CHEMICAL ENGINEERING TRANSACTIONS
VOL. 66, 2018
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Songying Zhao, Yougang Sun, Ye Zhou

ISBN 978-88-95608-63-1; **ISSN** 2283-9216
DOI: 10.3303/CET1866012

Application of Polystyrene in Building Materials Based on Chemical Hydration Reaction

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Today, white pollution caused by waste polystyrene become heavier over years. How to make the waste profitable has been plaguing people as a hotspot. A new way to develop new materials is to dope polystyrene material and coal with cement mortar to prepare a new type of building insulation blocks. This study prepares the building insulation mortar with polystyrene and coal ash, and modifies it with admixture NF-30, lime and gypsum, in an attempt to unveil its chemical hydration hardening and other properties. The findings show that, as doped with polystyrene, the thermal conductivity, hydration heat, flexural strength, and compressive strength of the mortar all abate, but its weather resistance and water tolerance seem good. Thanks to extremely low thermal conductivity, it can be used to prepare the insulation mortar in accordance with the code of building energy efficiency. The new type of coal ash-polystyrene modified insulation mortar block features large thermal resistance and low heat bridges, and non-condensation, which well fits the bill for heating in winter.

1. Introduction

Polystyrene is also known as thermoplastics. The plastics industry has been developing rapidly since its inception in the 20th century (Döğüşcü et al., 2017; Wang and Zhang, 2011). In a variety of plastics, the average annual growth rate of demand for polystyrene foam in the global market reaches 10% or so (Khoukhi et al., 2016). Plenty of foam plastics scatter along traffic trunk lines, rivers and lakes, tourist resorts, streets and alleys, causing a widespread “white pollution” (San-Antonio-González et al., 2015, Doroudiani and Omidian, 2010). For the moment, landfill and incineration are common ways for disposing polystyrene materials, but these material will not decay and be degraded easily, thus causing the extravagancy of considerable resources, widespread contamination to the environment and other issues (Gao et al., 2012). An effective way that the waste polystyrene got recycled is to follow the roads of the resource-saving development and sustainable development. The recycling and resource regeneration of waste polystyrene is the best way to reduce resource waste, rationally utilize energy resource, protect the environment and eliminate white pollution.

Polystyrene materials features low density, light weight, low water absorption, extremely low thermal conductivity and insulation, chemical stability, resistance to aging and acid and alkali corrosion (Xiong et al., 2013, Ratiarisoa et al., 2016). Such polystyrene materials can be applied in buildings to prepare a kind of building insulation mortars, or building insulation panels, etc. It is uniquely characterized by good energy efficiency, chemical resistance and environmental greenness (Cevik et al., 2011). Polystyrene materials are generally doped with coal ash when preparing building insulation mortars, in order to reduce its cost, improve its properties, and make waste solids profitable. The pozzolanic activity of coal ash also promotes the formation of gel phases (An et al., 2017). This study traces the chemical hydration hardening and other properties of the building insulation mortar prepared from plystyrene materials and coal ash herein, and modified with admixture NF-30, lime and gypsum. This provides the clues to applying polystyrene materials in building materials.

Please cite this article as: Li H., Ren Y., 2018, Application of polystyrene in building materials based on chemical hydration reaction, Chemical Engineering Transactions, 66, 67-72 DOI:10.3303/CET1866012

2. Analysis of properties of polystyrene mortar

2.1 Age strength of admixture NF-30 modified concrete

The water reduction rate of the admixture NF-30 can reach 18%, which can significantly reduce the water-cement ratio and increase the fluidity of fresh slurry (Gao et al., 2009, Wang et al., 2015). NF-30 water reducer not only has a water reducing effect, but also plays dispersing, moistening and lubricating functions, increasing the slurry hydration area and rate (Zhou et al., 2010). Here, we use washing oil, industrial naphthalene, sulfuric acid and oxidant to prepare NF-30 at high temperature. The stirring speed, washing oil dose, sulfonation temperature and sulfonation time, etc., in the preparation process all have an impact on the flowability. The effect of the sulfonation temperature on the fluidity is shown in Fig. 1. It is obvious that the optimal sulfonation temperature is 160°C. NF-30 admixture retards the material coagulation and increases its surface tension, so that it seems better than the commercially available superplasticizers (Wang & Pan, 2017).

