Project Title:	Recycling Used Timber Formwork into Lightweight, Thermal-insulating Cement-bonded Particleboards
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Research Institution:	The Hong Kong Polytechnic University
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Objective

This feasibility study is to facilitate waste wood recycling from construction sites by exploring ways to transform end-of-life formwork into high-performance, eco-friendly, and low-cost cement-bonded particleboards.

Background

In 2013, approximately 3,600 tonnes of construction waste were disposed to landfill daily in Hong Kong, accounting for about 25% of the total landfill disposal. Approximate by 20% of total non-inert waste, which was the most dominant waste at construction sites, were disposed to landfills. Although wood formwork, the typical non-inert waste, was reused on site, at the end of its service life, it is contaminated with residual cement. Moreover, timber boards were usually accompanied with preservative chemicals such as chromated copper arsenate (CCA) to protect them from insects, fungi, and bacteria attack. CCA accounts for two-third volume of the preservative chemicals and poses a serious long-term risk of potential leaching and environmental contamination. Therefore, developing innovative approaches for timber waste recycling would present significant environmental benefits.

Data and Methodology

The research was divided into three phases as summarized below.

Phase 1 - A series of experiments were conducted to explore the manufacturing process of cement-bonded particleboards with strong mechanical properties and high dimensional stability. Initially, wood aggregates, OPC binder, and accelerators were homogeneously mixed by a mechanical mixer and compressed in a steel mould. The particleboards were then demoulded after 24 hours and subjected to 7-days or 28-days air curing at 20℃ and 95% humidity in a curing chamber. The aggregate-to-cement ratio, water-to-cement ratio, and the resulting densities were investigated for achieving the mechanical strength required by ISO 8335 international standard for particleboards.

Phase 2 - The manufacturing process and mixture design were improved to produce functional and tailored cement-bonded particleboards. The particleboards were carbonated and assessed by spraying 1% phenolphthalein on the cross-section of samples as a pH indicator test. To reinforce the particleboard strength, two types of basalt fibre were applied. The flexural strength and tensile strength of the particleboards were then measured by a standard testing machine at a loading rate of 0.3 mm min^{-1} to calculate the fracture energy and elastic modulus. The compressive stress was also examined by a universal testing machine with a maximum capacity of 3000 kN at a rate of 0.6 MPa s^{-1} with the corresponding strain measured by strain gauges attached to the sample surface. In addition, thermal conductivity was measured by Quick Thermal Conductivity Meter; the performance of sound insulation was evaluated using a sound reduction index (ASTM E336, 2012), and impact noise reduction was measured by a tapping machine (ASTM E492, 2009).

Phase 3 - Structured interviews and questionnaires were conducted to identify significant factors that affect decision-makers in government and private construction enterprises in using recycled products. There are eight questions in the questionnaire, including past behaviour of interviews, perceived costs, benefits and social pressure identified, factors determining the use of recycled materials, decision-makers for the use of recycled materials and product evaluation on innovative recycled particleboards. Ten structured face-to-face interviews were conducted. The interviewees came from government, construction-related organizations and environmental consultants.

Results and Findings

The results and findings for each phase were listed below.

Phase 1 - The results showed that using coarse wood particles (2.36-5 mm), 2% $CaCl_2$ as additives, wood-to-cement ratio of 3:7, water-to-cement ratio of 0.3 and design porosity of 5%, the cement-bonded particleboards had strong mechanical properties and high dimensional stability. The bending strength and thickness swelling of a 28-day sample were 12.8 MPa and 0.76%, respectively, which could fulfill the international standard requirement for cement-bonded particleboards (9 MPa and 2%, respectively). Besides, 1% chopped basalt fiber addition dramatically enhanced the strength and stiffness of the products.

Phase 2 - The results showed that CO_2 curing significantly facilitated cement hydration and accelerated $Ca(OH)_2$ transformation into $CaCO_3$, which contributed to strength development and carbon sequestration (as high as 9.2 wt%) in the particleboards. Besides, the particleboards presented excellent properties in terms of thermal insulation and noise reduction. The thermal conductivity of the cement-bonded particleboards was only 19% of the ordinary concrete boards, and the noise insulation effectiveness of the particleboards was also better than the ordinary concrete boards, especially at a low sound frequency (32-100 Hz).

Phase 3 - Structured-interview results showed that waste recycling intention is influenced by perceived benefits and costs, social and moral values, and behaviour control beliefs. Regulatory compliance was the most determining factor affecting individuals' decision-making in using recycled materials. Questionnaire results demonstrated that the industry would like to have "high fire resistance" and "high mechanical strength" properties in the recycled products.

Recommendations

Interior decorative wall panels and noise barriers are two major potential applications of cement-bonded particleboards. Therefore, relevant technical parameters should be assessed in detail. For interior decorative wall panels, fire and thermal insulation should be evaluated and the fire resistance of the particleboards can be improved by using some fire retardants and protective coating. As for noise barriers, the various acoustic properties should be evaluated, and the acoustic properties could be improved by varying pore structure and surface treatment.

Furthermore, based on the bench-scale results, the optimum mixture design and manufacturing parameters should be further evaluated in the pilot-scale validation. To ensure the applicability to different waste formworks, a demonstrative production line should be set up in construction site. From the pilot-scale results, technology upgrading may need to be conducted to simplify the process, reduce the production cost, enhance the production efficiency and improve the quality of products.