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Effect of oxygen concentration and temperature on ignition time of polypropylene

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Abstract The presented article deals with the assessment of combined impact of temperature and flow of oxidising atmosphere, its oxygen concentration and heat flux on the ignition time of isotactic polypropylene (PP). The ignition time was determined in a specially adapted hot air Setchkin furnace at temperatures (450 and 600 °C), density of heat flux (12.4 and 26.4 kW m^{-2}), flows of oxidation mixture (6 and 8 L min^{-1}) and volume oxygen concentrations (3, 9, 15, 21, 27, 33, 39, 45 and 50 %). Obtained data allows us to assume that the temperature influence on PP induction period of ignition increases with decreasing flow rate of oxidising atmosphere. At the flow of oxidising mixture equal to 6 L min^{-1} and temperature of 600 °C, oxygen concentration had only a negligible impact on the the induction period of ignition in the analysed period. From the presented results, the induction period of ignition depends on the temperature and also on the flow rate of oxidising mixture and oxygen concentration in it. In addition, heat flux has a significant influence on the induction period. However, the quantification of the heat flux influence was not possible with the applied experimental device.

Keywords Integral model of ignition · Heat flow · Oxygen concentration · Thermal decomposition · Ignition time · Polypropylene

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Introduction

Initiation is the most important phase of fire development [1]. This statement is supported by the fact that if initiation does not occur, fire does not start up.

Fire tests are crucial to the development, screening and evaluation of materials with improved fire safety [2]. Many fire tests have been developed for assessing ignitability, flammability, flame retardancy and fire hazards [3].

Practically, a specific part of materials in fire department is in the initiation phase during the whole phase of pre-flashover. Therefore, determination and comparison of the substantial initiation parameters (ignition and flash ignition temperature, ignition and flash ignition induction period and critical heat flux) enables us to make a relative comparison of materials or products from the point of fire dynamics.

Induction period of ignition or flash ignition is defined as the time interval between the thermal loading of the sample at a constant temperature or by the selected temperature programme and ignition or flash ignition. According to Simon and Kolman [4], in some cases, an accurate determination of the induction period is of utmost importance for the safety and the quality management.

Several authors have dealt with the assessment of the influence of individual described parameters on induction period. For example, Zachar [5] and Terenova [6] determined the ignition temperatures and corresponding induction periods for natural and synthetic polymers, respectively. The ignition temperatures of Beech, Oak and Poplar were 410, 420 and 390 °C, respectively. The corresponding induction periods were 540, 455 and 548 s, respectively. The ignition temperature of polymeric roof damp proof foil was 380 °C and the corresponding induction period was 7 min. Osvaldova [7] and Zachar [8] analysed the influence of the heat flux on the induction period of ignition of selected wooden materials, while Kacikova [9] and Kacikova and Kacik [10] examined the influence of heat flux on the change of selected parameters of materials. According to Osvaldova [7] and Zachar [8], the ignition period exponentially increase with material distance from radiant heater increase. Bubenikova and Velkova [11] examined influence of temperatures on degradation of wooden materials by analysis of selected thermal degradation products (formaldehyde, acetaldehyde, vanillin, 2-furaldehyde). From the presented results, the concentration investigated thermal decomposition products' increase with temperature increase. Martinka et al. [12] examined influence of temperature and oxygen concentration on degradation of birch wood by analysis of main burning emissions (CO, NO_x and total organic carbon). From the presented results, the concentration investigated thermal decomposition products' increase with temperature increase. Heat release rate can be estimated from the concentration of CO in burning emissions. According to Xu et al. [13] and Lim et al. [14] heat release rate has close relationship with CO concentration in fire effluents.

During fire in the pre-flashover phase, combustible materials and products in fire department are under the simultaneous effect of increased temperature of ambient gasses (air and fire effluent), heat flux from the flame and bordering constructions, reduced oxygen concentration in oxidising atmosphere as well as the movement of oxidising atmosphere. Hence, the goal of the presented article is to assess the simultaneous influence of temperature, density of heat flux, oxygen concentration in oxidising atmosphere and its flow on the induction period of the ignition of polypropylene (PP) as one of the most common synthetic polymer.

In the automotive industry, isotactic polypropylene (iPP) is one of the most used polymeric materials [15].

Experimental

The simultaneous influence of heat flux, temperature, flow of oxidation mixture and volume oxygen concentration on induction period of ignition was assessed using the specially adapted hot air Setchkin furnace. In the experiment, we used iPP, in the form of granules. The weight of samples was (3 ± 0.05) g.

