Composites: Part B 50 (2013) 193–201

Contents lists available at SciVerse ScienceDirect

Composites: Part B

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

Optimization of processing variables and mechanical properties in rubber-wood particles reinforced cement based composites manufacturing technology

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ARTICLE INFO

Article history:
Received 22 February 2012
Received in revised form 14 September 2012
Accepted 29 October 2012
Available online 19 November 2012

Keywords:
A. Discontinuous reinforcement
A. Hybrid
A. Moulding compounds
B. Mechanical properties

ABSTRACT

The manufacturing processes of rubber crumb–wood particle reinforced cement based composites (RWCC) which shortened the pressing cycle and enhanced the properties were completely investigated. Meanwhile, optimal processing conditions as well as properties of strength were tested to validate the predicted variables and properties. Mechanism effects of interacting process variables [density, duration of pressure time (namely, pressure time) and pressure] on properties of RWCC were opened out. The RWCC performance was evaluated by measuring its flexural strength (FS), modulus of elasticity (MOE) and internal bond (IB) strength. The experimental results were statistically analyzed by using Response Surface Method (RSM) software to identify the significant manufacturing process variables for RWCC. In the process variables, density and duration of pressing time had more significant influences on mechanical properties (FS and MOE and IB), but had little effect on strength performance caused by pressure. In addition, the microstructure of RWCC was clearly examined by using a scanning electron microscope (SEM). The mechanism effects were also revealed through analyzing the microstructure of the interface of rubber crumb/wood particle/cement. The results of a comprehensive evaluation for properties of RWCC with the highly active polymeric methylene diphenyl isocyanate adhesive (PMDI) as binder system not only present excellent mechanical properties, but also possess some of functional properties such as optimized acoustic properties and energy conservation. Finally, the optimal manufacturing process parameters were obtained by means of the maximizing mechanical properties.

1. Introduction

The development of advanced wall materials is highly concerned about around the world. Wall materials are becoming lighter in weight, stronger in strength, more functional in properties and having better reutilization. The development of building materials and technologies in China should follow the trend of cyclic economy that calls for reducing consumption of natural resources and energy, increasing the recycling rate of building materials, eliminating and reusing different types of wastes, so as to make the construction material industry to be an energy-saving, material-saving and multi-functional green industry. Moreover, in recent years, with the rapid development of automobile industry, how to recycle waste tires and solve "black pollution" problems has become a global concern. Research and exploration on new ways to recycle waste tires and solve "black pollution" problems seems more important and urgent than ever before in China.

Extensive researches of waste tire–cement composite have been conducted in the recent years [1,2]. Tire crumb-reinforced cement based composites have shown to improve cement ductility, toughness, thermal conductivity and acoustic properties, but their compressive and flexural strengths are impaired [3]. Some studies demonstrated that surface modification of rubber and incorporation of fibers into rubber–cement composites can improve strength properties of the composites [4].

Regarding the hot point of study the tire rubber and wood or non-wood composites, Song and Hwang [5] examined the wood-waste tires composites and found that the ratio of wood fiber to rubber particles and amount of PMDI were the significant factors that influenced board mechanical properties. Yang et al. [6] studied the straw-waste tire composites. The test result showed that straw–waste/tire rubber composites had similar mechanical

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http://dx.doi.org/10.1016/j.compositesb.2012.10.024

properties compared to wood–rubber composites when PMDI resin was used as binder. The sound insulation property of wood/used tire rubber composite panel was investigated by Zhao et al. [7], this composite also possessed better sound insulation and durability. Moreover, the microstructure of the composite was examined using a scanning electron microscope (SEM).

From the perspective of material complementarities and reasonable usage, incorporation of tire rubber crumbs and wood particles/fibers into cement can also improve composite flexural and tough properties and impact resistance, lower composite weight, and enhance thermal preservation and energy saving. Besides, the tire crumb–wood particles reinforced cement composites (RWCC) were prepared from PMDI, waste tire rubber crumbs and wood particles. PMDI resin is used as binder in order to improve interface adhesion while waste tire rubber crumbs and wood particles are the reinforcements of composites. Due to the possession of highly reactive and unsaturated –NCO groups, PMDI resin can react not only with hydroxyl groups of wood, but also with water in the wood. Besides the chemical bonding, PMDI resin can also develop strong mechanical bonding because the small molecules of PMDI are capable to diffuse into the wood or rubber substrate. In addition, the reaction of PMDI with water generates considerable quantity of heat, which can prompt the process of the reaction [8,9]. The waste tire rubber is an ideal raw material for the functional composite panel because it possesses some unique properties: excellent energy absorption, characteristically large elastic deformation, better sound insulation, durability and abrasion resistance, anti-caustic and anti-rot [10]. Thus, the composites can apply in so many places as functional products. The novel building composites completely meets the demands for green construction materials and low carbon emission economy.

