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UTILIZATION OF SILICA FUME IN MANUFACTURING OF CEMENT BONDED PARTICLEBOARDS

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Abstract:
Silica fume, which is a highly reactive pozzolanic byproduct of producing silicon metal or ferrosilicon alloys, is known to improve both the mechanical characteristics and durability of concrete. This study investigates the effect of using silica fume as cement replacement materials on some properties of cement bonded particleboard from Douglas fir woods [Abies mordmanniana (Stev.) Spach. Subsp. Nordmanniana]. For this purpose, the three-layer cement bonded particleboards [CBPBs] with 1200kg/m^3 target density and 1/2 - 1/3 wood-cement ratios were produced by replacing cement with different percentages of silica fume (10, 15, 20%). As cement curing accelerator, $CaCl_2$ was used at 5% ratio (based on cement weight) for all the boards. The CBPBs produced were tested, according to the related EN Standards, to determine their mechanical and physical properties including modulus of rupture, modules of elasticity, internal bond strength, screw withdrawal strength, density, moisture content, water absorption and thickness swelling. The modulus of rupture values ranged from 9 MPa to 13.6MPa, while the modulus of elasticity values ranged from 5000MPa to 6500MPa. The internal bond strength values ranged from 1.05MPa to 1.95MPa. It was recorded that silica fume performed the improvements up to 20% at modulus of rupture and up to 40% at internal bond strength of the CBPBs. The mechanical properties of all the board types were over the requirements by EN 634-2 standard. Silica fume provided an improvement up to 50% at the thickness swelling values of the CBPBs. The results demonstrated that silica fume had a significant effect on the properties of CBPBs.

Key words: *cement bonded particleboards; nordmann fir; silica fume; technological properties.*

INTRODUCTION

Cement bonded particleboards (CBPBs) have been rapidly accepted and used in many countries for application in the building industry, because they possess a lot of outstanding merits including water, fire, decay, moisture and weather resistance, low cost, no health hazards, high stiffness, high durability and simple production processes ect., compared to conventional wood-based building materials (Wei et al. 2004; Maail et al. 2011). However, there are some problems impeding the development of the CBPBs. The most important one of them is that alkali-and water soluble sugars and extractive in wood inhibite the hydration reaction of cement, resulting in low strength value of wood-cement composites. Some methods such as NaOH, hot and cold water extractions, addition of effective chemicals, CO_2 Injection have been applied to improve the compatibility and to overcome this problem between wood and cement. Wood-cement ratio, water-cement ratio, cement type, addition type and amount, wood particle geometry and harvesting season, pressing conditions, in addition to wood species, also have influence on the quality of wood-cement composites.

Most researches have been focused on understanding the inhibitory properties of wood species, the compatibility of wood when mixed cement and water and improving the compatibility between wood and cement. However, because CBPBs is used mainly for building applications, it appears logical to pay more attention to the relation between the hydration process of wood-cement-water mixtures and the strength development of board (Wei et al. 2000).

Ordinary Portland cement is more expensive than wood materials. Therefore, it is a costly component and is responsible for a high proportion of the raw material cost (Wei et al. 2000). The application and use of mineral admixtures in concrete and wood-cement composites have been widely studied in recent decades to improve the resistance and durability of their composites and reduce the cement consumption (Kanning et al. 2014).

Silica fume is a byproduct resulting from the reduction of high – purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or silicon alloys. It is a material which may be a reason of air pollution. It is much cheaper than cement. Therefore, it is very important in terms of economical point of view (Rasol 2015). Hydration of cement primarily involves the reaction of calcium silicates C_3S and C_2S with water (H) to produce calcium silicate hydrate (C-S-H) and calcium hydroxide [$Ca(OH)_2$] (Young et al. 1974). The silica fume reacts with this $Ca(OH)_2$ in cement paste to form calcium silicate hydrate gel (C-S-H).

Silica fume is known to enhance both the mechanical characteristics and durability of concrete. Effects of silica fume on mechanical and durability of concrete were investigated by many researchers (Amudhavalli et al. 2012; Ajay et al. 2012; Ghutke and Bhandari 2014; Srivastava et al. 2014) and they reported the inclusion of silica fume up to 15% replacement level with cement in concrete have improved the bond strength, the bond strength of silica fume concrete increased in the range of 37 - 43% as compared to the referral concrete. In addition, it was reported that silica fume also decrease the voids, capillary, absorption and porosity of concrete because fine particles of silica fume reacts with lime present in cement.