Induction periods of ignition were assessed at two temperatures (450 and 600 °C) and corresponding heat fluxes (12.4 and 26.4 kW m^{-2}), two flow rates of oxidising mixture (6 and 8 L min^{-1}) and nine volume concentrations of oxygen (3, 9, 15, 21, 27, 33, 39, 45 and 50 %).

Heat flux was calculated from the known surface temperature of ceramic cylinder in the interior of the furnace (surface temperature of ceramic cylinder corresponds to the temperature of oxidising atmosphere) according to Stephan–Boltzmann law.

The used experimental devices are described in detail by Martinka [16].

Results and discussion

The dependency of the induction period of PP ignition on temperature and volume oxygen concentration is shown in Fig. 1 (for the flow of oxidising atmosphere 6 L min^{-1}) and Fig. 2 (for the flow of oxidising atmosphere 8 L min^{-1}). The density of heat flux on the sample at temperatures 450 and 600 °C was 12.4 and 26.4 kW m^{-2}, respectively.

From the experimental data, the exponential relationship of the induction period of ignition to oxygen concentration was derived. Equations (1, 2) describe the relationship of the induction period of ignition to oxygen concentration at the flow of oxidising mixture 6 L min^{-1} and at temperatures 450 and 600 °C, respectively. Equations (3, 4) describe the relationship of the induction period of ignition to oxygen concentration at the flow of oxidising mixture 8 L min^{-1} and at temperatures 450 and 600 °C, respectively.

Close exponential relationship of induction period of ignition to oxygen concentration is confirmed by the values of coefficients of determination R^2, which approach 1 (0.95 for Eqs. 1, 3, 4 and 0.96 for Eq. 2).

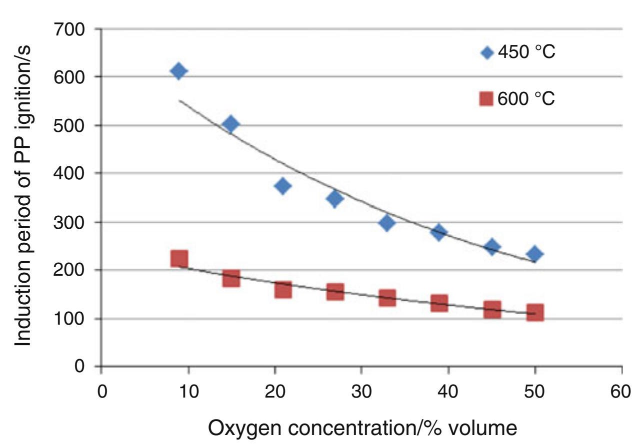

Fig. 1 Influence of temperature and oxygen concentration on induction period of PP ignition at the flow rate of oxidising mixture 6 L min^{-1}

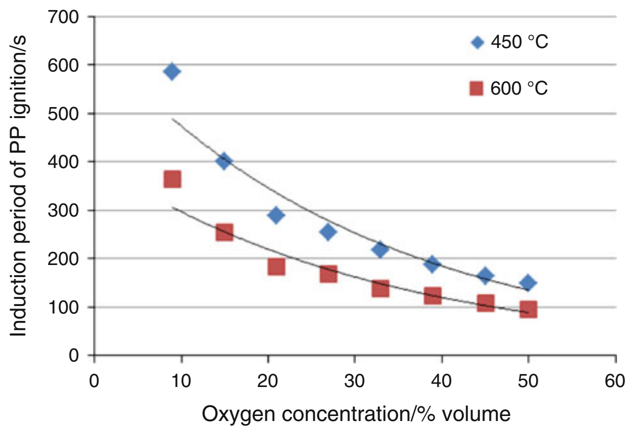

Fig. 2 Influence of temperature and oxygen concentration on induction period of PP ignition at the flow rate of oxidising mixture 8 L min^{-1}

$$t_{ig} = 676.15 \cdot e^{-0.023\phi_{O_2}} \quad (1)$$

$$t_{ig} = 237.21 \cdot e^{-0.016\phi_{O_2}} \quad (2)$$

$$t_{ig} = 647.79 \cdot e^{-0.031\phi_{O_2}} \quad (3)$$

$$t_{ig} = 401.26 \cdot e^{-0.03\phi_{O_2}}, \quad (4)$$

where t_{ig} is induction period of PP ignition in seconds and φ_{O_2} is the volume oxygen concentration in % volume.