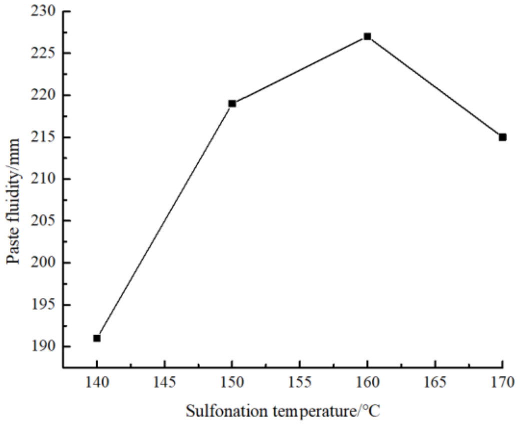

Figure 1: The effect of sulfonation temperature on cement paste fluidity

2.2 Waste polystyrene cement mortar modified with coal ash

The experimental material used is ordinary P.O 42.5 Portland cement. Chemical compositions of cement and coal ash are shown in Table 1. Coal ash can not only reduce the cost but also improve the workability of the mortar to a certain extent. Solid polystyrene material comes from garbage recycling products which are processed and smashed into particles of 2.0-2.5 mm. Polystyrene foam granules are doped in the glue sand by the mass ratios of 0%, 1%, 2%, 2.5%, 3%, 3.5%, 4% and 4.5%, respectively. Pour fresh mortar into a 40*40*160 test mold, cover it with polyethylene film, demold after curing for 1 day, and place it in a standard curing room until the test age is reached. The effect of the polystyrene foam of different doses on the compressive strength of cement mortar in the age range is shown in Fig. 2. Obviously, the strength of cement mortars at 3d, 7d, 28d, and 60d decreases as the dosage of polystyrene foam increases, but slowly at a range of 2.0%-2.5%. The mechanical properties are good.

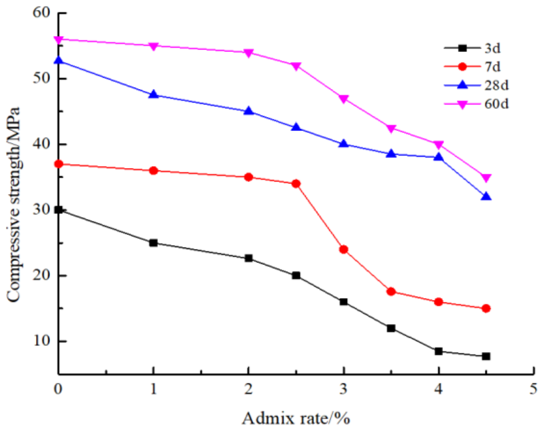

Figure 2: Effects of EPS replacement on compressive strengths of cement mortar

Table 1: Chemical compositions of cement and fly ash

Raw material	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	SO_3	TiO_2
Cement	20.40	5.58	2.58	2.13	62.65	0.77	3.03	0.20
Fly ash	27.65	32.59	4.42	1.44	1.64	0.70	0.14	0.16

3. Preparation of polystyrene insulation mortar blocks

3.1 Experiment and durability analysis of polystyrene insulation mortar block

Cement, coal ash and polystyrene materials are in accordance with the section 2.2. Lime is calcareous lime with a CaO content of more than 78%. Gypsum is desulfurized type. The ratio of test sample is shown in Table 2. In the test of mechanical properties of mortar, a 40*40*160 test block is used, and in the test of thermal insulation performance, the DRX-1-PB thermal conductivity meter is used to measure the mortar. Fig. 3 gives the flexural strengths of mortar specimens at different ages. It can be seen that the flexural strength decreases with the increase of the dosage of coal ash and polystyrene foam. Incorporated lime and gypsum play an inciting effect, but its strength is inferior to that of pure cement mortar. The compressive strength of mortar samples at different ages is shown in Fig. 4, and it changes in a law consistent with the flexural strength. The polystyrene foam does not have gelling property, not participate in the hydration reaction, and only plays a filling role. However badly, due to defects in density and strength, the the mortar strength weakens obviously. The curve of the thermal conductivity of the sample is shown in Fig. 5. It can be clearly seen that the thermal conductivity of the sample decreases significantly with the increase of the dosage of polystyrene foam, and rapidly when the polystyrene foam is low dose, and slowly when it is high dose.