Although many studies related to usage of silica fume as cement replacement materials in concrete have been carried out, there is no a comprehensive study about usage of silica fume as cement replacement materials in wood-cement composites and its effects on properties of the boards. Therefore, this study will be useful in terms of utilise of silica fume in wood-cement composite industry and thus, increasing its economic value

OBJECTIVE

The objectives of this study were to investigate the effect of silica fume on physical and mechanical properties of cement bonded particleboards from douglas fir woods, to determine the optimal silica fume usage ratio, to reduce its harmful effects to the environment and to increase its economic value by expanding the usage areas of silica fume. Therefore, the CBPB panels were produced using two wood-cement ratios (1/2 and 1/3) and three silica fume ratios of 10, 15 and 20% as a substitute for cement. The mechanical and physical properties, including modulus of rupture (MOR), modules of elasticity (MOE), internal bond strength (IB), screw withdrawal strength (SW), density (D), moisture content (MC), water absoption (WA) and thickness swelling (TS), of CBPBs, respectively, were determined according to the related standards.

MATERIAL, METHOD, EQUIPMENT

The Douglas fir woods [*Abies mordmanniana (Stev.) Spach. Subsp. Nordmanniana*] used in the this study were supplied as sawmill wastes by Trabzon Organized Industrial Zone, Turkey. Used as binder, ordinary Portland cement, CEM II B-M (P-LL) 32.5 R type was purchased from Askale Cement Co. in Turkey. In order to mitigate any adverse effects of water- and alkali-soluble products in wood, calcium chloride ($CaCl_2$), which purchased as solid state from Tetra Chemicals Europe AB in Sweden, was used as 5 wt. % based on weight of cement for all the board groups. Silica fume, supplied by Antalya Eti Elektrometalurji Co. in Turkey, was replaced with cement at ratios of 10, 15 and 20%.

Sawmill wastes were firstly chipped by means of a drum chipper and then grinded into smaller particles in a knife ring flaker. Then, the wood particles were classified in a laboratory type screen machine. The particles that remained between 3–1.5mm sieve and 1.5–0.5mm sieve were utilized in the core and outer layers, respectively. The shelling ratio (core layer/outer layers) was selected as 65/35% for all the board groups. The wood-cement ratios were 1/3 and 1/2, based on the oven dry weight for the three-layer CBPB manufacture. The amount of distilled water was adjusted by means of the formula below, founded by Simatumpang (1979),

$$Water\ (liter) = 0.35C + (0.30 - MC)W \tag{1}$$

where: C is the cement weight (kg), MC is moisture content (oven dry basis) of wood particles, and W is oven dry wood particle weight (kg). Experimental design is given in Table 1.

Table 1

Experimantel design

Board types	Silica fume (%)	Wood-cement ratio
A	0	1/3
B	10	1/3
C	15	1/3
D	20	1/3
A1	0	1/2
B1	10	1/2
C1	15	1/2
D1	20	1/2

The wood–cement-water mixes were mat formed as three layers on an aluminum plate inside a compact laminated mould. Hand-formed mats were compressed in a laboratory type hot press using a pressure of 18-20kg/cm^3 for 24 hrs. In the first 8 hours of the pressing process, a temperature of 60°C was applied and then pressing was continued for 16 hrs in ambient temperature. All the boards were produced at a dimension of 450x450x10mm and a target density of 1200kg/m^3.To complete hydration of cement, the boards after pressing were conditioned in a climate room with a temperature of 20°C and a relative humidity of 65% for 28 days and then cut into test samples according to the requirements stated in the European Standards.

Physical and mechanical properties including density, moisture content, water absorption, thickness swelling, modulus of rupture, modulus of elasticity, internal bond strength and screw withdrawal strength, of the boards were determined according to EN 323 (1993), EN 322 (1993), ASTM D1037 (2006), EN 317 (1993), EN 310 (1993), EN 319 (1993) and EN 320 (2011), repectively.

