RESEARCH ON THE CLADDING SYSTEMS OF THE BUILDINGS FROM THE PERSPECTIVE OF THE FIRE REACTION OF COMPONENT MATERIALS

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ABSTRACT

During a fire in a building, the fire contribution is influenced by the parameters that influence the initial fire condition and, after ignition, the uncontrolled fire evolution. Specialists assess the fire behavior of the building using a set of hypotheses and conditions of the fire scenario. Due to the fact that the initiation and evolution of the fires is different, it is necessary to determine the fire behavior of the constructions and of the materials they are made of, under specified conditions, by exposure to a specified firing ignition source into a precise context. Researchers from NIRD URBAN-INCERC, INCERC Bucharest Branch, have conducted lately several experimental tests on the fire behavior of building façades made of ETICS-type thermal insulation systems. They have determined the mechanisms of initiation and propagation of flame on the building façade under natural ventilation conditions and the behavior of ETICS systems depending of different fire scenarios.

Keywords: cladding systems; fire reaction; building fire; external fire; fire materials

REZUMAT

În timpul unui incendiu al unei clădiri, contribuția la foc este influențată de parametrii care influențează starea inițială de incendiu și, după aprindere, evoluția necontrolată a focului. Specialiștii estimează comportamentul la foc al clădirii folosind un set de ipoteze și scenarii de incendiu. Datorită faptului că inițierea și evoluția incendiilor este diferită, este necesar să se determine comportamentul la foc al construcțiilor și al materialelor din care sunt confecționate, în condiții specificate, prin expunerea la o sursă de aprindere specificată într-un context precis. Cercetătorii de la INCD URBAN-INCERC, Sucursala INCERC București, au efectuat în ultima perioadă mai multe teste experimentale privind comportamentul la foc al fațadelor clădirii realizate din sisteme de izolare termică tip ETICS. Ei au determinat mecanismele de inițiere și propagare a flăcării pe fațada clădirii în condiții de ventilație naturală și comportamentul sistemelor ETICS în funcție de diferite scenarii de incendiu.

Cuvinte cheie: fațade; reacție la foc; incendiu; foc exterior; materiale combustibile

1. CONTEXT

The large-scale use of the outer cladding systems of buildings with polystyrene thermal insulation (ETICS) for the thermal rehabilitation of existing buildings and the construction of new ones requires knowledge of the fire behavior for these thermal insulation systems as a whole and from the point of view of the materials they are made of. This study aims to present the reaction behavior of ETICS systems and the materials these systems are made of.

During a fire, the fire contribution is influenced by the initial fire condition and by the uncontrolled fire evolution, estimating the behavior requiring a set of hypotheses and conditions of the fire scenario (Drysdale, 1998). Due to the fact that the initiation and evolution of the fires is different, it is necessary to determine the fire behavior of the constructions and of the materials they are made of, under specified conditions, by exposure to a specified firing ignition source in a precise context.

In Romania, cladding systems are tested only for the fire reaction because natural scale tests are not regulated and accepted to prove the possibility of using new thermal rehabilitation systems with different construction solutions of incombustible barriers and framed thermal insulation in a fire reaction class lower than that required by regulations.

The rapidly increasing utilization of advanced lightweight materials, including light alloys, polymers, and fiber-reinforced composites that are highly flammable (Xin and Khan, 2007) poses significant fire risks, impacting people, environment, and the economy. They can be often found in exterior cladding systems, otherwise known as exterior insulation finishing systems (EIFS) or external thermal insulation composite systems (ETICS). These systems are designed to be cost effective solutions for thermal insulation, weather resistance, and aesthetic exterior wall finishes. The most basic exterior for a cladding system consists of an insulation layer, often a polymer such as polystyrene (EPS), polyisocyanurate (PIR) or polyurethane (PU) and a surface finish layer that can be a surface coating or a sandwich panel (such as an aluminium composite panel, ACP).

The fire behaviour of a building façade is dependent on the overall system performance, rather than on the performance of the individual components. A façade system includes the cladding and the insulant characteristics, but also the cavities, cavity barriers, mounting and fixings, substrate, and any singularities, such as window frames (Lalu et al, 2016).

This paper aims to evaluate the materials that can be used in cladding systems.

2. MATERIALS AND METHODS

Researchers from NIRD URBAN-INCERC, INCERC Bucharest Branch, have conducted lately several experimental tests on the fire behavior of building façades made of ETICS-type thermal insulation systems to determine the mechanisms of initiation and propagation of flame on the façade height under natural ventilation conditions, and of the behavior of ETICS systems under different fire scenarios.

The different components of the façade system were certified to have passed regulatory tests for fire safety, although it is arguable whether the refurbished façade system was actually compliant.

