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Light-weight wood–magnesium oxychloride cement composite building products made by extrusion

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ABSTRACT

Magnesium oxychloride (MOC) cement is a type of non-hydraulic cement with yellowish color in nature and low alkalinity exhibiting many other properties superior to Portland Cement (PC). In this study, light-weight wood–MOC cement composite building products, with sawdust and/or perlite as aggregate, were made through extrusion. Physical, nailing and mechanical properties of these composites were investigated. It was found that the specific dry densities of the wood–MOC cement composites were close to 1.0 and they were nailable like hard natural wood. Their flexural strength decreased as temperature increased. By replacing 50% sawdust in weight by perlite, the composite exhibited less die swell and better performance in resisting high temperature.

1. Introduction

Magnesium oxychloride (MOC) cement, also known as Sorel cement, is a type of non-hydraulic cement. As an air-dried magnesia-based cementitious material, MOC cement was developed shortly after the invention of Portland Cement (PC) [1]. It is formed by mixing magnesium oxide (MgO) powder with magnesium chloride ($MgCl_2$) solution. MOC cement has many properties superior to PC including: lower carbon emission, higher fire resistance, higher abrasion resistance, higher temperature resistance, lower thermal conductivity, lower shrinkage and creep and better durability [2]. MOC cement sets and hardens much quicker than PC making it ideal for rapidly repairing infrastructure, such as highway and airport runway. The lower alkalinity of MOC cement makes it good when using with glass fibers without the aging problem which is very common when glass fibers are mixed with PC. MOC cement is also good for mixing with wood particles and sawdust to make wood-like composites and building products. One of the greatest advantages of these composites is that MOC cement has yellowish color in nature which is very close to the color of many natural woods. In wood–PC composites, the lignin compounds and adverse chemicals in woods may retard the hydration of PC, resulting in the wood–PC composites having very low early strength. MOC cement, on the other hand, can largely reduce this problem, resulting in a perfect match between wood and cement for composites for building industry and residential applications, such as window and door frames, door panels, sidings and partition walls.

Light-burnt MgO, one of the raw materials required for making MOC cement, is normally obtained by calcinations of magnesite ($MgCO_3$) at a temperature of around 750 °C, which is much lower than 1400 °C, the temperature, needed for calcinations of cement clinker. The quality and reactivity of the formed MgO powder is largely affected by its thermal history (i.e., calcination temperature and duration) and particle size. This in turn affects both the reaction rate and the properties of the reacted products of MOC cement. The hydration of MOC cement takes place in a through-solution reaction with four main reaction phases being $2Mg(OH)_2{\cdot}MgCl_2{\cdot}4H_2O$ (phase 2), $3Mg(OH)_2{\cdot}MgCl_2{\cdot}8H_2O$ (phase 3), $5Mg(OH)_2{\cdot}MgCl_2{\cdot}8H_2O$ (phase 5), and $9Mg(OH)_2{\cdot}MgCl_2{\cdot}5H_2O$ (phase 9) [3]. It has been found that phases 3 and 5 can exist at ambient temperature while phases 2 and 9 are only stable at temperature above 100 °C [4]. Recently, the hydration, microstructure, and physical and mechanical properties of MOC cement and the reactivity of MgO in MOC cement have been thoroughly studied [5–8].

Extrusion is an advanced material processing technique that can be used to produce high performance fiber-reinforced cement-based composite building materials and products. In extrusion,

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semi-solid dough-like fresh cement mixture, normally reinforced by short discrete fibers, is forced through a die of desired cross-section using either an auger or a ram. During this process, the fresh mixture is subjected to high compression and high shear, which densifies the cement matrix, improves the fiber–matrix bond, and aligns fibers in the direction of extrusion [9–11]. As a result, the mechanical performance and durability of the composites are superior to cast composites with similar mix proportions. As a material processing technology, extrusion has many superior properties as compared to other material processing technique in manufacturing cement-based building products, which include mass production with low cost, environmental friendly, low energy and water consumption, and better quality control of final products. Besides, it is easy to make laminar structure, sandwich structure etc. through multi-layer extrusion or co-axial extrusion. This technique has gradually drawn research and industrial interests due to the increasing awareness of carbon emission, energy and water consumption. Recently, the European Commission has funded a 2.72 million Euro project – *Nanotechnology Enhanced Extruded Fiber Reinforced Foam Cement Based Environmental Friendly Sandwich Material for Building Application (FIBCEM)*, through the 7th Framework Programme to an inter-European Union (EU) consortium with 10 partners from 5 EU member state countries in which the first author was appointed as the Scientific Coordinator. The FIBCEM project aims at exploring a low-energy extrusion technology, to replace traditional fiber-cement techniques such as the Hatschek process which was invented more than 100 years ago and is still the main material processing technique in fiber-cement building material industry, for manufacturing cement-based building products like roof tiles and sidings to reduce labor and material costs, energy and water consumption, and carbon emission. Hatschek method is a commercial material processing technique for making asbestos cement and cellulose fiber-cement composite sheets. Though the Hatschek method is featured a continuous operation like screw extrusion, composites made by this method are usually brittle [9]. Besides, Hatschek process generates high level of waste water and delamination of layers was found in the cement-based materials made by this method during the freeze–thaw cycle [12]. Therefore, an alternative processing method for cement-based building materials and products is desirable. In line with this, extrusion is a good candidate to replace traditional Hatschek process.

