Amirkabir University of Technology
(Tehran Polytechnic)
Vol. 47, No. 1, Summer 2015, pp. 33- 36

Amirkabir Journal of Science & Research (Mechanical Engineering)
(AJSR - ME)

Theoretical and Experimental Analysis of Asbestos Phenolic Ablative Insulation

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(Received 21 March, 2013, Accepted 4 January, 2015)

ABSTRACT

One of the major challenges in high-speed flights is aerodynamic heating. This is why thermal protection system (TPS) is being used. One of the main components of TPS is ablative insulation. In present study, one-dimensional theoretical and experimental analysis of ablative insulations have been done. Phenolic resins with maximum thermal destruction efficiency are being used in charring ablative insulations. When an ablative insulation is exposed to heat flux, its surface gets warmer and as the destruction begins, it produced gases to go out and do cooling. Governing equations of these phenomena have been discretized by the finite difference method and have been solved transient and implicitly. Thermophysical properties have been evaluated by nominal curves and Pyrolysis constants have been obtained by / through the thermochemical reactions. Validation of numerical solution has been done by oxy-acetylene test. By increasing the time, the difference between numerical and experimental results increases. One reason for difference between results could be 1D-modeling, where all of the actual 3D energy is accumulated in one dimension in the numerical solution. Nonetheless, there is good agreement between numerical and experimental results and the average of absolute errors is 7.54%.

KEYWORDS

Thermal Protection System, Pyrolysis, Ablation, Oxyacetylene Test, Phenolic Asbestos, Finite Difference Method.

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1-INTRODUCTION

One of the major challenges in flying vehicles is friction of their outer skin with air that leads to high temperatures in hypersonic speeds. This phenomenon, which is called aerodynamic heating, can cause damages in internal structure and electronic systems of the vehicle. This is why the thermal protection system is used in such vehicles. Some types of these insulations are charring. The most important phenomena in these insulations are *ablation* and *pyrolysis*. The schematic of these phenomena has been shown in figure 1.

In present research ablation phenomenon and recession process are modeled by surface chemical reaction theory and thermophysical properties has been considered to be temperature dependent which add complexity of the problem but accuracy of the results increases compared to the other researches [1-7].

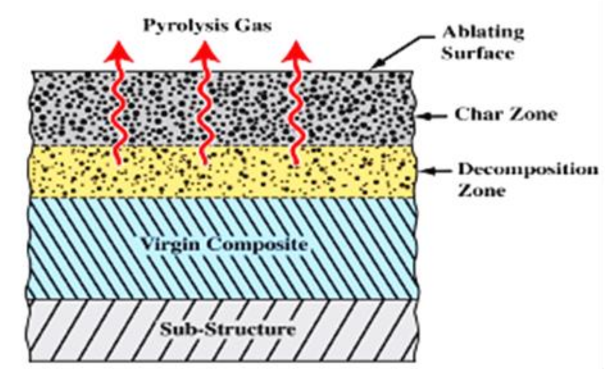


Figure 1- Schematic of pyrolysis phenomena [8]

2- METHODOLOGY

Governing equations of ablative insulation, which is based on energy balance, are shown in eq.1;

$$\left(\rho c+\Delta\hat{H}_P\frac{\mathrm{d}\rho}{\mathrm{d}T}\right)\frac{\partial T}{\partial t}$$

$$+\left[c_{pg}G+v_\infty\left(\rho c+\Delta\hat{H}_P\frac{\mathrm{d}\rho}{\mathrm{d}T}\right)\right]\frac{\partial T}{\partial x}=\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right) \quad (1)$$