In addition to rapid fire spread, large volumes of smoke can be produced. Smoke inhalation is known to be the largest cause of death and the largest cause of injury from fire. In most cases the smoke from the burning façade appears to have entered the building before the contents of each apartment ignited, so the smoke toxicity of the façade is an important factor in the tragedy. On exposure to smoke, the victims become incapacitated (unconscious) and, unless they are rescued, death is likely to follow. Incapacitation and lethality may be estimated for 50% of an exposed population in terms of a fractional effective dose (FED), following ISO 13571 (incapacitation) or ISO 13344 (lethality). When the FED equals 1, the equations predict that half of the exposed population would be incapacitated or killed. Fire safety engineers may use a precautionary factor of 10 (i.e. FED < 0.1) to ensure the life safety of occupants in the event of fire.

Fire toxicity is a function of both material and fire condition (Hao and Wei, 2017). It has been shown that the yield of major asphyxiants, hydrogen cyanide (HCN) and carbon monoxide (CO), increases by a factor of 5 to 20 as the fire grows from well-ventilated to under-ventilated. The ventilation condition of burning polyethene (PE), pouring out of the aluminium composite material (ACM) screens is uncertain, while the insulation foams behind the ACM will have undergone the more toxic under-ventilated burning. There is an increasing danger of smoke toxicity because of the release of HCN from rigid and flexible urethane foams. It has been shown that, when PIR foam burns, it generates HCN and CO in dangerous quantities. The refurbishment of tall concrete buildings often involves covering the exterior with a rainscreen façade system, consisting of an outer-screen, a cavity and an inner layer of insulation. The outer-screen may be aluminium composite material (ACM), high-pressure laminate (HPL), or mineral fibre board. ACM consists of two thin sheets of aluminium sandwiching a layer of polymer (usually PE), PE filled with metal hydroxide fire retardant (FR), or predominantly noncombustible (NC), as inorganic composite or metallic filling. FR panels contain around 65% aluminium hydroxide or magnesium hydroxide, having a fire retarding effect through endothermic dehydration and the subsequent release of water, to suppress flaming.

In this study, various outer-screens, and the certified insulation foams, were tested alongside other phenolic and PIR foams and two non-combustible insulation boards, of glass wool (GW) and stone wool (SW).

The aim of this paper was to assess the fire safety of combinations of typical rainscreen façade products using micro-scale decomposition and bench-scale fire behaviour and toxic product evolution. The results are related to the large-scale tests, on more than 8 m rainscreen façade systems (Simion et al., 2018).

Three different ACM panels used as cladding were tested. References of the products are as follows:

•Alpolic-limited-combustibility cladding;

•Alpolic-reduced-combustibility cladding;

•Reynobond PE standard cladding with polyethylene core.

Three different insulants were used in combination with each of the cladding types for the test combinations, as follows:

• Kingspan K15 phenolic foam;

• Celotex RS PIR;

• Mineral wool.

The thickness of the insulant was 50-100 mm.

All samples were tested at an applied heat flux of 50 kW m^{-2}, following ISO 5660. However, the results have been re-scaled so they are presented in kW/m^2. ACM products were tested complete with the aluminium sheets. The insulation materials were tested as blocks of 20×100×100mm^3, cut from the larger boards, without the external aluminium foil facing. All samples were tested without the upper retaining frame. Where foam samples showed significant distortion, they were held in place using a wire grill specified in ISO 5660.

The smoke toxicity of the insulation materials was determined using the steady state tube furnace (SSTF), following ISO TS 19700 under the three flaming fire conditions described in ISO 19706: well ventilated, small under-ventilated, and large under-ventilated. The emission rate of carbon dioxide was calculated from the gas concentration in the duct and flow rate. The contribution of the burner (Babrauskas and Parker, 1987) for carbon dioxide was removed in the table thereafter, considering stoichiometric combustion of propane and a flame of 100 kW, as per ISO 1970332 formulas.

3. RESULTS AND DISCUSSIONS

Roughly, the tests involving ACM show close patterns, with limited degradation sometimes visible inside the cavity but limited by the fire barrier. The charring depth is similar for the 3 insulants, with traces of combustion at approximately 10 mm depth.

This means that combustion occurred so quickly at the surface of the material, that the insulants contributed little to the combustion, and this contribution probably stopped after the destruction of the cladding.

The heat release rate (HRR) in cone calorimetry (Table 1) shows notable differences in the combustibility of the different panels. All of the panel materials ignited in the cone calorimeter, although this only appeared to involve the paint finish for ACM_NC1 and NC2 and MWB_1 and MWB_2. High, sharp peaks of heat release rate were observed for ACM_PE1 and ACM_PE2, reaching a maximum of 1300 and 1050 kW/m^2. ACM_PE1 and ACM_FR1, both from the same manufacturer, showed a notably earlier time to ignition than their competitor panels. Given this similarity of the TGA curves for these fillings, this suggests a thicker or more easily ignited paint layer, or a difference in absorptivity of radiant heat after the paint layers were burnt off. Almost no residue remained between the aluminium plates after the test for PE1 and PE2. The ACM_FRs underwent sustained flaming, but with a significantly lower HRR. It is clear that the combination of the protective aluminium sheets, and the metal hydroxide fire retardant at around 75% loading effectively reduces the flammability under these conditions. The $Al(OH)_3$ of ACM_FR2 is notably less effective than the $Mg(OH)_2$ of ACM_FR1 and ACM_FR3.