2. Materials and testing

2.1. Materials and mix formulations

In this study, light-burnt MgO powders, supplied as an industry raw material from Ji'nan, China, were used as one of the raw materials for making MOC cement in laboratory, which had a purity of 96%. Another raw material for making MOC cement was $MgCl_2$ crystals, which was also industrial-grade chemicals with the purity of 98% from Israel. The chemical compositions of the light-burnt MgO powders are shown in Table 1 while the microstructure of MgO powders under Scan Electronic Microscope (SEM) is shown in Fig. 1. The two images in Fig. 1 were taken from the same MgO powder sample but from different angles. Sawdust, which was obtained from a wood workshop as residuals when cutting natural and/or recycled wood, was used as aggregates for both composites. There were some wood fibers in the sawdust as observed from naked eyes. However, the sawdust was incorporated into the wood–MOC cement composites without any special pretreatment. Perlite was also used to partially replace sawdust in Composite 2 as aggregate, which was obtained from the same source as those used elsewhere [13] for making light-weight fire-resistant wall panels through extrusion technique. It had a bulk density of 160 kg/m^3 and specific gravity of 0.30 with a thermal conduction coefficient of 0.050 w/mk and water absorption volume ratio of about 50%. Over 99.9% perlite particles passed the 1.18 mm sieve followed by 11.81% passing the 0.6 mm sieve, 9.78% passing the 0.3 mm sieve, and 3.45% passing the 0.15 mm sieve in particle size distribution tests. According to the provider, about 35% bulk volume of the perlite aggregates will be lost under 1 MPa pressure. The chemical compositions of perlite are also shown in Table 1. Perlite is a kind of light-weight cellular filler formed by heating the crushed natural volcanic mineral. When this kind of glassy aggregate is mixed with PC, it can undergo either alkali silica or pozzolanic reactions in wet environment [14]. The lower alkalinity of MOC cement, on the other hand, can largely reduce this adverse possible alkali silica reaction in MOC cement. In total, two light-weight wood–MOC cement composite materials were made and extruded using sawdust and/or perlite as aggregate. The mix formulations of these two composite materials are shown in Table 2. Polyvinyl acetate (PVA) and glass fibers are two types of fibers used to reinforce cement composites. PVA fibers are able to enhance ductility of cement composites but they have relatively lower strength, modulus of elasticity and ignition point compared with glass fibers. On the other hand, glass fibers are brittle and deteriorate quickly in the alkali environment of PC. MOC cement has lower alkalinity than PC so potentially glass fibers are compatible with MOC cement composites to improve their strength and stiffness. Therefore, it may demonstrate great advantage by hybrid usage of PVA and glass fibers in MOC cement composites. Therefore, in this study, a hybrid usage of PVA and glass fibers was adopted to reinforce the wood–MOC cement composites. The physical and mechanical properties of short discrete PVA fibers and glass fibers used to reinforce the wood–MOC cement composites are shown in Table 3. It should be noted that glass fibers was not bundled rather they were discrete when they were incorporated into wood–MOC cement mixtures. Besides, $MgSO_4$ can be a minor ingredient for making MOC cement. In this study, the amount of $MgSO_4$, in this case 300 g, is small compared with that of $MgCl_2$, which is 1200 g in the solution. For each composite, two types of full-scale building products, i.e., door frame and door panel, were made through a single screw arguer extruder (as shown in Fig. 2a).

Table 1
Chemical compositions of light-burnt MgO and perlite (% in weight).

	CaO	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	K_2O	Na_2O	MgO	TiO	SO_3
MgO	1.4	0.8	0	0.8	0	0	0	96.6	0	0.1
Perlite	0.76	72.9	12.9	0.53	0.05	5.30	2.57	0.16	0.05	0

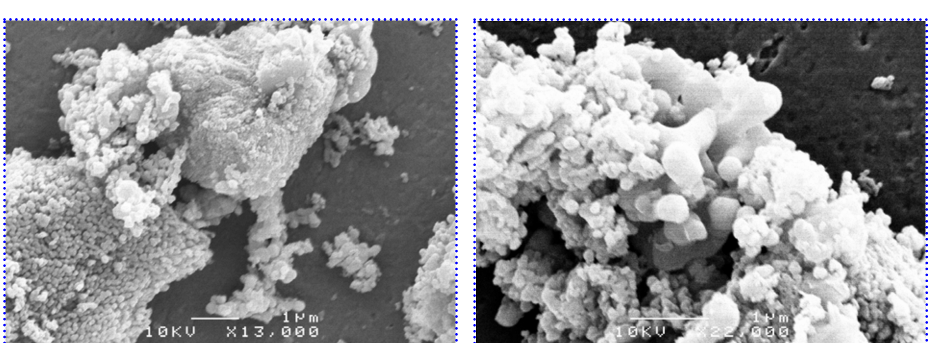

Fig. 1. Microstructure of the light-burnt MgO powder under SEM.

