Construction and Building Materials 34 (2012) 77–82

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Evaluation of cement-bonded strawboard against alternative cement-based siding products

Parviz Soroushian [a], Maan Hassan [b,c,*]

[a] Civil and Environmental Engineering, Michigan State University, East Lansing, MI 48824-1226, United States
[b] Building and Construction Engineering, University of Technology, Baghdad, Iraq
[c] Michigan State University, United States

ARTICLE INFO

Article history:
Received 15 October 2011
Received in revised form 4 January 2012
Accepted 23 February 2012
Available online 29 March 2012

Keywords:
Cereal straw
Cement-bonded particleboard
Cement composites
Carbonation
Flexural strength
Pretreatment

ABSTRACT

Cement-bonded strawboard was developed as a new siding product with desired aesthetic attributes, workability and engineering characteristics. The high extractive and wax content of straw presents important challenges to production of cement-bonded strawboard. A broad variety of straw pretreatment techniques were evaluated for enhancement of straw compatibility with hydration of cement. Accelerated processing techniques involve applying pressure for densification and heating system were used. Use of admixtures and the specifics of strawboard production techniques were also essential to successful development of cement-bonded strawboard. The complementary use of these measures contributed towards development of cement-bonded strawboards which met the standard requirements for cement-based siding products and did not exhibit any degradation upon exposure to accelerated aging effects.

1. Introduction

Agricultural residues are primarily the stems, leaves, and chaff of crops remaining in fields or at processing facilities after greater-value products of the plants (for example, grain, seeds, nuts, tubers, etc.) have been harvested [1]. Agricultural residues are mostly generated at two different stages: (1) after harvesting the main crop, such as straw in cereal production; and (2) after processing the plant in industrial operations, such as bagasse in sugar industry. Agricultural and allied industrial wastes are generated in tremendous quantities.

Cereal straw is generated at quantities which exceed those of edible grains (wheat, corn, rice, barley, rye and oats). Although crop residues retained on soil provide conservation benefits, excess quantities are still available which represent major inputs of effort and expense in the form of labor, fuel, water and nutrients. The annual domestic and worldwide production of straw exceed 140 million and 2 billion tons, respectively, about half of which can be harvested with outlasting damage to the soil [2–4]. If the residues are not utilized to their fullest extent, a major part of the production is wasted. Removal of straw also yields the following benefits [5]: (1) better herbicide performance; (2) improved weed control; (3) reduced rate of herbicide application; (4) reduced bacteria load on the land and thus reduced occurrence of straw-borne diseases; and (5) reduced tillage costs.

Residue management decisions have immediate short-term implications and many long-term economic consequences. New technologies for value-added use of agricultural residues can generate industrial activities with major economic benefits to rural communities [1]. A 10% (110 million m^2/yr) share of US siding markets for strawboard would make value-added use of about 1 million tons/yr of cereal straw; the resulting direct benefits to rural economies (value-added markets for straw, new employment opportunities in production plants) are estimated at about \$100 million/yr, with additional indirect financial benefits of about \$300 million/yr. Close to 15 strawboard production plants would be needed to serve this market share. These plants, due to the economy of residue transportation, would be located in rural areas, where close to 5000 new employment opportunities would be created. The initial focus of this investigation is on cereal straws; regional rates of cereal crop production would thus be a key factor in locating cement-bonded strawboard manufacturing plants making value-added use of different cereal straws.

2. Impact of agricultural residues on hydration of cement

The competitive reinforcement value of straw has led to major activities towards development of different classes of “strawboard”. There is a very long tradition of using straw in clay and similar building materials.

---

* Corresponding author at: Building and Construction Engineering, University of Technology, Baghdad, Iraq. Tel.: +964 7901151092/+1 517 488 4793.
E-mail addresses: hassanm4@msu.edu, maan_s_h@yahoo.co.uk (M. Hassan).

0950-0618/\$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2012.02.011

Nomenclature

CBCB	cement-bonded cellulose fiberboard
CBPB	cement-bonded wood particleboard
CBSB	cement-bonded strawboard

Cereal (wheat, barley, rice, and others) straw is a major by-product of agricultural activities, which is available in excess amounts. Current applications as supplementary animal feed, fuel and feedstock for chemical industry still leave substantial quantities of surplus straw [6–9]. Straw is distinguished from wood by a relatively high concentration of (water-soluble) extractives; potential inhibitory effects of such extractives on hydration of cement and stability of straw in alkaline environments need to be addressed for successful use of straw in conjunction with cement [10,11]. An environmentally preferred approach to effective use of straw in cement-based products involves accelerated CO_2 curing to overcome the inhibitory effects of straw on hydration of cement, and to lower the alkalinity of the cement-based matrix for improved compatibility with straw [2]. Once the inhibitory and stability concerns are addressed, straw offers desirable reinforcement attributes for use in cement-based products. These attributes add to the value of straw as an economical and environmentally friendly substitute for mechanically milled wood in thin-sheet cement products.

Ide and Simpson [12] confirmed the inhibitory effects of cereal straws on hydration of cement. While hot water extraction proved effective in improving compatibility of inhibitory wood species with cement, this was not the case with cereal straws. Eusebio and Suzuki [13] investigated compatibility with cement of rice straw and coconut coir dust. Results revealed that cold and hot water extractives of rice straw retarded strength development of cement in conventional curing processes; coconut coir dust extractives, on the other hand, did not adversely affect strength development of cement. This observation highlights distinct attributes of various agricultural residues.

