Thermal Degradation Modeling of a Composite Material

A. RICCIO*, M. DAMIANO*, M. ZARRELLI**, M. GIORDANO** and F. SCARAMUZZINO*

Keywords: modeling, fire behavior, thermal degradation, FEM

ABSTRACT

The thermal degradation issue, from the wood pyrolysis studies by Bamford et al. in [1] and Kung in [2], to the analysis of ablator materials for space applications performed in [3], has been seriously investigated since many years ago. However, in the last 30 years the development of numerical models for the simulation of the thermal degradation has become massive due to the use of modern experimental devices providing novel experimental data for validation purposes. An example is given by the numerical one-dimensional heat transfer models based on the non-linear partial differential equation (PDE) of energy conservation, introduced in [1-7].

In this paper, the fire behavior of E-glass vinyl ester is investigated by analyzing the thermal degradation that take place within this composite material during exposure to an heating source at high incident power. A numerical model, based on the one proposed by Henderson et al. [4] is developed and implemented in two commercial software: COMSOL, which allows to use a PDE interface and ANSYS which allows to implement an user defined physics by writing scripts in Ansys Design Parametric language (APDL).

The numerical simulations' results obtained in the COMSOL and ANSYS environments, on a composite sample have been compared with literature experimental data in terms of the mass loss rate (MLR) (see figure 1) and temperature profiles over the sample thickness [5]. As it can be deduced by figure 1, it is worth noting that the differences in the implementation lead to different results: the first model solves the equations simultaneously, while the second one is interrupted at each time step for the parameters evaluation.

---

*Department of Industrial and Information Engineering, Second University of Naples, Aversa, ITA

**IMCB-Institute of Composite and Biomedical Materials, CNR-National Research Council, Portici, ITA

e-mail: aniello.riccio@unina2.it

In order to evaluate fire behavior from the MLR [7], the effective heat of combustion is needed [8].The definition of the non-linear thermal properties of a woven fabric E-glass vinyl ester is needed to assess the fire performance of this composite material. In this study the thermal properties are evaluated taking into account the degree of decomposition function while the approach to describe the density variation with time uses an Arrhenius *n-th* order kinetic rate equation.

The real boundary conditions of the experimental setup have been reproduced by applying a thermal flux (including the external flux of the heater, the convective and radiative exchange through the environment) to the heated surface and placing a ceramic plate under the specimen.

In the ANSYS platform, the mathematical model for the thermal energy conservation is solved with an implicit numerical scheme. In order to calculate the heat generation due to convective heat flux of the pyrolysis gases, the mass loss at each load step is considered.

All the numerical predictions show a good agreement with experimental data present in literature, for both the implemented model, being the ANSYS implementation more cost-effective and accurate. The implementation into a commercial finite element code give access to many future applications on geometrically complex structures where the fire behavior is of main concern.

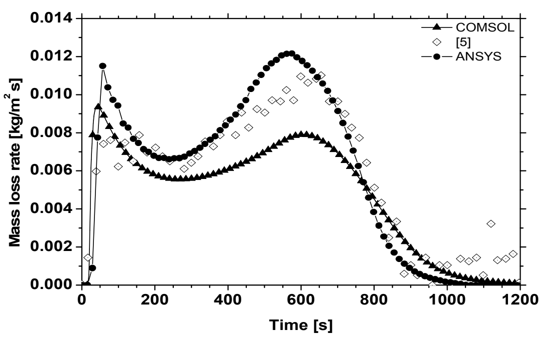

Fig. 1 Model prediction versus experimental data for the MLR at 60 kW/m^2.

REFERENCES

[1] Bamford, C. H., Crank, D.H. and Malan, J., 1946. The combustion of wood. Part1. Cambridge Philosophical Society Proceedings Biological Sciences, 42, pp 166–182.

[2] Kung, H.C., 1972. A mathematical model of wood pyrolysis. Combustion and flame, 18 (2), pp 185–195.

[3] Munson, T. R., Mascola, R. E., Brown, J. D., Spindler R. J. and Klugerman, J., 1962. An advanced analytical program for charring ablators. Volume 1: Analytical formulation, data interpretation and flight simulation. NASA.

[4] Henderson, J.B., Wiebelt, J.A. and Tant, M.R., 1985. A model for the thermal response of polymer composite materials with experimental verification. Journal of composite materials, 19, pp 579–595.

[5] Lattimer, B. Y., Ouellette, J. and Trelles, J., 2011. Thermal response of composite materials to elevated temperatures". Fire Technology, 47, pp 823-850.

[6] Florio, J. Jr., Henderson, J.B., Test, F.L. and Hartharan, R., 1991. A study of the effects of the assumption of local-thermal equilibrium on the overall thermally-induced response of a decomposing, glass-filled polymer composite. Int. J. Heat and Mass Transfer, 34, pp 135–147.
[7] Mouritz, A.P. and Gibson, A.G., 2006. Fire properties of polymer composite. Springer, 2006.
[8] Lattimer, B.Y., Hunt, S.P., Wright, M. and Sorathia, U., 2003. Modeling fire growth in a combustible corner. Fire Safety Journal, 38, pp 771–796.