Table 2
Mix proportions for door frames and door panels (all values are in weight in g).

Composite	MgO	Sawdust	Perlite	$MgCl_2$ solution[a]	$MgSO_4$	PVA fiber	Glass fiber	Water[b]	Other solution
1	3000	1500	0	3000	300	60	120	2150	450
2	3000	750	750	3000	300	60	120	2150	450

[a] The $MgCl_2$ solution had the concentration of 25% (in weight of $MgCl_2$) with 120 g Carboxymethyl Hydroxypropyl Cellulose (CMC) powder and 60 g Polymer Polyacrylamide (PAM) powder dissolved in both used as rheology enhancing admixture.
[b] Water added into the fresh composites consisted of two parts: (1) 1400 g PAM solution with the concentration of 3% (in weight of PAM powder); and (2) 750 g pure water.

Table 3
Properties of short polyvinyl alcohol (PVA) fiber and glass fiber.

Fiber	Density (g/cm^3)	Tensile strength (MPa)	Elastic modulus (GPa)	Length (mm)	Diameter (μm)	Aspect ratio
PVA fiber	1.30	1500	36	6	14	430
Glass fiber	2.53	3600	70	12	8	1500

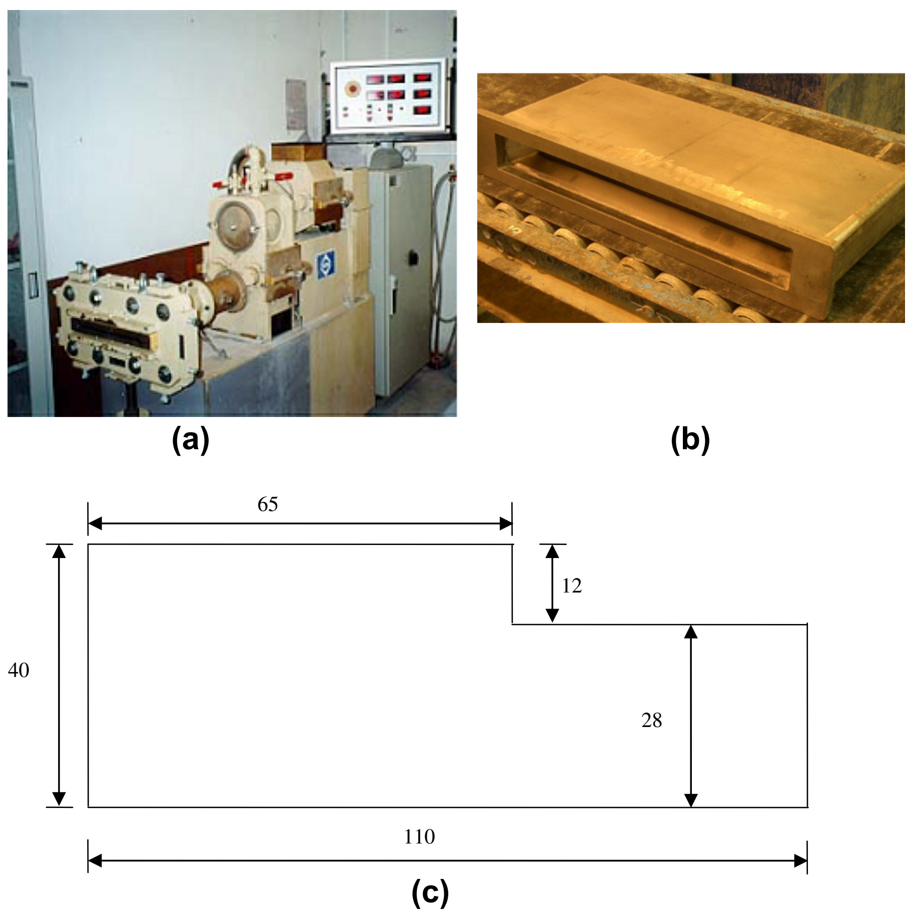

Fig. 2. The extruder and dies: (a) the single-screw extruder; (b) the door-panel die; and (c) the inner geometries of the door-frame die (all dimensions are in mm).

