A numerical model for the simulation of the vertical UL 94 test

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Introduction:

Polymeric materials, in particular thermoplastics, tend to melt and drip at elevated temperatures. In fire situations, these effects can lead to higher burning rates or, on the contrary, remove the fuel and heat from the fire source. Predicting the fire behavior of these materials is usually done via a set of standardized experiments. The most important is the so-called "vertical UL 94 test" [1](Fig. 1). On the other hand, the numerical simulation could provide an important alternative to this costly experiment when testing new materials.

Figure 1: UL 94 test

However, computer modeling and simulation of thermoplastics in fire is extremely complex. The phenomena involved include fluid flow, heat transfer and material degradation among others. In addition, the drastic changes in shape pose a severe challenge to traditional modeling methods. There exists, by now, no established methodology for simulation of this complex problem.

Objective:

To develop a new computational procedure for the modelling of fire behavior of polymers in the vertical UL 94 scenario.

PFEM:

For modeling the polymer flow, the PFEM [2] is chosen. The PFEM is a numerical method that uses a Finite Element mesh to discretize the physical domain and to integrate the differential governing equations. According to their density, acceleration and velocity, and subject to the force of gravity, the mesh nodes can move freely and even separate from the main analysis domain. A robust and efficient remeshing algorithm connects the nodes into a finite element mesh for solution of the state variables in the new configuration. An overview of the algorithm is given in [3].

The way the PFEM solution process operates, for the problems we are solving here, is schematically shown in Fig. 2.

A typical solution with the PFEM involves the following steps:

The starting point at each time step is the cloud of points defining the polymer domain(Fig.2a).

1.Identify the boundaries (Fig.2b) .

2.Discretize the analysis domain (Fig.2c).

3.Solve the Lagrangian equations

4.Move the mesh nodes to a new position(Fig.2d),

5.Go back to step for the next time step.

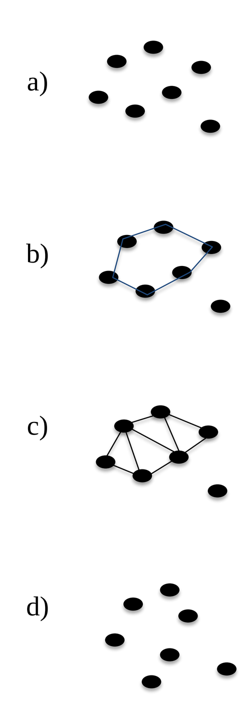

Figure 2: PFEM strategy

Governing equations:

The equations that govern the behaviour of the polymers are the following:

Mass eq.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \left(\rho \mathrm{v} \right) = 0$$

Momentum eq.

$$\frac{\partial \rho \mathrm{v}}{\partial t} + \nabla \cdot \left(\rho \mathrm{v} \mathrm{v} \right) = \nabla \cdot \sigma + \rho \mathrm{v}$$

Temperature eq.

$$\frac{\partial \rho C T}{\partial t} + \nabla \cdot \left(\rho C \mathrm{v} T \right) = \nabla \cdot \left(\kappa \nabla T \right) + Q$$

where v is the velocity, ρ is the density, σ is the Cauchy stress tensor, *C* is the heat capacit, κ is the thermal conductivity, T is the temperature and Q the heat source per unit volume.

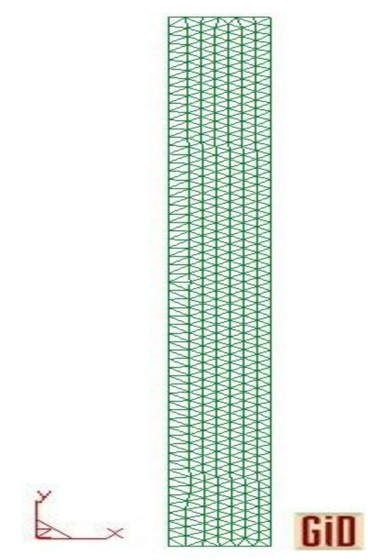

Figure 3:Geometry

Model Setup:

The UL 94 setup is represented by a rectangular sample (125x13x1,5 mm) positioned in the vertical direction and exposed to an external heat flux (Fig. 3). Temperature-dependent material properties such as density, conductivity and vistosity among others were obtained from [4]. Flame produced by a Bunsen burner was estimated according to [5]. Additionally, the heat originating from the polymer combustion and the heat feedback from the flame was considered constant following [4]. Thermal decomposition effects is based on single step first order Arrhenius law.