Validity of the Eqs. (1–4) is limited particularly at low oxygen concentrations (approximately below 6 %), when the initiation, or the maintenance of flame burning is not possible even at extreme temperatures and heat fluxes. The PP ignition has not been observed at oxygen concentration 3 % in oxidising atmosphere and temperatures 450 and 600 °C. The thermal decomposition of only has been observed at oxygen concentration 3 %.

Already the visual analysis of Figs. 1 and 2 allows us to assume that the temperature influence on induction period of ignition increases with decreasing flow rate of oxidising atmosphere. Considering the arrangement of the experimental device, this can be justified by a lower heat removal from the burning zone. At the flow of oxidising mixture equal to 6 L min^{-1} and temperature of 600 °C, oxygen concentration had only a negligible impact on the induction period of ignition in the analysed period. At temperature 600 °C, time increase of the induction period would become more distinct only at oxygen concentrations below 9 %.

Conclusions

From the presented results, we can state that the induction period of ignition (and hence the ignition temperature) depends, apart from the temperature, also on the flow rate of oxidising mixture and oxygen concentration in it. In addition, heat flux has a significant influence on the induction period. However, the quantification of the heat flux influence was, with the applied experimental device, not possible. Further research has to be oriented at the development of the device that will allow independent setting of temperature of oxidising mixture and heat flux on the sample.

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References

1. Babrauskas V. Ignition handbook. Issaquah: Fire Science Publishers; 2003.
2. Patel P, Hull TR, Moffatt CP. Peek polymer flammability and the inadequacy of the UL-94 classification. Fire Mater. 2012;36:185–201.
3. Wang Y, Zhang J. Influence of specimen size and heating mode on the ignitability of polymeric materials in typical small-scale fire test conditions. Fire Mater. 2012;36:231–40.
4. Simon P, Kolman L. DSC study of oxidation induction periods. J Therm Anal Calorim. 2001;64:813–20.
5. Zachar M. Selected decidious wood species flash ignition and ignition temperature determination. In: Mrackova E, Markova I, editors. Proceedings of fire engineering 3rd international scientific conference. Zvolen: Technical University in Zvolen; 2010. p. 431–8.
6. Terenova L. Hydro-isolating belts in structural members of new buildings in terms of the fire safety. In: Mrackova E, Markova I, editors. Proceedings of fire engineering 3rd international scientific conference. Zvolen: Technical University in Zvolen; 2010. p. 403–10.
7. Osvaldova L. The resistance of individual parts of spruce wood against ignition. In: Klement I, editor. Proceedings of technological processing of wood. Zvolen: Technical University in Zvolen; 2006. p. 143–8.
8. Zachar M. The influence of heating on thermal degradation of chosen kind of wood. Zvolen: Technical University in Zvolen; 2009.
9. Kacikova D. The changes of chosen spruce wood characteristics in consequence of its thermal loaded by radiant heat. Acta Fac Xylologiae. 2007;49:53–9.
10. Kacikova D, Kacik F. The influence of thermal loading of spruce wood on its lignin chances. Acta Fac Xylologiae. 2009;51:71–8.
11. Bubenikova T, Velkova V. The decomposition products of wood thermal degradation. Delta. 2007;1:18–20.
12. Martinka J, Kacikova D, Hroncova E, Ladomersky J. Experimental determination of the effect of temperature and oxygen concentration on the production of birch wood main fire emissions. J Therm Anal Calorim. 2012. doi:10.1007/s10973-012-2261-2.
13. Xu Q, Majlingova A, Zachar M, Jin C, Jiang Y. Correlation analysis of cone calorimetry test data assessment of the procedure with test of different polymers. J Therm Anal Calorim. 2011. doi:10.1007/s10973-011-2059-7.
14. Lim J, Lee JH, Kim S. Estimating the fire behavior of wood flooring using a cone calorimeter. J Therm Anal Calorim. 2011. doi:10.1007/s10973-011-1902-1.
15. Barany T, Izer A, Menyhard A. Reprocessability and melting behaviour of self-reinforced composites based on PP homo and copolymers. J Therm Anal Calorim. 2010;101:255–63.
16. Martinka J. The influence of oxygen concentration and temperature on the products of burning and thermal decomposition of chosen organic polymers. Zvolen: Technical University in Zvolen; 2010.