RESULTS AND DISCUSSION

Mechanical Properties

The averaged measured values of MOR and MOE were plotted against wood and silica fume amounts in Fig. 1. It can be observed that MOR values were improved with increasing the wood content (wood/cement ratio from 1/3 to 1/2) in the boards in contrast to MOE. Papadopoulos et al [2006] and Ashori et al [2012] obtained the similar results. An increase in the amount of wood up to a certain amount enhanced the compression factor in the boards due to that wood is lighter than cement and this led to increase the contact surface area between the particles and the distribution of load applied on the boards. This resulted in more strength of the boards. Moslemi and Pfister (1987) explained the stuation with smilar expressions. However, MOE values decreased with increasing wood content due to fact that wood has less elasticity modulus than concrete.

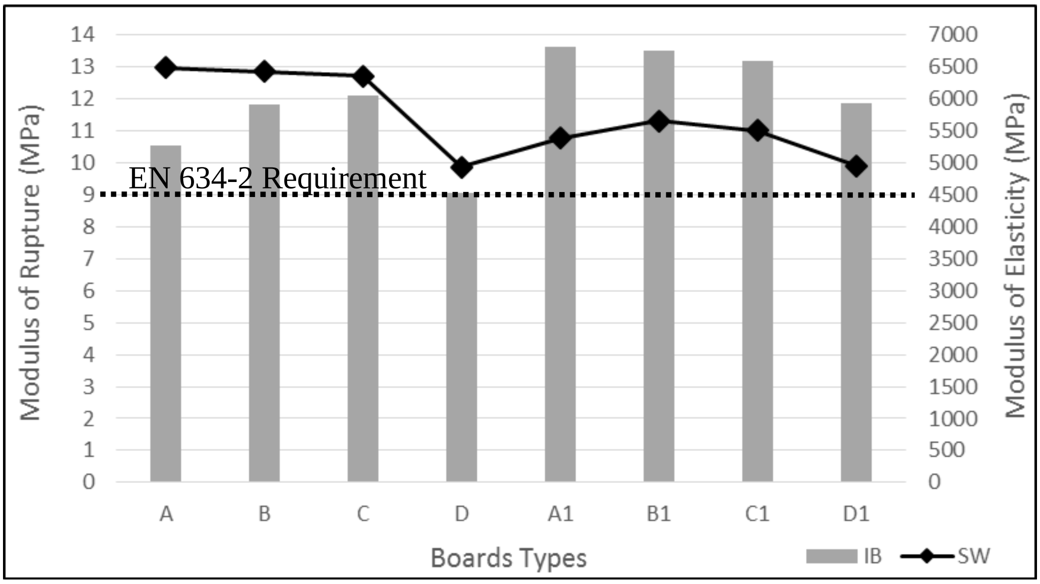
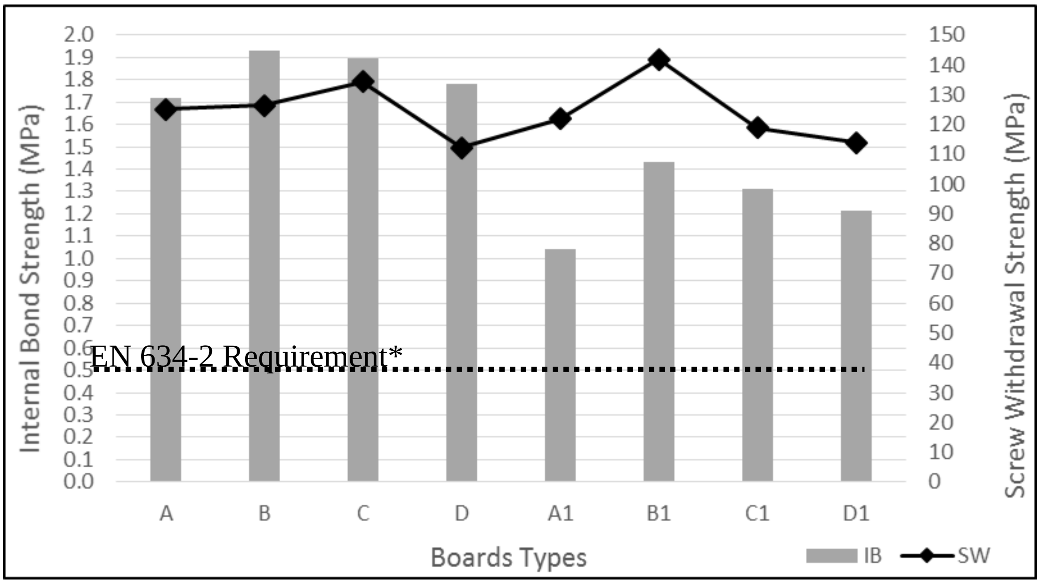


Fig. 1.
MOR and MOE properties of the boards.

