Construction and Building Materials 163 (2018) 438–445

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Mechanical and thermo-gravimetric properties of unsaturated polyester resin blended with FGD gypsum

Habib Tabatabai *, Morteza Janbaz, Azam Nabizadeh

Department of Civil and Environmental Engineering, University of Wisconsin-Milwaukee, WI 53211, USA

HIGHLIGHTS

- Properties of polyester resin blended with FGD gypsum were studied.
- Ambient mechanical properties were markedly enhanced with up to 50% gypsum content.
- TGA results showed major improvement in mass retention with higher gypsum contents.
- FGD gypsum can form an exterior barrier protecting the interior areas from fire.
- FGD gypsum can potentially be a low-cost additive for fire resistance in polymers.

ARTICLE INFO

Article history:
Received 13 January 2017
Received in revised form 5 November 2017
Accepted 6 December 2017

Keywords:
FGD gypsum
Industrial by-product
Polyester resin
FRP
Thermo-gravimetric analysis
Mechanical properties
Fire resistance

ABSTRACT

A major disadvantage of polymeric materials is their flammability and generation of toxic gases under fire. Mechanical and thermo-gravimetric properties of an unsaturated polyester resin blended with Flu-Gas Desulfurization (FGD) gypsum were assessed. Limited open flame tests were also performed. Results indicate that ambient mechanical properties of polyester resin can be enhanced with up to 50% FGD gypsum content. TGA results show significant improvement in mass retention proportional to gypsum content. Under direct fire, FGD gypsum can form a protective physical barrier on the resin's exterior surfaces. FGD gypsum can potentially be an effective and low-cost fire-resistance additive for polymers.

1. Introduction

Over the past two decades, there has been increased interest in the use of fiber-reinforced polymer (FRP) composites in civil/structural engineering applications. The primary uses of FRP laminated composites have been in the repair and seismic retrofit of structures. FRP laminated composites are sometimes wrapped around inadequately-reinforced columns to increase strength and ductility of columns when subjected to earthquake loads. They have also been used to improve the flexural/shear strength of beams and slabs. Full-size FRP members have also been used in new construction. Although FRP composites offer enhanced corrosion resistance and superior strength-to-weight ratio, they are susceptible to significant damage in fires.

Typical resins used in manufacturing FRP composites (thermosets such as polyester or vinyl ester resins and thermoplastics such as polyethylene or polyurethane) are all extremely flammable and produce significant toxic smoke. The lack of fire resistance is a major impediment to widespread use of FRP composites and other polymer-based materials in civil engineering structures, especially in indoor applications. Polyester resins are typically used in FRP composites due to their rapid curing, good mechanical properties and relatively low cost. As compared to epoxy resins, polyester resins are more sensitive to elevated temperatures [1].

Some fire resistance requirements may be satisfied by using fillers such as Alumina Trihydrate (ATH) in the resin. On the other hand, specialized resins containing halogens such as bromine, or phenol resins, or additives such as antimony oxide can be used for fire resistance as well. However, these measures may not provide adequate protection [2].

In 2004, a study sponsored by the Federal Aviation Administration (FAA) reported relationships between structure, composition,

* Corresponding author.
E-mail addresses: ht@uwm.edu (H. Tabatabai), mjanbaz@uwm.edu (M. Janbaz), azam@uwm.edu (A. Nabizadeh).

https://doi.org/10.1016/j.conbuildmat.2017.12.041
0950-0618/

and fire resistance to evaluate fire-safe polymeric materials [3]. The most efficient approach would be to produce inherently fire-resistant polymers with high thermal stability [3]. However, this approach is not easy to accomplish and is expensive [3]. Other common approaches include addition of flame-retardant additives. Additives are designed to either chemically react or physically combine to provide less flammable polymers [3].

Some use intumescent coatings to achieve fire resistance. Wang et al. [4] synthesized a phosphorus-containing polymer for amino intumescent fire-resistant coating applications. Experimental results from fire protection tests on plywood board indicate that fire protection duration could be significantly extended after application of intumescent coating [4].

Ji et al. [5] studied the combustibility of FRP composites using nanoclay reinforced intumescent coating. The fire retardant coating enhanced fire resistance and post-fire bending strength of RC beams [5]. In 2006, Giancaspro reported that a thin layer of a fire-resistant paste composed of an inorganic geopolymer resin could improve the fire resistance of balsa sandwich panels [6].