2.2. Preparation of fresh mixture and extrusion

To make MOC cement and prepare fresh wood–MOC cement mixture for extrusion, $MgCl_2$ crystals were dissolved into water to prepare a solution with the concentration of 25%. Then rheology enhancing admixtures, Polymer Polyacrylamide (PAM) and Carboxymethyl Hydroxypropyl Cellulose (CMC), were dissolved into the $MgCl_2$ solution 1 day before preparing the fresh wood–MOC cement mixture for extrusion. It should be noted that PAM is a new type of rheology enhancing admixture for cement-based materials for extrusion purpose which is much cheaper than traditional rheology enhancing admixtures such as Methocel and CMC [15]. But it is not as effective as Methocel or CMC in enhancing rheology of cement-based mixtures. Therefore, a hybrid usage of PAM and CMC as rheology enhancing admixture was adopted for wood–MOC cement composites tailored for extrusion in this study by considering the balance of efficiency in processing and cost of final products. To increase the dissolving of the high molecular weight rheology enhancing admixtures, in this case PAM and CMC, in the $MgCl_2$ solution, water bath curing method was adopted in which the container with the $MgCl_2$ solution, PAM and CMC, was put in water bath with the temperature of around 60 °C for a couple of hours. Finally a transparent gel was reached. To prepare the fresh mixture suitable for extrusion, first, 2/3 MgO powder was mixed with around 2/3 sawdust and/or perlite in dry state for around 3 min. Then around 2/3 $MgCl_2$ solution, with the rheology enhancing admixtures, and 2/3 water were added into the mixture for another 3 min mixing with a higher speed. Then the remaining 1/3 MgO powder, 1/3 sawdust and/or perlite and 1/3 $MgCl_2$ solution were added into the mixture for another 3 min high speed mixing. Finally the remaining 1/3 water was gradually added into the fresh composite for another 2–3 min mixing till dough-like fresh mixture was reached. The fresh mixture was then fed into the hopper of the single-screw extruder (see Fig. 2a) to make the desired building products, i.e., door frame and door panel, in this research.

The door panel was extruded through a stainless steel die (see Fig. 2b) with the cross-section of 300 mm in width and 20 mm in thick, giving a nominal thickness of 20 mm for the products. The die land is around 150 mm in length along the extrusion direction. However, due to die swell, i.e., the extrudate expanded after being pushed out of the die, the actual thickness of the door panel varied which was greater than the nominal value, 20 mm. The inner geometries of the cross-section of the die used for extruding door frame is shown in Fig. 2c which also gives the sizes of the cross-section of the extruded door frame. The door-frame die land length is 420 mm along the extrusion direction, which is much longer than that of the door-panel die. Thus the fresh wood–MOC cement mixture was subjected to longer and stronger shearing and compressing in the door-frame die. Consequently, it was found that the die swell of the extruded door frames was much less than that of the door panels, giving the actual sizes of the extruded door frames very close to those expected (as shown in Fig. 2c).

2.3. Curing and sample cutting

Right after the fresh mixture was extruded out of die, it was placed under plastic sheet at normal laboratory environment with the temperature of around 20 °C and relative humidity of around 60% for 1 day. Then the extrudate was moved to a steam curing chamber with the temperature of 60 °C and relatively humidity of around 60% for 3 days. The hardened extrudate was then moved out of the steaming curing chamber and dried at normal laboratory environment for 1 day. It should be noted that the main purpose of this research was to develop an extrusion technique for producing wood–MOC cement composite door frame and panel for an industry partner whose business is mainly manufacturing precast cement-based building products. In line with this, the curing regime used for their products as described above was adopted to accelerate strength development of the MOC cement composite products developed in this study. Some of the hardened door frames made by extrusion developed in this study are shown in Fig. 3. It should be noted that in Fig. 3 only the first line, from the left hand side, of door frames and panel with wood-like yellowish color were developed in this study. Other door frames with darkish color contained various amount of fly ash which replaced MgO. They were the products developed in other parallel study in this series of research which however are not reported in this paper.

Some extruded door panels were cut into plate samples with 250 mm in length and 75 or 50 mm in width in a wood workshop using a cutter for wood at a wood workshop. These plate samples were cut along either the extrusion (longitudinal) direction or the transverse direction (see Fig. 4 for illustrating where the plate samples were cut from an extruded door panel). The extruded door panel had a width of 300 mm, which was cut into three plate samples with the width of 75 mm each plus one plate sample with the width of 50 mm along the extrusion (longitudinal) direction. Along the transverse direction, plate samples were also cut with 250 mm in length and 75 or 50 mm in width. It was found that the hardened wood–MOC cement composites made by extrusion could be easily cut just like hard natural wood. These plate samples were used for investigating physical properties and flexural strength of the extruded wood–MOC cement composites along the longitudinal and the transverse directions with and without being subjected to high temperature treatment. As aforementioned, MOC cement demonstrates many properties superior to PC such as better performance in resisting high temperature and fire. But obviously wood particles and sawdust used as aggregate in this study have very low resistance to high temperature or fire. Therefore, one of the purposes of this study was to investigate the performance, in terms of physical and mechanical properties, of wood–MOC cement composites after being subjected to high temperature treatment. These measured properties were then compared to those of the wood–MOC cement composites without being subjected to high temperature treatment to assess their performance in resisting high temperature.

Fig. 3. Extruded door frames (note: in the right three door frames, MOC was partially replaced by fly ash, resulting in dark color, which are products developed in parallel research and beyond the scope of this specific paper).

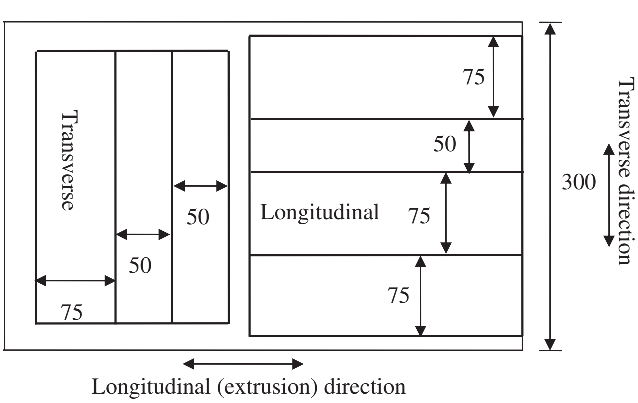

Fig. 4. Illustration for where door plate samples were cut from extruded door panel (all dimensions in mm).