Results:

The procedure presented above is used to simulate the interaction of the dripping behaviour and gassification of the materials in the UL 94 scenario.

**** Dripping***

Figure 4 shows images of the PFEM simulating PC/ABS+BDP [4]. The images show that the viscosity functions applied enable PFEM to reproduce the basic dripping behaviour of the material. The sub-model for thermal decomposition was turned off in order to assess the influence of the viscosity individually. The mass loss curve is shown in Fig.5.

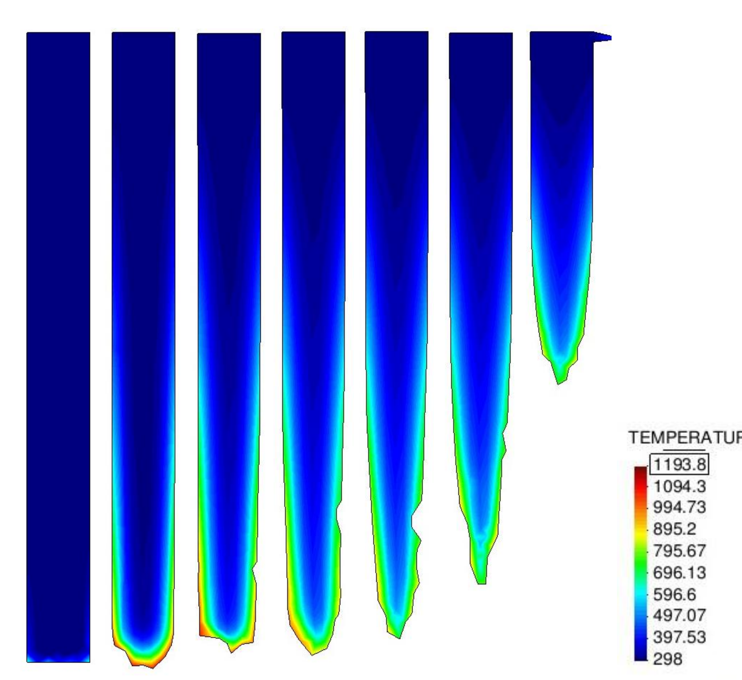

Figure 4: Images of PFEM 2D for PC/ABS+PTFE.

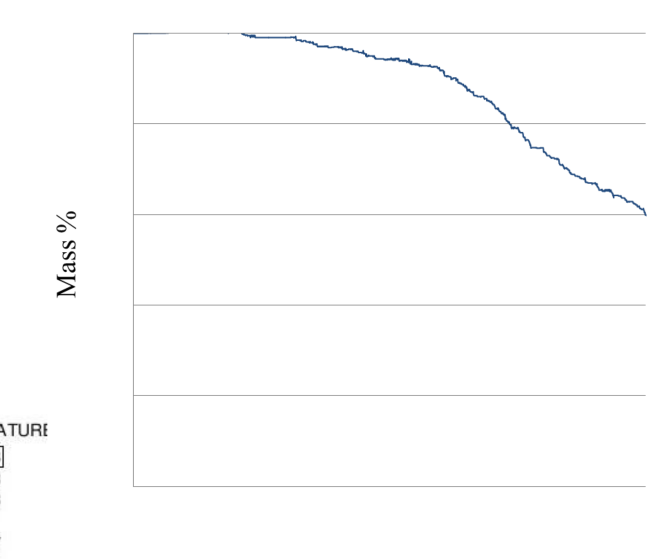

Figure 5:Mass

* ***Dripping and Gasification***

Figure 6 shows PFEM simulations of PC/ABS+PTFE taken every 10 seconds. The effect of gasification is displayed in Fig 6b. This consumes both mass and energy when the material is heated up.