Chiu et al. studied thermal degradation and combustion behavior of unsaturated polyester resin modified with phenolic resin [7]. The results showed that the addition of phenolic resin improved heat resistance and flame retardation. Other researchers have evaluated the effect of magnesium hydroxide on flame retardation of unsaturated polyester resin [8]. Results show that resin samples containing magnesium hydroxide had higher ignition time and improved flame resistance.

The earlier works noted above indicate a wide variety of approaches that have unfortunately not yet led to widespread application and use of effective fire-resistant polymers. Factors such as cost, degree of effectiveness, and/or application issues have limited their use to specialized applications. In typical indoor construction applications, gypsum drywall products are routinely used to achieve the required fire ratings. Gypsum, whether in drywall form or directly applied, is a cost-effective and code-recognized barrier system for fire resistance. This raises the question of whether gypsum particles, as additive, could also improve the fire resistance properties of polymers. Flue Gas Desulfurization (FGD) gypsum is an industrial by-product obtained during the process of removing sulfur emissions from many coal burning power plants that employ the special processes needed to remove them. The development of FGD gypsum-modified polymers could provide an effective and low-cost protection system that could shield the bulk of the polymer from burning through early formation of a physical gypsum barrier, and thus reduce the emission of toxic gases in a fire.

Table 1
Typical characteristics of We Energies' FGD gypsum (dry basis) [14].

Purity ($CaSO_4 \cdot 2H_2O$)		>95%
Impurities	$CaCO_3$	<2%
	$MgCO_3$	<1%
Particle Size -% passing 200 mesh sieve		>95%

Table 2
Polyester resin and FGD gypsum proportions.

Mix	PHR	Gypsum content (% of total mass)	Resin content (% of total mass)
R0	0	0	100
R10	10	9.1	90.9
R20	20	16.7	83.3
R30	30	23.1	76.9
R40	40	28.6	41.4
R50	50	33.3	66.7
R70	70	41.2	58.8
R100	100	50	50
R200	200	66.7	33.3
R400	400	80	20

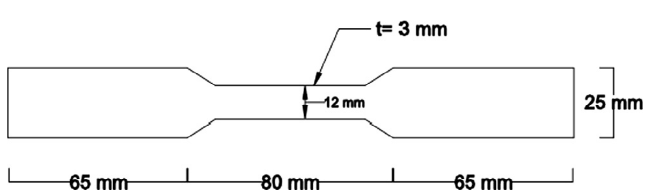

Fig. 1. Dog-bone tensile test specimen.

2. Objective and scope

The main objective of this study was to determine whether FGD Gypsum can be a suitable additive for the unsaturated polyester resin by improving its mechanical and thermo-gravimetric properties. This study takes the first step toward development of an FGD gypsum additive that could enhance fire-resistance of polymers while also improving ambient mechanical properties.

FGD gypsum was added at fractions of up to 400 percent by weight of resin (400 parts per hundred parts resin or PHR). The use of PHR in describing the additive content is common in the resin industry and is therefore employed here. Tensile strength, modulus of elasticity, impact resistance and thermo-gravimetric properties were evaluated on unsaturated polyester resins augmented with various FGD gypsum contents. In addition, limited open flame exposure tests were performed. Scanning Electron Microscopy (SEM) was used to examine size distribution of FGD gypsum as well as fracture surfaces in various resin-FGD gypsum composites.

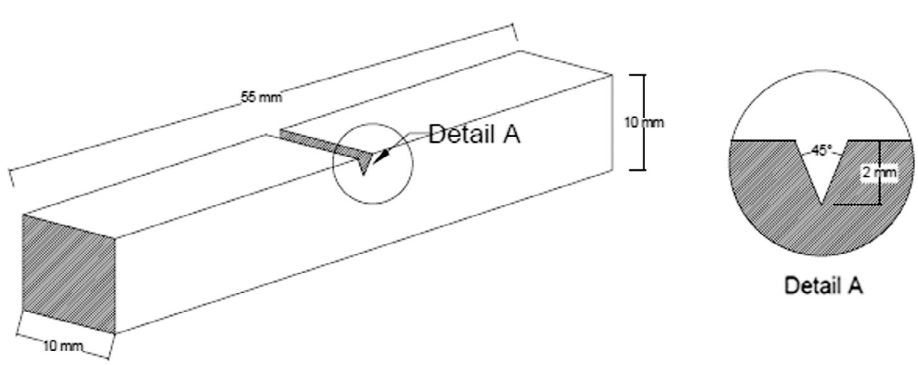

Fig. 2. Standard pendulum impact test specimen [15].