All the insulation foams show very rapid ignition and early peak HRR. However, the highest peaks are an order of magnitude less than those of the ACM_PE. Figure 1 shows clear differences between the burning behaviour of PIR and phenolic foams.

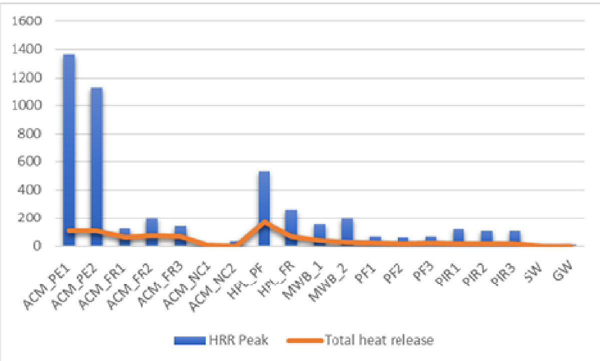

Fig. 1. Calculated HRR Peak and the Total heat release

Each insulation product was burnt under three fire conditions, representing well-ventilated, small under-ventilated and large under-ventilated. For smoke, only insulation products were investigated. The smoke toxicity of ACM fillings and the yield data for insulation is discussed further.

The HCN yields for phenolic foam are low, corresponding to their low nitrogen content, but increase with under-ventilation. The HCN yields for the PIR are significantly larger and increase by a factor of 2 to 4 in the transition from well-ventilated to under-ventilated.

The PIR shows a higher initial peak HRR and lower steady burning rate, after formation of a protective char layer; the phenolic foams show a lower initial peak HRR but a higher steady burning rate. This shows a slightly lower first peak HRR, but surprisingly, an enhanced second peak. A summary table of the parameters measured by cone calorimetry is presented below.

Table 1. *Measurements on cone calorimeter*

Material	Peak	Total heat
ACM_PE1	1364	106
ACM_PE2	1123	107
ACM_FR1	123	62
ACM_FR2	195	71
ACM_FR3	144	66
ACM_NC1	14	3
ACM_NC2	30	1
HPL_PF	530	172
HPL_FR	263	67
MWB_1	150	38
MWB_2	194	28
PF1	64	19
PF2	62	18
PF3	65	20
PIR1	116	16
PIR2	107	14
PIR3	108	15
SW	6	0,07
GW	9	0,8
ACM_PE1	1364	106

The mineral wool insulation did not ignite, so its non-flaming combustion cannot be compared directly to the flaming combustion of the foams. However, they were tested under the three conditions used here for the combustible materials for completeness. The yields are all very low, as may be expected, and correspond to a small amount of binder, as seen in TGA and MCC. As expected, the mass-loss fell with decreasing oxygen concentration, but surprisingly, the CO and HCN yields also fell, while the hydrocarbon yields increased, showing that flaming combustion was not the predominant gas phase process.

During a fire, the separation elements of the compartment can accelerate or slow down the fire rate depending on their thermal insulation. In materials such as concrete and bricks, due to the high temperature, the conductivity quickly dissipates the heat from the room to the structural elements, thus reducing the room temperature leading to a slower growth of fire.

The insulating materials (mineral wool, polystyrene) have a relatively low thermal inertia (heat accumulated), as opposed to the previous ones, which causes the accumulation of heat in the room, the increase of the temperature and the rapid evolution of the fire.

4. CONCLUSIONS

Tests performed are discriminant between solutions. They highlight that, for tested compositions, the cladding is the most important parameter driving global fire behaviour. ACM-PE-based cladding systems gave very different results from the other solutions tested. This was especially visible in heat release rates, where fire intensity was very high, whatever the insulant used in the system. The contribution of the insulant was only remarkable in these tests during the decay phase. The cavity barrier was largely ineffectual in the 3 tests with ACM-PE cladding, as the integrity of the cavity was not ensured.

Additional gas analyses highlighted a very well-ventilated condition of combustion with the ACM-PE-based cladding compositions, probably enforced by the test setup and entrainment inside the cavity. Carbon monoxide release was low in proportion. Hydrocarbon release was remarkable, but no other species was detected within the limits of detection achievable in this setup.

For the solutions with ACM-FR and ACM-A2 claddings, the results for all of the insulants trended in a similar manner in these test conditions, especially when compared with the performance of ACMPE-based compositions.

In these tests and tested compositions, the cladding was the governing part of the constructive system, and the contribution of insulants remained low in terms of energy or gases evolved. This confirms reaction tests according to BS 8414-1 and supplements the results with gases evolved and heat released from the beginning to 30 minutes without external action such extinction. These tests highlight also, that the reaction tests might have developed much more higher with the ACM-PE cladding, if they had not been extinguished. For such constructive systems, use of intermediate-scale tests is a very powerful tool to complete any reference real-scale test, for example in the case of extended applications.

Unfortunately, intermediate scale tests as well as the reference BS8414-1 test do not cover all the details of a façade constructive system and single points, such as window frames, could have an important effect. Their effects on fire behaviour of the façade require further evaluation.

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