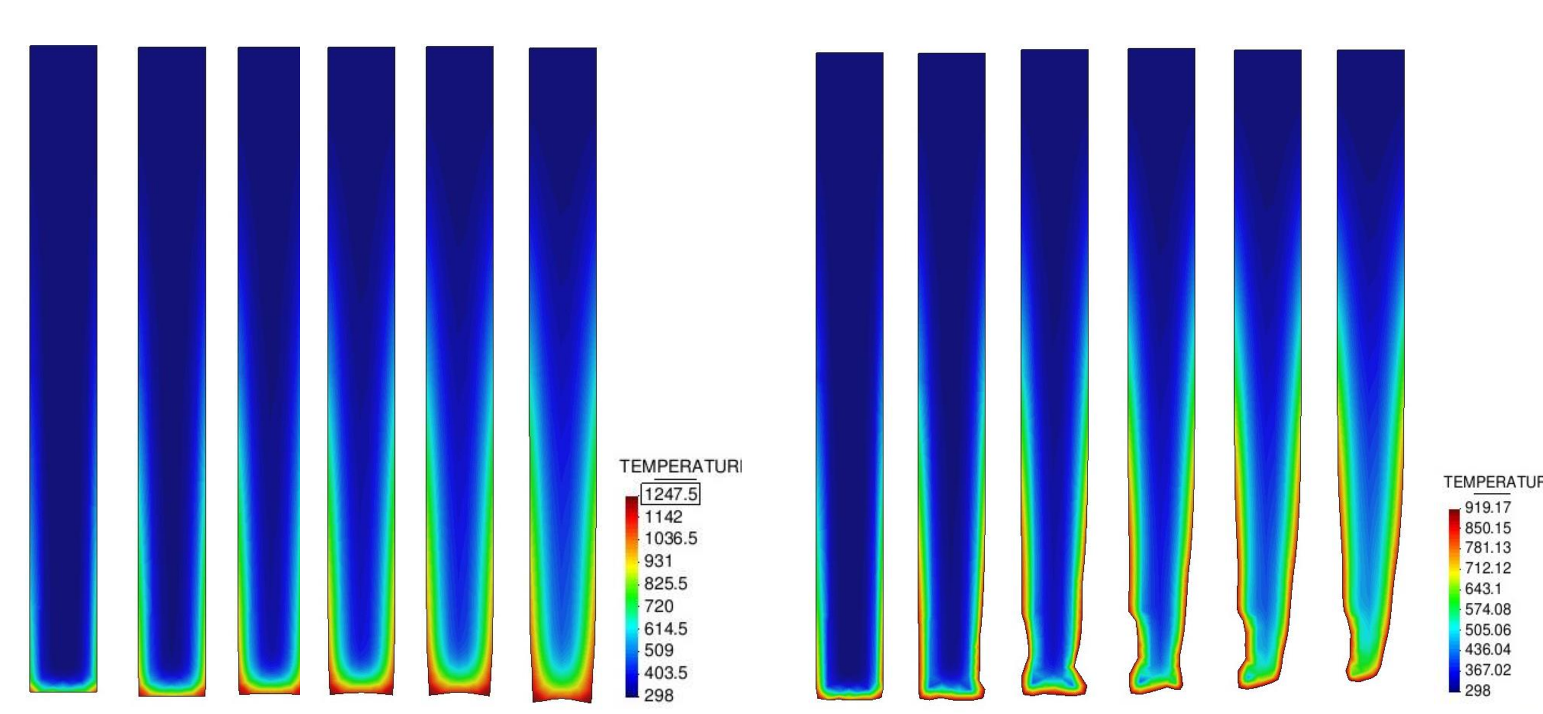

Figure 6: Images of PFEM 2D for PC/ABS+PTFE.

Conclusions

The numerical results show that PFEM can be successfully applied to modelling numerically the complex behaviour of polymers in the UL 94 test including the essential aspects of dripping and gasification in a qualitative as well as quantitative manner already. Nevertheless, consideration of the heat input due to the combustion and radiation is needed for the further improvement of the modelling[4].

References

[1] IEC 60695-11-10. Fire hazard testing - part 11–10: test flames - 50W horizontal and vertical flame test methods, 1999.

[2] PFEM, http://www.cimne.com/pfem/

[3] Oñate E, Idelsohn SR, Del Pin F, Aubry R. The particle finite element method. An overview. International Journal of Computational Methods 2004; **1**:267–307.

[4] F. Kempel et al., Modelling the vertical UL 94 test: competition and collaboration between melt dripping, gasification and combustión, Fire and Materials, 2014, doi 10.1002/fam.2257.

[5]Hamins A., Bundy M., Dillon SE. Characterization of candle flames. Journa of Fire Protection Engineering 2005;15:265-285