3. Results and discussion

3.1. Bulk density and die swell ratio

As aforementioned, the nominal thickness of the extruded door panel is 20 mm while the actual thickness was greater than this value due to the die swell. Die swell is a common phenomenon for extrudate especially for those with porous, light-weight and/or soft aggregates such as sawdust, wood residuals and perlite. In this study, the thickness of the door panel was measured at three positions (as illustrated in Fig. 5) from each plate sample with the average value taken as its actual thickness, which was also used for calculating its bulk density and flexural strength. The die swell ratio is then obtained for each plate sample as:

$$\text{Die Swell Ratio} = \frac{\text{Actual Thickness(in mm)} - 20}{20} \times 100\% \qquad (1)$$

In addition, the dry bulk density of each door panel plate sample was calculated by dividing its weight by its actual volume. These results are shown in Tables 4 and 5, respectively, in which Table 4 gives the average thickness, bulk density and die swell ratio of plate samples made of Composite 1 with sawdust solely as aggregate and Table 5 those of Composite 2 with sawdust and perlite as aggregate. It can be seen that both composites possessed a density very close to that of water with Composite 2 demonstrating a slightly higher value than Composite 1. The die-swell ratios are comparable along the longitudinal and the transverse directions for both composites from door panel plate samples. No die swell measurement was taken from door frame samples. Compared with Composite 1 in which only sawdust was incorporated as aggregate, Composite 2 in which 50% sawdust was replaced by perlite exhibited much smaller die-swell ratio, i.e., less than 50% of that of Composite 1. This may be ascribed to the smaller particle size of perlite which filled in the gap among sawdust and wood particles with relatively larger size in the composite, resulting in a denser microstructure. However, the bulk density of Composite 2 was only slightly greater than that of Composite 1, indicating that partially

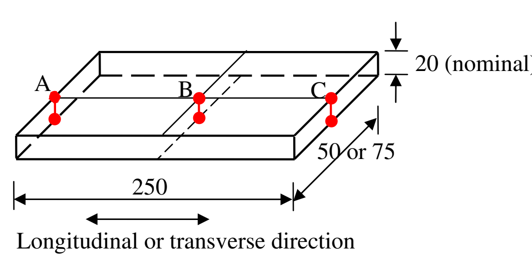

Fig. 5. Illustration for where the thickness of plate samples was measured (all dimensions are in mm).

Table 4
Average thickness, density and die-swell ratio of wood–MOC cement Composite 1.

Direction[a]	Average thickness (mm)	Density (kg/m^3)	Die-swell ratio (%)	Direction[a]	Average thickness (mm)	Density (kg/m^3)	Die-swell ratio (%)
L	21.275	1080	6.37	T	23.375	1031	16.88
L	22.675	1075	13.38	T	21.750	1014	8.75
L	22.750	1083	13.75	T	21.700	1020	8.50
L	22.550	1090	12.75	T	22.200	1040	11.00
L	22.500	1107	12.50	T	22.375	1039	11.88
L	22.375	1087	11.88	T	22.425	1043	12.13
L	22.775	1044	13.88				
L	21.550	1021	7.75				
L	21.075	1073	5.38				
Average	22.169	1073	10.85	Average	22.304	1031	11.52

[a] L means longitudinal direction and T transverse direction.

Table 5
Average thickness, density and die-swell ratio of wood–MOC cement Composite 2.

Direction[a]	Average thickness (mm)	Density (kg/m^3)	Die-swell ratio (%)	Direction[a]	Average thickness (mm)	Density (kg/m^3)	Die-swell ratio (%)
L	21.425	1038	7.13	T	20.675	1099	3.38
L	21.125	1149	5.63	T	20.350	1130	1.75
L	21.725	1107	8.63	T	21.100	1188	5.50
L	21.000	1221	5.00	T	21.350	1201	6.75
L	20.625	1199	3.13	T	21.250	1209	6.25
L	20.150	1204	0.75	T	21.900	1210	9.50
L	21.050	982	5.25	T	21.075	1013	5.38
L	21.000	1003	5.00	T	21.300	1016	6.50
L	20.825	1026	4.13	T	21.250	996	6.25
Average	20.992	1103	4.96	Average	21.14	1118	5.70

[a] L means longitudinal direction and T transverse direction.