MOR and MOE values of all the boards met the requirements for ordinary Portland cement bonded particleboards for use in dry, humid and external conditions stated in EN 634-2 (2007). The highest values were obtained from the boards with 15% silica fume among the boards with 1/3 wood-cement ratios.The figure showed that adding silica fume up to 15% significantly improved MOR values of the boards with 1/3 wood-cement ratios and MOE values of the boards with 1/2 wood-cement ratios.

The averaged measured values of IB and SW were given in Fig. 2. Contrary to MOR values, IB values decreased with increasing wood content. The highest IB and SW values were obtained from the B and B1 groups including %10 silica fume while the lowest values were obtained from the referance boards (A and A1) including no silica fume. IB values of all the boards were over the minimum values required for ordinary Portland cement bonded particleboards for use in dry, humid and external conditions stated in EN 634-2 (2007).



*This standard requirement is valid only for IB values

Fig. 2.
Properties of IB and SW strength of the boards.

Hydration of cement produces calcium hydroxide [Ca(OH)2] and calcium silicate hydrate [C–S–H gel]. C-S-H gel is the main product of the hydration of Portland cement and is primarily responsible for the strength in cement based materials. $Ca(OH)_2$ is is a by-product which is unresistant, water-soluble and non-contributing to the strength of cement based products. Silica fume reacts with $Ca(OH)_2$ and generates C-S-H gel (Metha 1987). This leads to an increase in the strength of cement bonded particleboards. The reason of the improvement in mechanical properties of the boards with silica fume may be that the amount of calcium silicate hydrate in the boards increased due to fact that silica fume reacted with $Ca(OH)_2$.

Silica fume, wood-cement ratio and interaction of both had a significant effect on mechanical properties (MOR, MOE, IB and SW) based on the results of statistical analysis at 99% confidence level. The results of homogenous subsets of the board were given in Table 2.

Table 2

Homogenous subsets for mechanical properties of WCPB

Board Types	MOR	MOE	IB	SW	Board Types	MOR	MOE	IB	SW
A	c	a	b	b	**A1**	a	c	d	b
B	b	b	a	b	**B1**	b	a	a	a
C	a	c	a	a	**C1**	c	b	b	bc
D	d	d	b	c	**D1**	d	d	c	c

Physical Properties

Thickness swelling and water absorption in wood-cement composites mainly depend on wood-cement ratio and hydration reaction of cement. Fig. 3 showed the averaged thisckness swelling values of the boards soaked for 2 and 24 hours. The boards with 1/3 wood-cement ratio had much lower thickness swelling values than that of tha boards with1/2 wood cement ratio. In additon, it was observed that silica fume significantly improved the thickness swelling values of the boards. All the boards with 1/3 wood-cement ratio met the requirements (<1.5%) stated in EN 624-2 (2007).