Table 2: Specimens ratio

Specimens No.	Lime/%	Plaster/%	Fly ash/%	EPS/%	NF-30 admixture/%
0	10.0%	5.0%	0%	0%	0.5%
1	10.0%	5.0%	5.0%	0.5%	0.5%
2	10.0%	5.0%	10.0%	1.0%	0.5%
3	10.0%	5.0%	15.0%	2.0%	0.5%
4	10.0%	5.0%	20.0%	2.5%	0.5%
5	10.0%	5.0%	25.0%	3.0%	0.5%
6	10.0%	5.0%	30.0%	3.5%	0.5%
7	10.0%	5.0%	35.0%	4.0%	0.5%
8	10.0%	5.0%	40.0%	4.5%	0.5%
9	10.0%	5.0%	45.0%	5.0%	0.5%

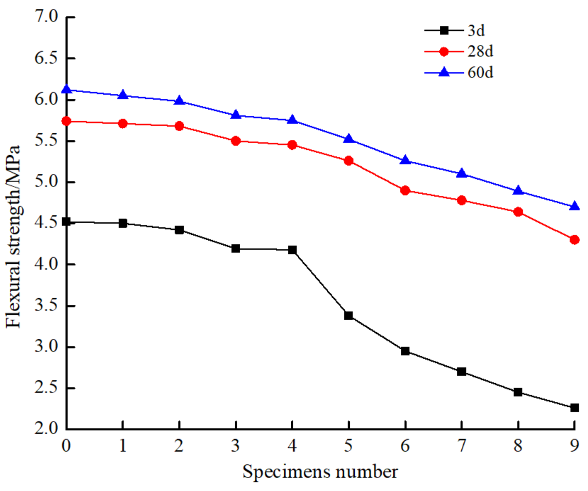

Figure 3: Flexural strength of the mortar with different age

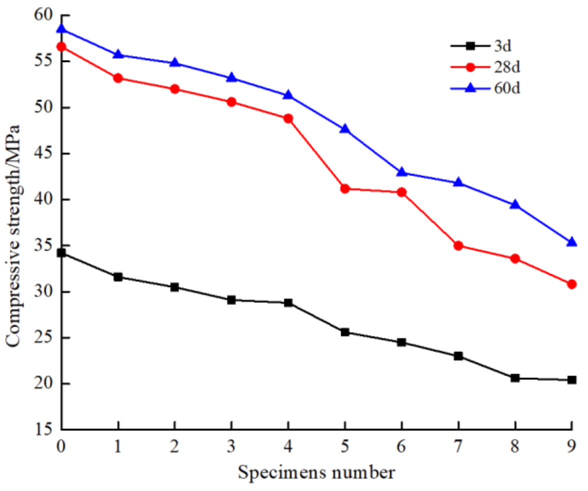

Figure 4: Compressive strength of the mortar with different age

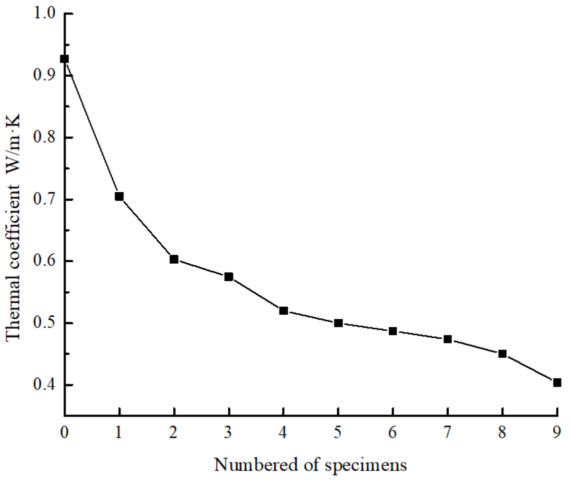

Figure 5: Specimens thermal conductivity curve

3.2 Weather resistance of insulation mortar blocks

Polystyrene are used in building materials. A kind of building insulation mortars is prepared from it for exterior surfaces of buildings. Whether or not they meet weatherability is a prerequisite for wide application. The heat of hydration at different ages of slurry samples is shown in Fig. 6. Polystyrene foam doped with coal ash can significantly reduce the heat of hydration of the cement-based materials overall, and the greater the dosage of coal ash, the more obvious the reduction in heat of hydration. The acid-resistance and freeze-thaw resistance of the insulation mortar blocks are found to be good in the weatherability test. The compressive strength of the samples is 50.8 MPa, 48.9 MPa after 30 cycles of the acid resistance test, 50.2 MPa after 30 cycles of freeze-thaw resistance tests, and 49.6 MPa after 30 drying and wetting cycles. It drops a little in any case. The water absorption rate is 2.0%, the softening coefficient is 0.7%, and the water tolerance of the composite mortar is required. In summary, the polystyrene foam can be doped to prepare the thermal insulation mortar with excellent water tolerance and weather resistance.

