Experiments and analysis of fire spread for PVC

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In this study, fire spread phenomenon of polyvinyl chloride (PVC), which is the most easily accessible among general purpose plastics, is analyzed by numerical analysis and compared with experimental results. Two models for solid pyrolysis[1] are adopted used to simulate the pyrolysis of solid materials. The first is a simple pyrolysis model in which a given heat release rate (HRR) occurs when the material reaches the ignition temperature. The second is a complex pyrolysis model that estimates pyrolysis rate using an Arrhenius type temperature function. The thermal properties are the density, the thermal conductivity coefficient, and the specific heat, which are commonly used to analyze flame spread phenomena using two pyrolysis models.

In order to use the simple pyrolysis model, we obtained the ignition temperature, and HRR over time at various heat fluxes (35, 50 kW/m^2) using cone calorimeter test (ISO 5660-1[2]). Ignition temperature is calculated by using ignition times for the various incident heat fluxes of cone heater(5 times). We can have a graph with x-axis of incident heat flux and y-axis of ignition time to power of (-n) using data. Here x-intercept of the interpolated straight line in the graph becomes the critical heat flux. Ignition temperature, T_{ig} is calculated by followed Eq.(1).

$$\varepsilon q_{cr} = h_c(T_{ig} - T_\infty) + \varepsilon\sigma({T_{ig}}^4 - T_\infty) \qquad (1)$$

Where q_{cr}, ε, h_c, σ, T_∞ are the critical heat flux, surface heat release rate, convective heat transfer coefficient, stefan-boltzmann constant and ambient temperature, respectively[3].

In the complex pyrolysis model, the pre-exponential factor and the activation energy are required, which are measured using pyrolysis combustion flow calorimeter (PCFC). HRR for times are measured as shown in Fig.1 at a heating rate of 0.8K/s, 1.6K/s, and 2.3K/s by PCFC. The parameters of kinetics of pyrolysis as pre-exponential and the activation energy are calculated by applying the kissinger method[4] using the temperatures, $T_{max,1}$, $T_{max,2}$ at the maximum HRRs. For thermal properties the specific measurement systems are used. differential scanning calorimeter (NETZSCH, DSC214) is used for the specific heat, and the thermal conductivity measuring device (EKO, HC-074) is used for the thermal conductivity coefficient, respectively. The input data for both simple and complex pyrolysis models are summarized in Table 1. The thermal properties after pyrolysis are optimized by repulsive particle swarm method with cone calorimeter tests[5].

The thickness of the specimen considered is 10mm and the mean value of the heat of combustion obtained by using PCFC is 11.9kJ/g. In order to evaluate the accuracy and usability of the data for two different pyrolysis model of PVC, the results obtained by numerical analysis with the data for two pyrolysis model are compared with the measured results for the specimen of PVC in the cone calorimeterand spread of flame tester(ISO 5658-2)[6] in Fig.2.

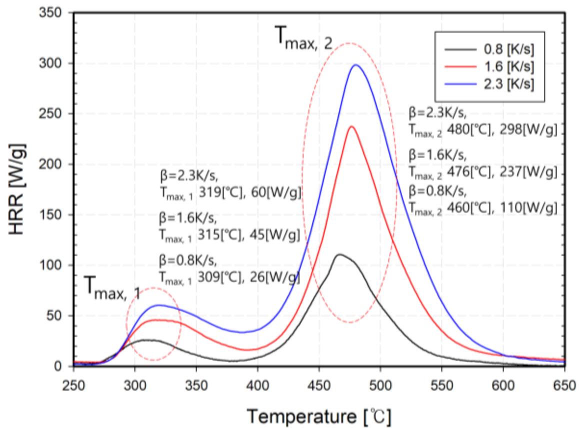


Fig.1 PCFC results of PVC

Table 1 Input data of pyrolysis model

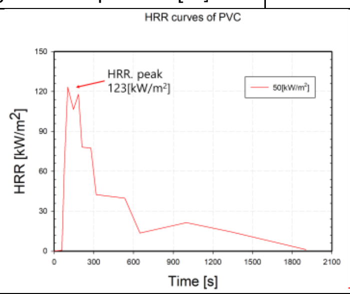
model	input data	value
simple pyrolysis	ignition temperature[℃]	468.6
		
complex pyrolysis	pre-exponential, A [1/s]	1.35.E+14
	activation energy, E [kJ/kmol]	2.19.E+05
thermal properties	specific heat [kJ/kgK]	0.84
	conductivity [W/mK]	0.19
	density [kg/m^3]	1449

Fig.2 Reaction to fire test-spread of flame

The program used for numerical analysis is NIST 's FDS(Fire dynamics simulator) ver.6.7.0. Table 2 shows the measurement values of the PVC specimen for the spread of flame tester and calculated values with two different pyrolysis models. The values in parentheses indicate the relative error of the numerical results of the measured values.

Ignition time, flame length, and heat for ignition obtained by using the complex pyrolysis model show more similar results to those of the actual experiment than those by the simple model. Flame spread obtained by the simple model is slower than flame spread by the complex model in this case. However, the complex pyrolysis model has a disadvantage that it requires more computing time than simple pyrolysis model.

In this study, thermal properties such as specific heat, thermal conductivity and pyrolysis parameters such as ignition temperature, HRR per unit area, and heat of combustion, pre-exponential and activation energy are obtained by cone calorimeter and PCFC measurements. Fire spreads are analyzed using two different pyrolysis models. Numerical analysis of complex pyrolysis model using pyrolysis rate showed more similar results for ignition and flame spread.

Table 2 Comparison of spread flame characteristic

spread of flame characteristics	measured	complex pyrolysis model (error)	simple pyrolysis model (error)
ignition time [s]	21.3	24(+13%)	88(+313%)
flame length [mm]	493.3	400(-19%)	330(-33%)
heat for ignition [MJ/m^2]	1.20	1.60(+33%)	5.24(+335%)

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