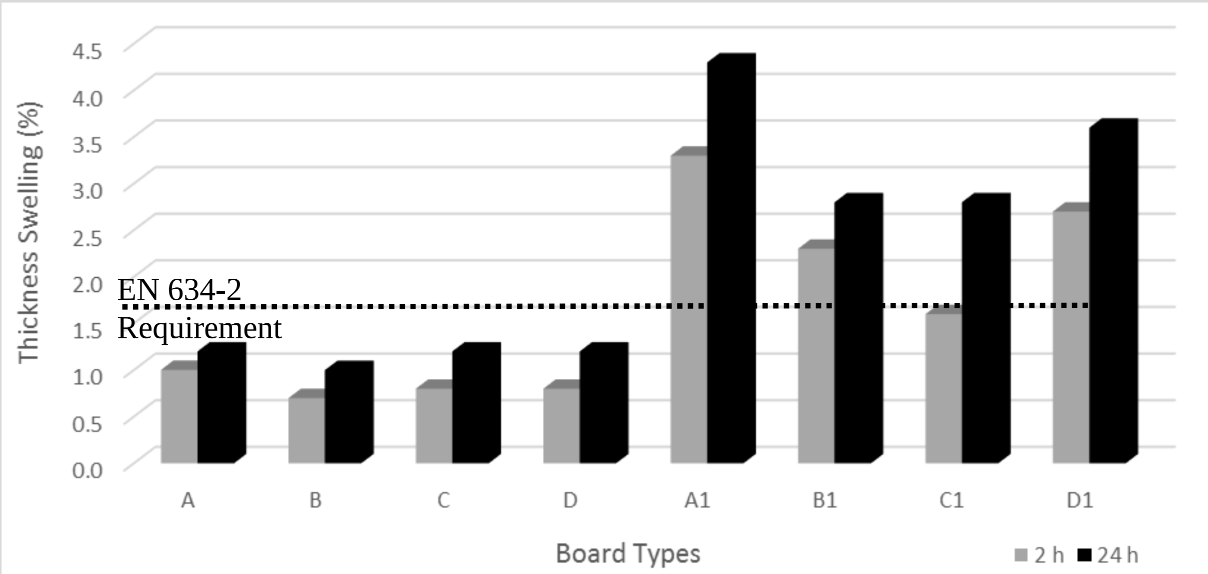


Fig. 3.
Thickness swelling values of the boards.

Physical properties of the boards including density, mositure content, water absorption and thickness swelling were given in Table 3. Moisture content (ranged from 9.4% to 11.9%) of all the boards met the requirement (MC: 9-12%) stated in EN 634-1 [2007]. Using silica fume up to 15% in manufacturing of the boards decreased WA and TS values of the boards. Particle size of silica fume is approximately 100 time smaller than that of Portland cement (Xu and Chung 2000). Therefore, silica fume may have created a tighter structure by filling the voids in the board. This may be the reason why the boards containing silica fume had the less TS and WA values. In addition, the increased hydration products (C-S-H) and the improved strength values also may have led to the lesser WA and TS values of the boards than the others.

Table 3

Physical properties of the boards

Board Types	Density (kg/m^3)	Moisture Content(%)	Water Absorption (%)		Thickness Swelling (%)	
			2 h	24 h	2 h	24 h
A	1.28	9.4	10.1 c	14.2 c	1.0 c	1.2 b
B	1.27	11.1	8.7 b	12.9 b	0.7 a	1.0 a
C	1.19	11.9	7.2 a	11.8 a	0.8 b	1.2 b
D	1.20	10.3	14.3 d	17.8 d	0.8 b	1.2 b
A1	1.22	9.7	15.8 c	20.4 b	3.3 d	4.3 c
B1	1.14	11	13.1 b	18.9 a	2.3 b	2.8 a
C1	1.17	11	11.1 a	18.9 a	1.6 a	2.8 a
D1	1.13	10.4	16.1 d	21.3 c	2.7 c	3.6 b

It was founded that the boards with 1/2 wood-cement ratio had more WA ratio than that of the boards with 1/3 wood-cement ratio because the wood content increased. Zhou and Kamdem (2002), Ashori et al. (2012) and Sudin and Swamy (2006) reported the similar results. Homogenity subsets for WA and TS values of the boards were also shown in Table 3. According to the results of statistical analysis (p:0.0001), silica fume and wood-cement ratio and interaction of both had a significant effect on WA and TS values of the boards.

CONCLUSIONS

The results obtained in this study investigated the effect of silica fume on physical and mechanical properties of cement bonded particleboards from Douglas fir woods, demonstrated that using silica fume up to 15% in manufacturing of wood-cement composites significantly improved their physical and mechanical properties. In addition, it was observed that silica fume had more effect on the boards with 1/3 wood-cement ratio than the boards with 1/2 wood-cement ratio. Using silica fume as cement replacement in manufacturing of wood cement composites will provide: 1) producing high strength and durability of wood-cement composites, 2) increasing the econamical value of silica fume, 3) decreasing the cost of wood-cement composites because silica fume is much cheaper than cement and 4) decreasing the air pollution caused by silica fume.

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REFERENCES

Amudhavalli NK, Mathew J (2012) Effect of silica fume on strength and durability parameters of concrete, International Journal of Engineering Sciences & Emerging Technologies, 3(1):28-35.

Ashori A, Tabarsa T, Amos F (2012) Evaluation of using waste timber railway sleepers in wood-cement composite materials, Construction and Building Materials 27:126-129.

Ashori A, Tabarsa T, Sepahvand S (2012) Cement-bonded composite boards made from poplar strands, Construction and Building Materials 26:131–134.

