulation to characterize its performance in terms of fire protection performance, sticking ability, water resistance, and surface morphology as well as bonding strength.
- A standard intermediate-scale fire resistance test furnace should be used to comply with the time-temperature curves specified by the ASTM E119 and ISO 834 standards or a custom designed time-temperature curve.