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NEW TESTING DEVICE OF INTUMESCENT PAINTS AT HIGH TEMPERATURES

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1. INTRODUCTION

In our earlier studies we have been concentrated on the estimation of fire protective behaviour of the intumescent coatings. This behaviour is explained by the appearance of a porous layer on the surface of the protected structural element due to the thermal (pyrolytic) decomposition of the paint. This foam-like layer has a low thermal conductivity, lower than that of the original, unaffected coating and lower than that of the resulting char.

The physical and chemical processes during this decomposition are very complicated and they cannot be modelled in an exact manner. Due to this fact, the investigation of the fire protecting coatings is based on the direct observation of some samples, and the simplest way of modelling the intumescent coating is that of characterizing its thermal conductivity with a global $\lambda(T, t)$ coefficient that is a function of temperature and time and it encloses the contribution of all the mentioned processes. Because the thickness of the coating is not constant (it is growing during the foam forming) this coefficient is often correlated with the initial thickness or it is given as the $\lambda(T, t)$ thermal conductivity of the studied coating.

We have tried to elaborate a very simple laboratory equipment and measuring method, using some samples made as metallic bands with a thin coating on both faces (fig. 1.). We expect that this thin coating (after a transient period) behaves as a homogenous layer. This metallic band is heat up by an electrical current (by the Joule-effect), the dissipated power is $P = U \cdot I$. This band must be enough long for the limitation of the side effects; its surface is computed using its length L and width W as $S = 2 \cdot L \cdot W$ (it has two faces). The heat flux is obtained as $\varphi = P/S$. Measuring the temperature of the metallic band and on the outer surface of the coating, using the first form of Fourier's law λ is obtained:

$$\varphi = -\lambda \cdot \frac{dT}{dx} \rightarrow \lambda = \varphi \cdot \frac{\Delta T}{t}, \quad (1)$$

where the $\Delta T/t$ temperature gradient is given as the difference of the temperature between the outer and inner face of the coating divided by its initial thickness.

This determination was made on different temperatures, in different states of the coating, and we have obtained λ as a function of the temperature. During the foam forming process at constant temperature λ had a nearly constant value; its value increases as the foam become carbonized. We have deduced the reaction rate using the length of the time interval with near constant λ .

The temperatures were measured using some PT100 sensors and a Fluke IR thermometer.

The obtained results were used in finite element modelling of the intumescent coating.

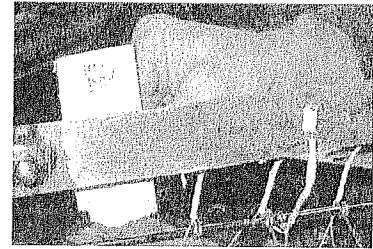
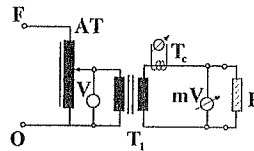


Fig. 1. The electric circuit of the experimental apparatus and one of the studied samples

Some problems arise here:

- a). in case of thick foam layers these tend to peel off at the edges; in this case the homogeneity of the temperature field is compromised;
- b). in case of high temperatures the PT100 sensors fail;
- c). the temperature curves used as thermal load curves in dimensioning refer to the ambient temperature and not to the temperature of the exposed surface, so the α factor of the Newton's cooling law and the ϵ emissivity have to be determined;
- d). in our experiments the direction of the heat flux and that of the gas bubbles was the same. In reality the heat penetrates from the outer surface (and not from the inner one, as in case of the electrically heated metallic bands), and the bubbles rise from the depth of the coating to the surface, carrying a certain amount of heat and contributing to the thermo-insulating property of the coating. In many cases ([3.]) this contribution is neglected, but we are not sure if reversing the cooler and warmer sides alters the foam forming process or not.

We hope to get answers and solutions using a modified apparatus.

2. THE MODIFIED APPARATUS

In its first version, as a response to the a) point of the previous list, we propose a slightly modified apparatus to estimate the thermal conductivity of the intumescent coating. This is based on that used in our earlier experiments but the metallic band will be replaced by a thin-walled metallic tube closed at both ends.

Because the sample has a circular symmetry and it has no edges, we will obtain a homogenous and continuous foam layer that will behave as a tube-like thermo-insulator.

In this case the heat flux through this tube-like coating is calculated as

$$\Phi = \pi \cdot \frac{T_i - T_o}{\frac{1}{2 \cdot \lambda} \cdot \ln \frac{\delta_o}{\delta_i}} \cdot l, \quad (2)$$

where l is the length of the tube, δ_i is the inner diameter of the tube, δ_o is the outer diameter of the coating (foam), T_i and T_o are the temperatures on the inner, respectively on the outer surface of the coating. The Φ flux is equal to the $P = U \cdot I$ electric power.

The measurements will be done in steady state situations, at constant temperatures, as in case of metallic bands.

The solution of the *b*) problem is the replacement of the PT100 sensors with some thermocouples embedded into the metallic tube.

To give an answer to the *c*) problem, supplementary we will measure the ambient temperature too, T_a . Because the (2) flux is dissipated in the surroundings, we can write the following energy balance equation:

$$\Phi = S \cdot [\alpha \cdot (T_o - T_a) + \varepsilon \cdot \sigma_0 \cdot (T_o^4 - T_a^4)], \quad (3)$$

where S is the area of the surface of the coating, σ_0 is the Stefan-Boltzmann constant.

The ε emissivity will be determined using the Fluke IR thermometer. This is equipped with a thermocouple etalon: when the temperature obtained using the IR bolometer and a set ε value is equal to that measured by the thermocouple, we can accept that ε value as the real emissivity of the coating (we suppose that it behaves as a "gray" body).

Having this ε , from (3) we obtain the value of α too (this will be a value for still air).

3. HEATING THE OUTER FACE

To estimate the effect of reversing the cooler and warmer sides we must build an electric furnace. This will have a cylindrical shape with an internal diameter about 150 mm. We will place the tube coated with intumescent paint in its axis.

The electric heating will provide a certain constant temperature, T_a , but because the heat losses through the walls the Φ flux won't be equal to the electric power. This flux can be determined by cooling the tube with air: if the mass flow of the air inside the tube is q_m , the temperatures at the entry and leaving cross sections are T_1 and T_2 , respectively, then the heat flux will be

$$\Phi = q_m \cdot c_p \cdot (T_2 - T_1), \quad (4)$$

where c_p is the isobaric specific heat capacity of the air. This determination needs the two temperatures and the mass flow.

With T_a , α and ε , from (3) we can compute the T_o temperature. We can try to measure it directly, using some thermocouples, but because of the fluid surface and high temperatures of the furnace this seems to be difficult.

The T_i temperature will be measured also with thermocouples, inside of the tube.

Having these values, from (2) we obtain λ . Because these determinations are rather difficult, we will use the obtained values only to estimate the effect of reversing the cooler and warmer sides.

4. CONCLUSIONS

The proposed methods have the advantages of the simple laboratory apparatus of determining the parameters of the intumescent coatings.

The obtained experimental values will be used in finite element modelling, which offers a general way to analyze structures protected by intumescent coatings against fire.

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