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Utilisation of waste cardboard and Nano silica fume in the production of fibre cement board reinforced by glass fibres

Morteza Khorami [a,*], Eshmaeil Ganjian [a], Azamalsadat Mortazavi [b], Messaoud Saidani [a], Adegoke Olubanwo [a], Alfred Gand [a]

[a] School of Energy, Construction & Environment, Faculty of Engineering, Environment & Computing, Sir John Laing Building, Much Park Street, Coventry University, Coventry CV1 2HF, United Kingdom

[b] Faculty of Art and Architecture of Islamic Azad University Tehran Center Branch, Niayesh boulevard, Punak, Tehran, Iran

HIGHLIGHTS

- Kraft fibre extracted from waste cardboard can be used in cement board production.
- Incorporating glass fibres with Kraft fibre can increase flexural strength of cement board.
- An appropriate amount of Nano Silica Fume can improve properties of cement board.

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ABSTRACT

In this research, Glass Fibres (GL), Kraft pulp Fibres (KF) and Nano Silica Fume (NSF) were used to produce Cement Composite Board (CCB).

Fifteen groups of mix proportions were produced to investigate the effects of fibre content and size along with the effect of NSF on interaction, bonding and mechanical properties of CCB. Density, Water Absorption, Moisture Movement, Flexural Strength test and Scanning Electron Microscopy observations were conducted. The results showed that some mixes could meet the standard requirements and also the inclusion of GL and NSF into the mix containing KF (extracted from waste cardboard) could enhance the characteristics of CCB.

1. Introduction

Cementitious composites are typically characterised as being brittle with low tensile strength and strain capacities. Fibres are introduced into the matrix to overcome these weaknesses [1,2]. The effectiveness of the fibre reinforcement depends on a number of factors, such as mix preparation process, size, type, geometry, volume and dispersion models of fibres [3,4].

Reinforcement fibres not only improve bearing capacity of CCB but also increase fracture toughness of specimens by decreasing the concentrated applied stresses acting on the tip of cracks [5,6].

Typical CCBs consist of two or more types of fibres. Some fibres are used to enhance the production process, other may have an important role in increasing the bearing capacity and fracture toughness [3–5]. Thus, the combination of fibres and materials can offer more benefits than the individual entities.

Different types of fibres from natural and synthetic sources have been investigated for their suitability in CCB. Cellulose fibres have increasing popularity over the past two decades, due to their renewability, accessibility, low-cost production process, mechanical property, and compatibility with hydrated cement media [1,6–8].

The interfacial bond between fibres and hydrated cementitious material has an important role in increasing the bearing capacity of CCB. It is essential to use appropriate fibres and accurate proportion of materials in the mix design to achieve the best efficiency of the product. For example, steel fibres have high tensile strength but are weak in interfacial bonding with hydrated cement products. So, they pull out from the matrix in the first stages of loading before reaching their maximum tensile strength. Several methods have been suggested to increase the interfacial bond such as applying additives, fibre treatment and decreasing the fibre-cement gaps

Abbreviations: GL, Glass Fibres; KF, Kraft pulp Fibres; NSF, Nano Silica Fume; CCB, Cement Composite Board; WA, Water Absorption; MM, Moisture Movement; FS, Flexural Strength; SEM, Scanning Electron Microscopy.

* Corresponding author.
E-mail addresses: morteza.khorami@coventry.ac.uk, mrz_khorrami@yahoo.com (M. Khorami).

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using the vacuum/compressive pressure in the production of CCBs [3,6,9,10].

Concerns have been raised regarding the use of CCBs in roofing and cladding applications, mainly due to long-term exposure to aggressive environments. The studies showed that CCBs containing cellulose fibres solely are more sensitive to aggressive ambient conditions and may undergo a reduction in flexural strength and fracture toughness over time. This is associated with a decrease in bearing capacity of CCBs, due to a combination of deterioration of cellulose fibres in the high alkaline environment, fibre mineralisation and volume increasing due to their high water absorption. The high alkaline matrix could easily decompose the lignin and hemicellulose phase that linked individual filaments and resulting in an inhibitory effect on hydration of cement and weakness in fibre structure. In addition, cellulose volume variation could create cracks in the interfacial zone leading to a decrease in fibre pull out strength [1,5,11,12].

To provide a less aggressive environment for cellulose fibres, the concentration of hydroxyl in the pore solution needs to be reduced. This could be done by introducing Sulpho Aluminate, Metakaolin or micro silica into the mix [13,14]. The addition of pozzolans such as Nano Silica Fume (NSF) in the cement composite reinforced by natural and polymeric fibres could increase the flexural behaviour of samples [3,11,15].

Previous research carried out by the first and second author has shown that the negative effects of lignocellulosic particles cement interaction can be controlled by NSF to enhance durability and flexural strength of CCB [3,5].