Ajay V, Rajeev C, Yadav RK (2012) Effect of micro silica on the strength of concrete with ordinary Portland cement, Research Journal of Engineering Sciences, 1(3):1-4.

EN 323 (1993) Wood-based panels-Determination of density, European Committee for Standardization, Brussels, Belgium.

EN 322 (1993) European Standard. Wood-based panels-Determination of moisture content, European Committee for Standardization, Brussels, Belgium.

ASTM D1037 (2006) Standard Test Method for Evaluating Properties of Wood-Based Fibres and Particle Panel Materials, USA.

EN 317 (1993) Particleboards and fibreboards-determination of swelling in thickness after immersion in water, Brussels, Belgium, 1993.

EN 310 (1993) Wood-based panels, determination of modulus of elasticity in bending and bending strength, Brussels, Belgium.

EN 319 (1993) Particleboards and fiberboards, determination of tensile strength perpendicular to plane of the board. European Committee for Standardization, Brussels, Belgium.

EN 320 (2011) Particleboards and fibreboards - Determination of resistance to axial withdrawal of screws, Brussels, Belgium.

EN 634-1 (2007), Cement-bonded particleboards - Specifications - Part 1: General requirements, European Committee for Standardization (EN), Brussels, Belgium.

EN 634-2 (2007) Cement-bonded particleboards - Specifications - Part 2: Requirements for OPC bonded particleboards for use in dry, humid and external conditions, European Committee for Standardization (EN), Brussels, Belgium.

Ghutke, VS, Bhandari PS (2014) Influence of silica fume on concrete, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), pp. 44-47.

Kanning RC, Portella KF, Braganca MOGP, Bonato, MM, Santos JCM (2014) Banana leaves ashes as pozzolan for concrete and mortar of Portland cement, Construction and Building Materials 54:460–465.

Maail RS, Umemura K, Aizawa H, Kawai S (2011) Curing and degradation processes of cement-bonded particleboard by supercritical CO2 treatment, Journal of Wood Science 57:302–307.

Metha PK (1987) Natural pozzolans, In:Molhotra, VM Suplementary cementing materials for comcrete, Minister of Supply and Services, Canada, pp. 3-31.

Moslemi AA, Pfister SC (1987) The Influence of cement –wood ratio and cement type on bending strength and dimensional stability of wood-cement composite panels, Wood Fiber Science, 19:165-175.

Papadopoulos, AN, Ntalos, GA, Kakaras I (2006) Mechanical and physical properties of cement-bonded OSB, European Journal of Wood and Wood Products, 64:517-518.

Rasol MA (2015) Effect of silica fume on concrete properties and advantages for Kurdistan Region, Iraq, International Journal of Scientific & Engineering Research, 5(1):170-173.

Srivastava V, Harison A, Mehta PK, Atul, Kumar R (2014) Effect of Silica Fume in Concrete, International Journal of Innovative Research in Science, Engineering and Technology, 3(4):254-259.

Sudin R, Swamy N (2006) Bamboo and wood fibre cement composites for sustainable infrastructure regeneration, Journal of Materials Science, 41:6917-6924.

Simatupang MH (1979) Water requirement for the production of cement-bonded particleboard, Holz Roh-und Werkstoff, 37:379-382.

Young JF, Berger RL, Breese J (1974) Accelerated curing of compacted calcium silicate mortars on exposure to CO_2. Journal of the American Ceramic Society. 57(9):394–397.

Zhou Y, Kamdem DP (2002) Effect of cement/wood ratio on the properties of cement bonded particleboard using CCA-treated wood removed from service, Forest Products Journal, 52(3):77-81.

Xu Y, Chung DDL (2000) Improving silica fume cement by using silane, Cement and Concrete Research, 30:1305-1311.

Wei YM, Fujii T, Hiramatsu Y, Miyatake A, Yoshinaga S, Fujii T, Tomita B (2004) A preliminary investigation on microstructural characteristics of interfacial zone between cement and exploded wood fiber strand by using SEM-EDS, Journal of Wood Science, 50:327–336.

Wei YM, Zhou YG, Tomita B (2000) Study of hydration behavior of wood cement-based composite II: effect of chemical additives on the hydration characteristics and strengths of wood cement composites, Journal of Wood Science 46:444-451.