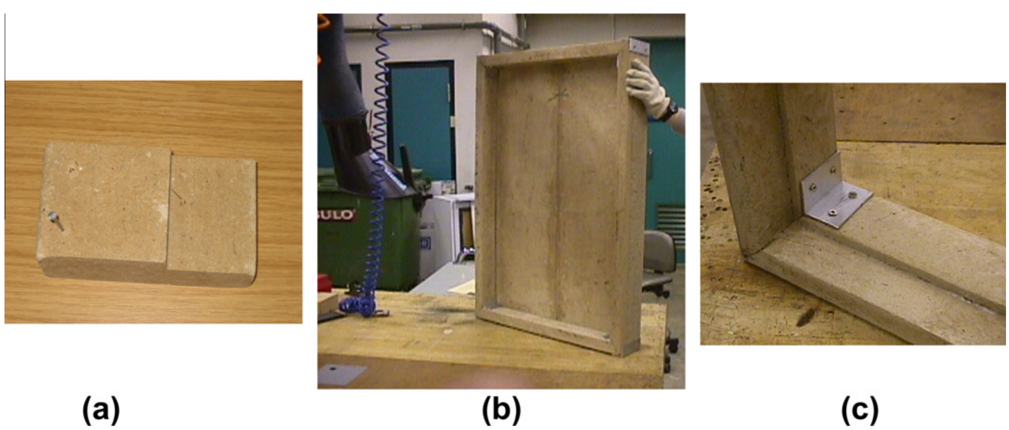

Fig. 6. Nailing performance of the extruded wood–MOC cement composites (a) door frame made of Composite 2 with a nail punched in; (b) door made of Composite 1; and (c) a corner of the door with frames connected by angle steel and nails.

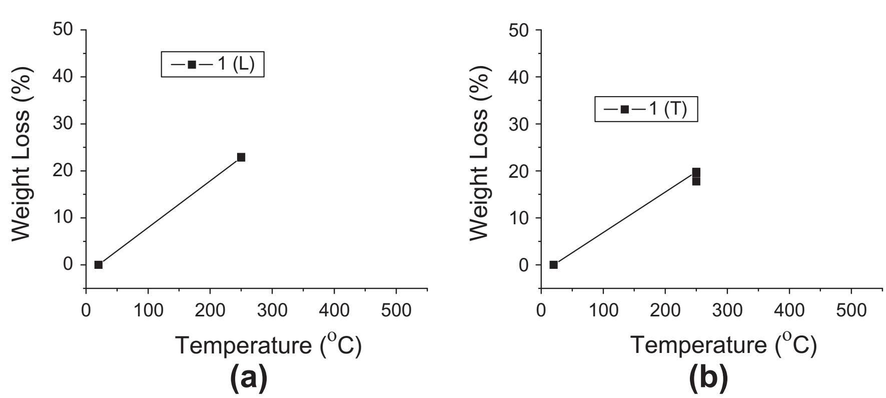

Fig. 7. Weight loss of Composite 1 along (a) the longitudinal (L); and (b) the transverse (T) directions.

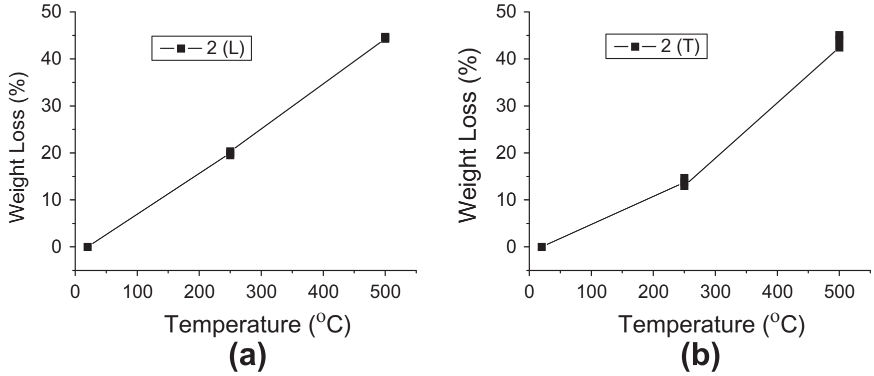

Fig. 8. Weight loss of Composite 2 along (a) the longitudinal (L); and (b) the transverse (T) directions.

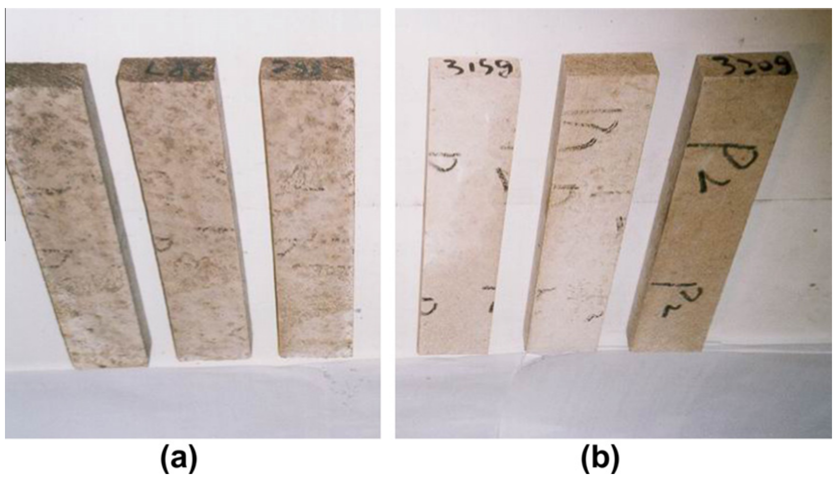

Fig. 9. Appearance of plate samples after being subjected to 250 °C: (a) Composite 1; and (b) Composite 2.

replacing sawdust by perlite does not increase bulk density significantly but it can largely reduce the die swell of extruded wood–MOC cement composite building products which is very desirable. The longitudinal lengths of the door panel plate samples were measured after being subjected to high temperature, in this case 250 °C and/or 500 °C. It was found that the decrease in longitudinal length was less than 1.0 mm for the 250 mm-long plate samples, resulting in very low shrinkage less than 0.4%. The good dimensional stability of the extruded wood–MOC cement composites may be ascribed to the MOC cement matrix which has been found demonstrating lower shrinkage and creep than PC [2].