Following concerns relating to asbestos hazard on human health, in the early 1970s, a global movement was established to remove asbestos fibres from a wide range of products such as asbestos-cement board. One of the most important synthetic fibres used as a replacement for asbestos fibres in cement board production is PVA (Poly Vinyl Alcohol) which can be relatively expensive. It should be taken into account that besides monopolising PVA production technology by several companies, difficulty in accessibility and the high cost of PVA are other adverse factors to using those fibres in some developing countries [1,4,16].

In this research, an attempt has been made to investigate the feasibility of producing CCB using a combination of GLs, KFs and NSF, which are relatively cost effective and also readily accessible in most countries.

GL has a number of advantageous such as low cost, high tensile strength, and high chemical resistance. It has already been used in cement mortar and demonstrated to have significantly improved the tensile strength and ductility characteristics.

The use of normal type GLs incorporated to CCB has shown poor durability due to the following:

i) Hydroxyl ions resulted from cement hydration can cause corrosion on the fibres.
ii) Precipitation of calcium hydroxide within the GLs, can change the microstructure of fibres from flexible to rigid. This may change the mode of failure from fibre pull out to fibre fracture.
iii) Densify the interfacial zone decrease fibres compliance, consequently the non-uniform tensile stress induced by flexural loading would disrupt fibre-bridging effect in cracks.

To overcome those above-mentioned problems, it has been suggested to apply “alkali resistant GLs” instead of normal GLs in production of CCB [4,17]. In other words, only alkali resistant GL should be used in cement composite, otherwise, due to chemical corrosion of normal GLs in alkaline media, CCBs can become brittle and weaker through the cement hydration process [18,19]. Currently, alkali resistant GL which is highly resistant to alkalis, acids and corrosion have been developed for reinforcing of cement composite.

The use of Nano silica fume in CCB has already been investigated by authors [3] and the results showed that NSF could increase the flexural strength, bending strength and fracture toughness of CCB reinforced by cellulose fibres.

In this research, the characteristics of CCB reinforced by Kraft pulp fibres extracted from waste cardboard and alkali resistant GL incorporating NSF have been investigated.

2. Experimental methodology

2.1. Materials

The materials used in this research include:

- Portland cement: Ordinary Portland cement Type I, satisfying the requirement of BS EN 197-1: 2000.
- Kraft pulp fibres extracted from waste cardboard and refined by using laboratory refiner equipment.
- Nano Silica Fume (Grade 999): particle size distribution, physical and chemical properties of Nano silica have been illustrated in Table1.
- Glass Fibres: GL has a three-dimensional structure and is considered as isotropic materials comprises of a long network of oxygen, silicon and other atoms arranged in a random fashion. The GLs provided for this research have the non-crystalline structure, that is, amorphous, with no distinct shape and classed as alkali resistant glass fibres. They were used in 3 mm and 6 mm lengths. The properties of Kraft fibres extracted from waste cardboard and GL are given in Table 2.

It should be noted that due to the short length of fibres, measuring the tensile strength was not possible with existing equipment.

The freeness of pulp is designed to give a measure of the rate at which a dilute suspension of pulp (3 g of pulp in 1 L of water) may be drained. The freeness, or the drainage time of pulp is related to the surface conditions and swelling of the fibres. Drainage of unrefined pulp, which is measured as freeness, can give an indication of:

- The fibre length. In which, the long fibres have more freeness compared to short fibres.
- Damage to fibres during pulping, bleaching or drying. In which, short fibres or fines that are produced during the pulping operation reduce pulp freeness.
- The refining energy required to achieve certain slowness during stock preparation.

In this study, the freeness test was carried out according to AS/NZS 1301.206s:2002 standard. Freeness is commonly called Canadian Standard Freeness (CSF) because it has been based on the test developed by the Canadian Pulp and Paper Research Institute. For the current study, CSF measured for KFs was around 560–600.

2.2. Production of the specimens

For each mix code, the slurry contains water, cementitious materials and fibres with a high water/cement ratio (i.e. around 3 by the weight of cement) was prepared in a mixer.

Then it is poured into a mould and subjected to vacuum and compressive stress of 7 kN/m^2 to form a flat sheet. After the slurry dewatering process, pad (dimensions 180 × 82 × 7 mm) was demoulded and cured for 21 days at 95% of relative humidity and air cured in the laboratory for 7 days at a temperature of 20 ± 2 °C. The cured specimens were subsequently tested.

2.3. Tests

The following subsections outline the tests undertaken in accordance with 1) BS EN 494:2004 + A3:2007 (Fibre-cement profiled sheets and fittings – Product specification and test methods) and 2) BS EN 12467:2004 (Fibre-cement flat sheets – Product specification and test methods).

Table 1
Physical and chemical properties of Nano silica fume.

Colour	White
Melting Point (°C)	Approx. 1650
Solubility (Water)	Poorly water soluble
Specific Gravity (Water = 1.0)	2.25
Bulk Density (kg/m^3)	95–105
Specific Surface (m^2/g)	50–60
pH Value	3.6–4.5