Due to the complexity of tire crumb, wood particles, and pretreatment of PMDI, incorporation of these three materials might make impacts on optimization process. Experimental designs for optimization have been commonly used for the optimization of multiple variables with minimum number of experiments [11–13]. The conventional method of optimization of processing variables, involves varying one parameter at a time and keeping the other constant. Response Surface Methodology (RSM) is an important tool to study the effect of both the primary factors and their mutual interactions to determine the optimal process conditions [14–16].

This paper mainly discusses manufacturing process of rubber-wood reinforced cement composites (RWCCs) with application of cold pressing technology, which is more energy-saving and convenient. This new composites and technology for the development of cement based composites made of tire rubber crumbs–wood particles reinforced with high activity polymeric methylene diphenyl isocyanate adhesive (PMDI) as coupling agent. The adopted PMDI as coupling agent for manufacturing process, not only enhances the properties of RWCC, but also generates a certain amounts of CO_2 gas by reacting with water. The CO_2 gas can accelerate hardening of RWCC panel, improve primary intensity of panel and shorten the molding cycle.

The objectives of this study are:

(1) To evaluate the effects of main influential processing parameters on properties of RWCC, and change trends of main influential processing parameters by adopted RSM in design expert design.
(2) To obtain an optimal technology based on the processing parameters for manufacturing of RWCC.
(3) To develop the mechanism effects of interactive processing variables on properties of RWCC.

2. Materials and methods

2.1. Materials

2.1.1. Cement

Type 42.5 ordinary Portland cement provided by Ji Dong Cement Corporation was used in this study. Main characteristics of this cement are presented in Table 1.

2.1.2. Wood and modification

The experiment adopted wood particles from waste building wood and recycled forestry industry machining residues. Larch wood was used in this study since it is commonly used in the construction industry in China. Since wood does not have a natural affinity with cement [17], some additives or surface treatment of the wood are required to improve compatibility of wood and cement [18]. In this experiment, wood particles were pretreated with 1 g/L of NaOH solution, and dissolved in phenolic acid, uronic acid and others which are bound with the polysaccharides in cell walls, then was washed with water for many times. This treatment could degrade hemicelluloses into pentosan. At the same time, a thin film was formed on the surface of wood, which, in return, prevented the release of "harmful substances" and enhanced adaptability to cement. Then treated wood particles were dried through specific dry machines and then ground. A screen analysis indicated that the particle length ranged from 5 to 25 mm, width from 1.0 to 10 mm, and thickness from 0.2 to 0.5 mm.

2.1.3. Tire crumb and modification

Rubber particles were prepared from waste tires with reinforced tendons being mechanically removed prior to grinding. The size of rubber particles used were 1 mm, 2 mm and 3 mm. Generally, rubber is an inert material with low surface energy. The lubricants in the tire rubber such as zinc stearate, anti-sticking agent, and activation agent for vulcanization of the tire rubber will impair the bonding strength between tire crumbs, wood particles and cement paste. Therefore, the use of coupling agents or chemical modification of the tire crumb surface in order to maximize mechanical properties of the composites is required.

2.1.4. Coupling agent

A commercial PMDI resin was used as coupling agent in this work. It was provided by Wan Hua Polyurethanes Co. Ltd. from China. Characteristics of PMDI are given as below:

Appearance	Brown liquid
NCO content	30.77%
Viscosity	200 cps
PMDI equivalent	142
Density	1.24
Functional degree	2.7

It is well known that PMDI has a rigid hard segment with great internal cohesive energy, resulting in higher cohesive strength than aliphatic isocyanate. Modification process was made by adding polyether into PMDI. Polyether can enhance flexibility of PMDI, attributing to the long and flexible molecular chain of polyether resulted from the steric hindrance from curved molecular structure.

2.2. Experimental procedures

2.2.1. Specimens

RWCC panel with a target density of 1250 kg/m^3 was manufactured, the ratio of water consumption to total contents of wood