Boundary conditions in both exposed surface and internal surface are shown in eq's 2-3;

$$q_\lambda=-\lambda\frac{\partial T}{\partial x}\bigg|_{x=S(t)}$$

$$=\underbrace{\left(\frac{\alpha}{c_p}\right)\left(I_e-I_w\right)}_{q_{hw}}-\varepsilon\sigma T^4+q_{reac}-\underbrace{\gamma G\left(I_e-I_w\right)}_{q_{blowing}} \quad (2)$$

$$q_\lambda=-\lambda\frac{\partial T}{\partial x}\bigg|_{x=0}=0 \quad (3)$$

Solving the equations above has been done by the finite difference code (FORTRAN), but before the solution procedure, all of the parameters in equations 1-3 should be evaluated. These parameters include ; thermal conduction coefficient (λ), specific heat of gas (C_{pg}), heat of pyrolysis (ΔH_P), mass flow rate of gas (G), change of density respect to temperature ($d\rho/dT$), recession rate of surface (v_∞), I_e and I_w which are enthalpy of gas in hot gas and wall temperatures. Some of these parameters are obtained by / through the experimental tests and some of the them have been calculated by empirical and semi-empirical relations.

The experimental part of study includes oxyacetylene test which is applied on 6mm thick asbestos-phenolic insulations. Coldwall heat flux of flame measured is equal to 8000 kW/m^2. Oxyacetylene test environment is the result of burning of acetylene with oxygen. Using the chemical reaction, one can calculate molecular mass and heat capacity of products.

$$C_2H_2+\frac{3}{2}O_2\xrightarrow{\Delta}2CO+H_2O \quad (4)$$

Through the thickness of insulations samples, in 2mm intervals K-type thermocouples have been located for the temperature measurement. In figure 2, the schematic of test setup has been shown. The test was conducted according to ASTM standard, E285-80 [9].

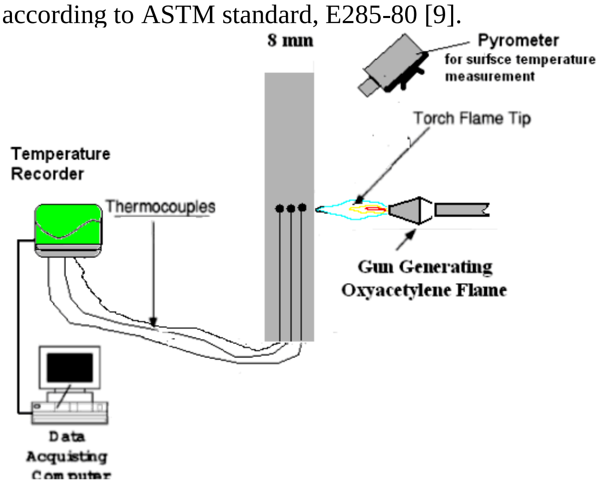
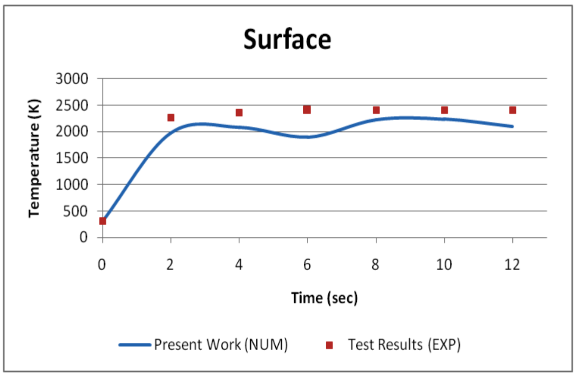


Figure 2- Schematic of test setup

3-SIMULATION RESULTS

In first step, the mesh independency has been checked by 5 numbers of total grid nodes which are shown in figure 3;