Eusebio [14] recognized the retarding effects of a local fibrous agricultural residue, rattan shavings, and devised processing means of overcoming this deficiency. Rapid curing techniques involving carbonation reactions were employed to overcome this problem. The resulting boards exhibited satisfactory levels of strength and dimensional stability.

3. Experimental program

Cement-bonded strawboards were manufactured at 1.35 bulk specific gravity (and 12 mm thickness) with the following mix proportions: Type I Portland cement (5600 g), silica fume (700 g), sodium silicate (1600 g), sodium bicarbonate (1300 g), straw (1000 g), water-repellant (100 g), and water (2100 g). Straw was pretreated through, immersion in lime-saturated water for 1 month at room temperature (followed by air drying). The cement-bonded strawboard mixture was prepared and subjected to hot pressing under conditions describe in the following sections. The strawboard was subsequently conditioned at 50% relative humidity and 22 °C for 14 days.

The competing commercial panel products used for evaluation of cement-bonded strawboard (CBSB) were: (i) cement-bonded wood particleboard (CBPB); and (ii) cement-bonded cellulose fiberboard (CBCB). The cement-bonded strawboard and commercial products were subjected to flexure testing (ASTM C 1185, see Fig. 1) in saturated condition (after 48 h of immersion in water). The bulk specific gravity, water absorption capacity, and thickness swell of strawboard and commercial specimens were also measured. Strawboard and commercial specimens were also subjected to 100 cycles of wet–dry cycles (ASTM C 1185), 100 days of immersion in warm water (ASTM C 1185), and 100 freeze–thaw cycles (ASTM C 666 – freezing in water); the aged specimens were subjected to flexure testing in saturated condition (ASTM C 1185).

3.1. Size reduction and pretreatment of straw

Straw was hammer milled on a 9 mm mesh (see Fig. 2), yielding the reinforcing elements (milled straw) for use in cement-bonded strawboard. Table 1 provides a summary statistics of the measured values of hammer milled straw length, width and thickness. Milled straw provides average length, width and thickness of 10.7, 1.1 and 0.16 mm, respectively, yielding mean slenderness ratio of 23 which is greater than wood “fibers” commonly used in cement-bonded wood particleboard. The higher slenderness ratio of straw is expected to enhance its reinforcement efficiency. The naturally low thickness of straw also implies that its moisture movements, when compared with those of wood particles of higher thickness, would impose less stress on the surrounding cement-based matrix. This is expected to enhance the durability of cement-bonded strawboard which compared with cement-bonded wood particleboard.

Straw extractives have strong retarding effects on hydration of cement. If used without any pretreatment, straw extractive and waxes would continue to leach out of cement-bonded strawboard under outdoor exposure conditions, and would undermine the aesthetics and performance characteristics of panels. Hence, it is critical to thoroughly remove the extractives and waxes from straw prior to its use with cement. The first pretreatment involved immersion of straw over a period of 6 h in hot (95 °C) lime saturated water, with 6 wt.% lime concentration, at straw to lime saturated water weight ratio of 0.10. The second pretreatment condition considered in this investigation involved immersion of straw in lime-saturated solution at room temperature over a period of 30 days, where the straw was washed with tap water every other day.

3.2. Preparation of the furnish

The key mix ingredients were pretreated straw, Portland cement, silica fume, sodium silicate, sodium hydrogen carbonate, water, and water-repellant. The mixing process started with preparation of a solution of sodium silicate in half of the mixing water, which was then blended with straw and cement. After about 5 min of mixing, sodium hydrogen carbonate was added, and mixing continued for another 5 min. The furnish provided sufficient open time for convenient shipment to press where it was spread and then pressed to targeted thickness and density.

3.3. Compaction and curing of cement-bonded strawboard

A scaled-up press system (see Fig. 3) was fabricated for production of 813 × 1016 mm (23 × 40 in.) cement-bonded strawboard. These dimensions were chosen to suit common stud spacing in residential siding applications; full-scale boards in commercial production would be 1219 × 2438 mm (48 × 96 in.). The scaled-up press included a 200-ton capacity hydraulic actuator, which was needed to apply the required pressure for densification of cement-bonded strawboard. The electrical heating system was also enhanced to enable heating of the relatively large panels. The surface of molds to be placed in this press, onto which the furnish would be spread, was textured so that the board would mimic the appearance of brick siding. At the targeted thickness of 12 mm, we could introduce deep, realistic textures without compromising the structural quality of boards.

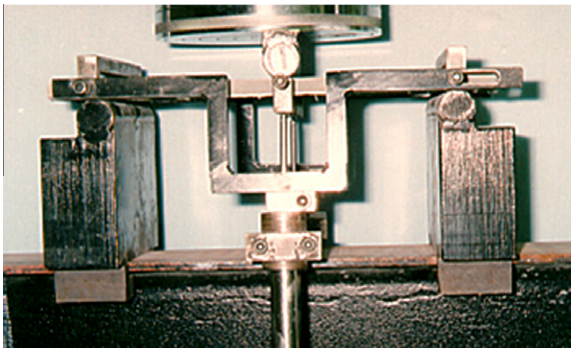

Fig. 1. The three-point flexural test set-up.