3.2. Nailing ability

Nailing ability is an important performance for wood–cement composites. Methodology has been proposed for evaluating nailing performance of cement-based composite materials [16,17]. It has been concluded that a cement-based composite with good nailing ability should be easy to nail, have a high resistance to cracking, and to be able to hold the nail after it penetrates into the composite [16]. In this study, nails used in residential construction for wood were punched into the hardened extruded wood–MOC cement door panel and door frame using a hammer by hand to assess the nailing ability of the hardened wood–MOC cement composites. No quantitative analysis of nailing ability of the extruded wood–MOC cement composites was conducted. Rather, the nailing ability of these composites was evaluated qualitatively by naked eyes against two of the three criteria proposed by Kuder and Shah [17]. These two criteria are (1) ease of nailing; and (2) resistance to cracking. Pictures of the extruded hardened wood–MOC cement composite door frame, made of Composite 2, with a nail punched in were shown in Fig. 6a. It can be seen that no cracking was found on the surface of the wood–MOC cement composite door frame around the nail. Thus it can be concluded that the dried wood–MOC cement composites were nailable. It is reasonably expected that the nailability would be even better in a nail gun test due to much higher impact velocity. But no such standard test was conducted in this study due to limitation in laboratory facilities. In addition, the extruded hardened wood–MOC cement door panels and door frames, made of Composite 1, were nailed together and

Fig. 10. Appearance of plate samples after being subjected to 500 °C (Composite 2).

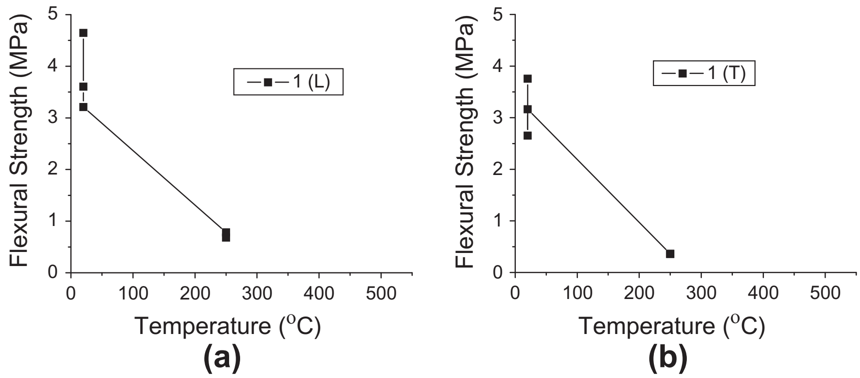

Fig. 11. Flexural strengths along (a) the longitudinal (L); and (b) the transverse (T) directions for Composite 1 (three data presented at each temperature).

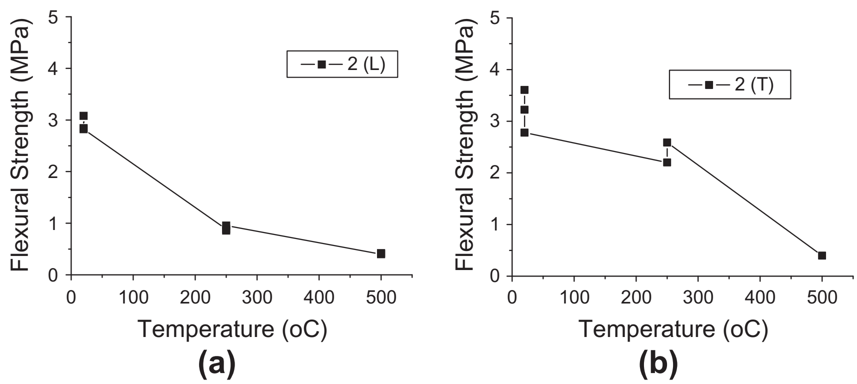

Fig. 12. Flexural strengths along (a) the longitudinal (L); and (b) the transverse (T) directions for Composite 2 (three data presented at each temperature).

a full-scale wood-like door was made at a wood workshop. It was found that the hardened wood–MOC cement composites made by extrusion could be easily cut. Again, no cracking was found near the nailed connections in the door made by the extruded light-weight wood–MOC cement composites, which further proved that the extruded wood–MOC cement composites were nailable.