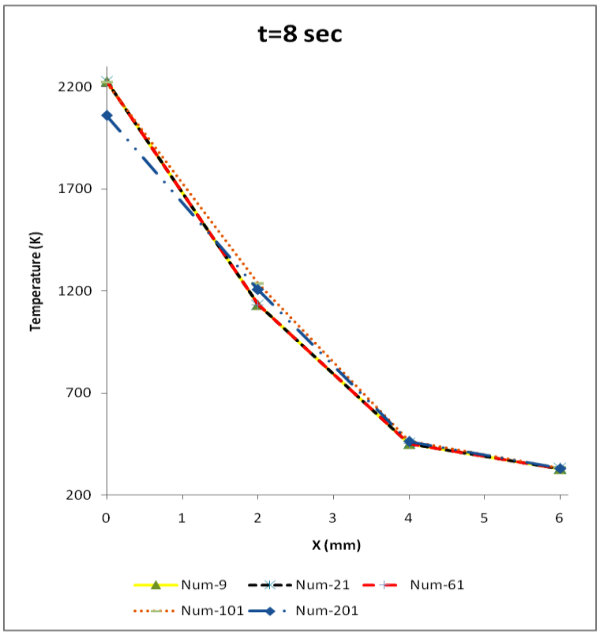
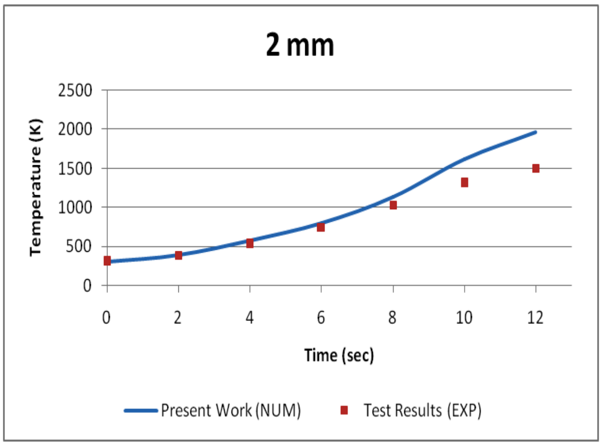
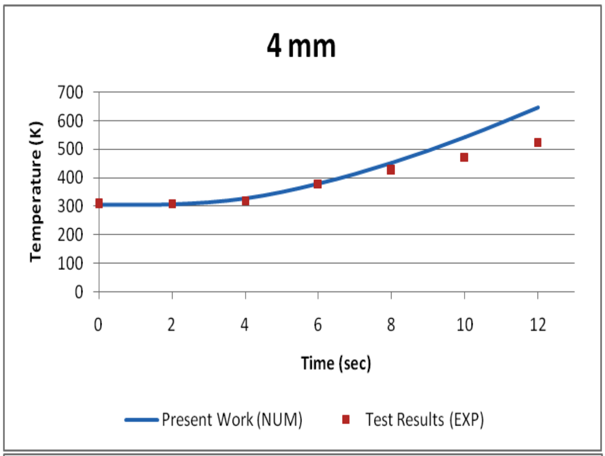


Figure 3-Mesh independency diagram

The temperature distribution along with the insulation thickness have been obtained through both experimental data and numerical solution results which are shown in figure 4;





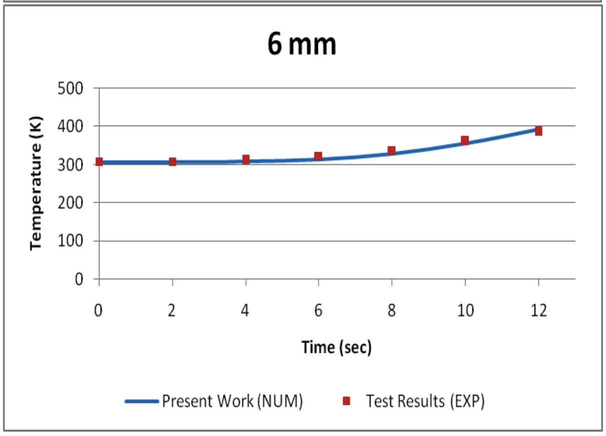


Figure 4: Temperature distribution at thermocouple locations

4-CONCLUSION

Current study is a combination of theoretical research, numerical challenges and experimental works. Modeling pyrolysis and ablation in charring materials is followed by many complexities. In this research, asbestos phenolic is chosen as a rare charring material where its properties are not available easily in the published articles. The thermophysical properties have been considered to be temperature dependant. New algorithm for node destruction is also introduced and together with the finite difference discretization lead to a good accuracy of modeling with an average of 7.54% in errors.

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