Iran Polym J (2016) 25:579–587
DOI 10.1007/s13726-016-0447-3

ORIGINAL PAPER

Phenolic foams, modified by nano-metallic oxides, improved in mechanical strengths and friability

Yuxiang Zhu[1] · **Zhengzhou Wang**[1,2]

Received: 27 January 2016 / Accepted: 7 June 2016 / Published online: 4 July 2016

Abstract Two kinds of nano-metallic oxides (nano-Al_2O_3 and nano-ZrO_2) were introduced separately into phenolic (PF) foams, and a series of PF foams modified with different loadings of the two nano-oxides were prepared. The test results of mechanical properties indicated that the flexural, compressive and impact strengths of the PF foams, modified by nano-Al_2O_3 at 5 phr loading, increased by 33, 46 and 51 % in the above order, and the strengths of the PF foams modified by nano-ZrO_2 at 5 phr loading increased by 31, 30 and 49 % in the same order, compared to the corresponding data of pure PF foam. The pulverization ratio of the modified PF foams decreased gradually with the increase in nano-oxides contents. The pulverization ratio of the PF foam modified by nano-oxides at 5 phr, decreased to 2.3 % for Al_2O_3 and that of ZrO_2 decreased to 2.2 %, which were quite lower than the pure PF foam value of 8 %. The combustion characteristics of the PF foams, modified by the nano-oxides, were evaluated by the limiting oxygen index (LOI), UL-94 and cone calorimetry tests. The LOI values of the foams modified by both nano-Al_2O_3 and nano-ZrO_2 decreased slightly with an increase in the loading of the nano-oxides, still all above 36 %. The UL 94 test results indicated that all foams could pass a V0 rating. The cone calorimeter results showed that the peak heat release rates of the modified foams were lower than 50 kW/m^2. Moreover, thermal stability of the foams modified by the nano-oxides was investigated.

Keywords Phenolic foams · Nano-metallic oxides · Mechanical strengths · Friability

Introduction

Phenolic (PF) foams have recently attracted much attention due to their excellent flame-retardant properties compared with polyurethane (PU) foams and polystyrene (PS) foams in the field of building insulation materials [1]. However, PF foams have some serious shortcomings such as brittleness and pulverization, which greatly limit their applications in some cases [2]. Thus, researchers have focused their attention on the toughening and strengthening of PF foams [3]. The commonly used toughening agents for PF foams include polyethylene glycol (PEG), polyurethane, epoxy resins, etc. Gao et al. [4] investigated the effect of PEG on the mechanical and flame-retardant properties of phenolic foams and observed a great increase in compressive and impact strengths, but a decrease in the limiting oxygen index (LOI). Auad et al. [5] applied epoxy resins to modify PF foams and found that the modification improved the compressive, shear, and friable properties of the PF foam; nonetheless, the flammability of the modified foam increased greatly. Moreover, polyurethane prepolymer has often been used to toughen PF foams [6].

During the last two decades, nanomaterials have been used to toughen and strengthen polymeric materials [7, 8]. The introduction of small amounts of nanomaterials into the polymer matrix can combine the advantages of the polymer matrix and the discrete nanomaterials and result in great improvements on thermal and mechanical properties [9]. Several researchers have also employed many kinds of

✉ Zhengzhou Wang
zwang@tongji.edu.cn

[1] School of Materials Science and Engineering, Tongji University, Shanghai 201804, People's Republic of China

[2] Key Laboratory of Advanced Civil Engineering Materials, Tongji University, Ministry of Education, Shanghai 201804, People's Republic of China