3.3. Weight loss and appearance after high temperature treatment

After the extruded door panels were cut into plates with 250 mm in length and 75 or 50 mm in width along the extrusion (longitudinal) direction and/or the transverse direction, some plate samples were moved into an electrical oven to subject to high temperature treatment. These samples were heated from room temperature at around 20 °C to the temperature of either 250 °C or 500 °C at the rate of 3 °C/min. After reaching the targeted temperature, the samples were remained in the oven for 1 h. Then, the oven was turned off and the samples were still kept inside for another 3 h, which was found long enough for the air temperature of the oven reducing down to room temperature. The plate samples were then taken out of the oven. Their weights were measured immediately and the weight loss ratio was calculated. The results are shown in Figs. 7 and 8, respectively, for Composites 1 and 2, respectively. Their appearance was examined as shown in Figs. 9 and 10 right after they were taken out of the oven. The samples were further cured at ambient temperature for 24 h in the laboratory prior to measure their flexural strength. It can be seen from Figs. 7 and 8 that weigh loss ratio of Composite 1, with sawdust as aggregate, is greater than that of Composite 2, with 50% sawdust by mass replaced by perlite, after being subjected to 250 °C, suggesting that sawdust contained more moisture than perlite. It was also found that Composite 1 cannot sustain temperature as high as 500 °C so that their performance, including water loss and flexural strength, at 500 °C were not investigated in this study. For Composite 2, the weight loss ratio can be as high as 45% after being subjected to 500 °C. As far as appearance, the color of Composite 1, with sawdust as aggregate, changed from yellow[2] to light dark (as shown in Fig. 9a) while that of Composite 2 did not change much (see Fig. 9b), remaining white, the color of perlite, after being subjected to 250 °C. When the oven temperature further increased to 500 °C, the color of Composite 2 turned even whiter (as shown in Fig. 10) indicating that most sawdust may have been burnt. Thus, it can be concluded that partially replacing sawdust by perlite could increase the high-temperature resistant performance of wood–MOC cement composites.

3.4. Flexural strength

All door panel plate samples, including those with and without high temperature treatment, were subjected to four-point bending test with the span of 225 mm conforming to ASTM C-1341 using a MTS material test system under the stroke rate of 0.4 mm/min to obtain their flexural strength. In total, there were four sets of experimental results, i.e., those for Composite 1 along the longitudinal (extrusion) direction and along the transverse direction, respectively, as shown in Fig. 11; and those for Composite 2 along the longitudinal (extrusion) direction and along the transverse direction, respectively, as shown in Fig. 12. It should be noted that the data, in this case flexural strength, presented in Figs. 11 and 12 came from different samples but the same batch of composite and the same type of products, in this case door frame or door panel. It can be seen

[2] For interpretation of color in Fig. 9, the reader is referred to the web version of this article.

from both figures that the flexural strength of the extruded wood–MOC cement composites decreased as the temperature increased. Composite 1 had higher flexural strength than Composite 2 in both the longitudinal and the transverse directions at room temperature, which may be ascribed to that there were more wood fibers in sawdust in Composite 1 compared to Composite 2 which strengthened it together with the PVA and glass fibers. In Composite 2, 50% sawdust by mass was replaced by perlite. Thus less wood fibers were in it. However, as temperature increased to 250 °C, the residual flexural strength of Composite 1 was lower than that of Composite 2 along both the longitudinal and the transverse directions, indicating that perlite had better fire resistance performance which protected the wood fibers in sawdust and the PVA and glass fibers to be less damaged in Composite 2, resulting in a higher flexural strength. In terms of the flexural strengths of the extruded composites along the longitudinal and the transverse directions, in general there was not much difference which may be because that the longitudinal and the transverse sizes of the door-panel die were comparable. Unlike in a shallow and thin sheet die where fibers were found to be aligned along the extrusion direction [18], fiber alignment in the near square flow field in the door-panel die was not significant, so that the flexural strengths of the wood–MOC cement composite door panel plate samples along the longitudinal and the transverse directions were comparable.

4. Conclusions

In this study, light-weight wood–MOC cement composites were developed and building products, full-scale door frame and door panel, made of these composites were extruded. The physical, nailing and mechanical properties of these composites, with sawdust and/or perlite as aggregate, were investigated with and/or without being subjected to high temperature treatment. The following conclusions can be drawn:

(1) The wood–MOC cement composites made by extrusion were light weighted and their dry density were very close to that of water.
(2) Replacing 50% sawdust by mass by perlite as aggregate can largely reduce the die swell and improve volume stability of the composites made by extrusion without increasing their bulk density much.
(3) Due to large volume of light-weight, porous and soft aggregates, sawdust and perlite in this research, incorporated into the composites, the hardened wood–MOC cement composites were nailable like hard natural wood which is very desirable for residential applications.
(4) The weight loss ratios of the extruded wood–MOC cement composites increased as the temperature increased. The extruded wood–MOC cement composite, with 50% sawdust by mass replaced by perlite as aggregate, exhibited much better high temperature-resistance performance; and
(5) The flexural strength of the extruded wood–MOC cement composites decreased as temperature increased along both the longitudinal and transverse directions. By replacing 50% sawdust by mass with perlite as aggregate, the composite exhibited higher flexural strength, thus better high temperature resistant performance, after being subjected high temperature treatment.

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