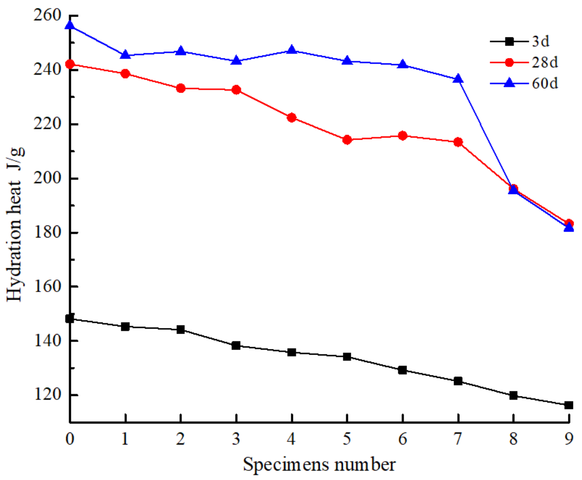

Figure 6: The hydration heat result of mortar different age J/g

4. Application of Polystyrene Insulation Mortar Blocks

4.1 Chemical hydration reaction

The early products of cement hydration are C-(A)-SH, ettringite and calcium oxide. Incorporated polyethylene foam affects the hydration of cement clinker to a certain extent. As doped with the gypsum and lime, the resultants of CH, AFt phase increase, and a strong alkaline environment is formed internally, which is conducive to the further hydration of cement clinker. The amount of hydration product of polystyrene insulation mortar block can be analyzed by DSC-TGA method. 28d DSC-TGA curve of No. 0 sample is shown in Fig. 7.

The sample presents obvious weightlessness at 50°C-150°C at a weight loss rate of about 9.25%, the first endothermic peak is the C-(A)-SH gel and the AFt phase dehydration; the second occurs at around 450°C, corresponding CH crystal is stripped of the strong crystallization water. The 28d DSC-TGA curve for No. 5sample is shown in Fig. 8, where the first endothermic peak appears at about 56°C as free water weight loss; the second is at about 87°C, corresponding C-(A)-S-H gel water loss occurs and weight loss is 5%, less than 9.25% of that of No. 0 sample. Obviously, the hydration product C-(A)-S-H gel decreases with the increase of coal ash; The third endothermic peak appears at 450°C, the weight loss rate is 1.25%, and the endothermic peak gets wider, which implies that the CH resultants are more. The properties of coal ash-EPS insulation mortar are given in Table 3. The heat-insulating mortar doped with polystyrene material has good workability and good workability, and the bond strength is much greater than that of the expanded perlite insulation mortar.

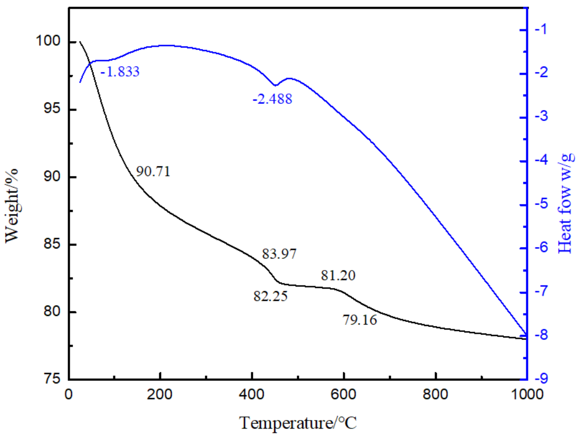

Figure 7: DSC-TGA curves of specimens 0 at 28d

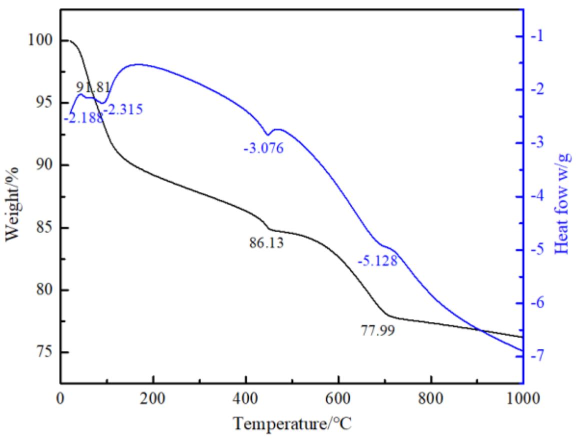

Figure 8: DSC-TGA curves of specimens 5 at 28d

Table 3: Fly ash-EPS insulation mortar performance

Performance	EPS	Expanded pearlite	PU
Dry bulk density kg/m^3	550	500	450
Working hours/h	5	5	5
Lump water absorption/%	12.2	45.5	10.5
Thermal conductivity(W/m·K)	0.454	0.536	0.414
28d compressive strength /MPa	40	46	54
15 cycle strength loss of freeze-thaw/%	6.4	14.2	6.1
15 wet and dry cycles of strength loss/%	4.6	9.7	4.5

4.2 Energy-saving application of thermal insulation mortar blocks

The polystyrene insulation mortar is modified by doped lime and gypsum to make the newly developed insulation mortar have a strong weather resistance. According to the available literature, it is found that the insulation test block doped with the polystyrene material features greater thermal resistance and lower thermal bridge, and non-condensation. Thermal coefficients of the walls in China are given in Table 4. It can be clearly seen that the thermal conductivity coefficient of the polystyrene-doped material is the minimum, better than that required in the building energy conservation code. The new coal ash-polystyrene insulation mortar block greatly simplifies the construction process, shortens the man-hour and improves the effect, and also lowers the thermal conductivity to satisfy the heating requirements in winter.

Table 4: Thermal data of wall structure

Material name	Thickness	Thermal conductivity	Hort storage coefficient	Correction factor
Plastering mortars	25	0.86	10.64	1
Reinforced concrete	220	1.73	17.1	1
Fly ash-EPS insulation mortar block	200	0.52	7.81	1
Bonded mortars	10	0.92	11.26	1
EPS thermal insulation mortar	30	0.062	0.31	1.1

5. Conclusions

Building insulation mortar is prepared from polystyrene and coal ash, and modified with admixture NF-30, lime and gypsum, in an attempt to unveil its chemical hydration hardening and other properties. The specific conclusions from experiment are drawn as follows:
(1) As the dosage of polystyrene foams increases, the thermal conductivity of the sample decreases significantly. When the dosage of polystyrene foams decreases, the thermal conductivity abates quickly; when the dosage is high, the thermal conductivity abates slowly.
(2) The coal ash and polystyrene foam materials can significantly reduce the heat of hydration of the cement-based material if doped with the two, and the overall heat of hydration debases, and the greater the dosage, the more obvious the heat of hydration decreases, and the polystyrene foam can be doped to prepare thermal insulation mortar with excellent water tolerance and weather resistance.
(3) The polyethylene foam added affects the hydration of cement clinker to a certain extent. As gypsum and lime are mixed, the products of CH and AFt phases increase and the interior exhibits a strong alkaline environment, facilitating further hydration of cement clinker.

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