Chapter

Mineral-Bonded Wood Composites: An Alternative Building Materials

Halil Turgut Sahin and Yasemin Simsek

Abstract

The manufacturing of cost-efficient construction materials is at the center of attention these days. The development of engineeringly design products has occurred mostly over the past few decades. However, the term of mineral bonded wood composite is relatively new, covers many of the products, and is used to describe a material that is produced by bonding woody material with mineral-based substrates. At present, millions of tons of bio-based composite materials are now manufactured annually from many wood species. Woods are sustainable and engineeringly have enough performance properties in composite matrix systems for many end-use areas. Thus, their utilization processes and intended uses vary accordingly. But at manufacturing, many variables affect binder hydration in composite structure and the networking/bonding between wood and binder. The mineral bonded wood products are high in density and the appropriate strength in the construction industry, an important advantage to engineering applications appears to lie in their ability to absorb and dissipate mechanical energy. Despite their higher weight-to-strength ratio, especially cement and gypsum bonded wood composites have become popular, for use in many internal and external applications to meet increasingly stringent building design regulations for insulation, and failure in service due to deterioration.

Keywords: mineral binder, wood-cement composite, gypsum, magnesia cement

1. Introduction

Wood is one of the first raw materials for construction purposes. Its usage has continuously increased since human beings. However, as a result of excessive wood utilization, natural forests have become depleted at scarcity value. Therefore, consumers have become more aware of the destruction of the natural forests for wood supply. After technological developments and intensive studies, many valuable constructional elements have been developed from lignocellulosic in recent years [1–3]. In this context, numerous alternative biomass sources such as; agricultural and forest residues, low-value woody materials, annual plants have been considered to use as wood substitute alone or in combination with synthetic binders to manufacture construction materials [4–7].

One of the interesting materials has been invented which using inorganic minerals as the bonding agent, called mineral-bonded wood composites. These products were first produced by an Austrian carpenter using wood shavings and gypsum together in 1914. However, cement-bonded wood composites called Wood Wool Cement Board (WWCB) were also produced in Austria in the 1920s and several others in Europe followed. Moreover, Cement Bonded Wood Chip Boards called Durisol were invented and commercially produced in the 1930s. After that, the cement-bonded coarse wood particleboards called Velox boards were produced in the 1950s. The first Cement Bonded Particle Board (CBPB) called Duripanel was produced in 1970. Since the first invention of these products in Europe, these materials have developed further with calling different names in the market, spread to the rest of the world. These days, numerous mils have been built throughout the world, mostly in manufacturing panel form [8].

Due to variables and wide range of properties, mineral bonded wood composite materials could be broadly divided into two distinct groups;

1. Composite materials in which woody materials (i.e. fibers, sawdust, chips) are incorporated as an aggregate in the mineral matrix,

2. Composite materials in which the mineral binder acts purely as a binder, (i.e. wood wool cement board, particleboard, or fiberboard).

However, the three most common mineral-bonded composite products could be found in the market. These are;

- Cement-bonded composites,

- Gypsum-bonded composites,

- Magnesia cement-bonded composites,

All these mineral-based binders have been used to manufacture low-medium density (360 to 800 kg/m^3), and medium-high density (800 to 1.400 kg/m^3) products.

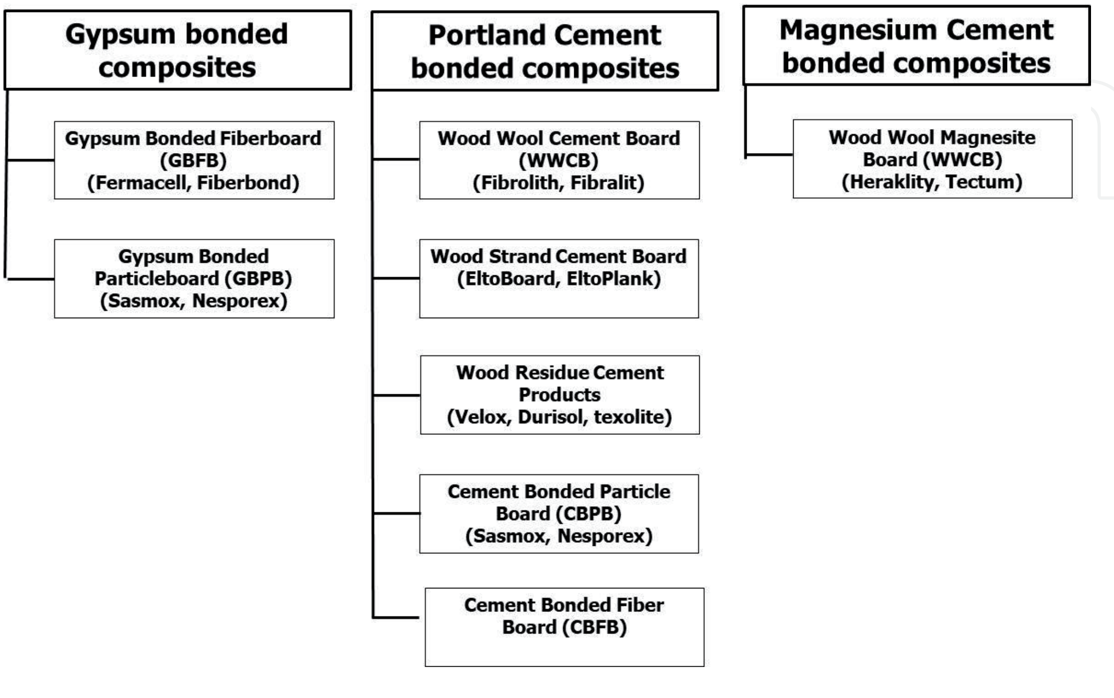

Figure 1.
The general classification of mineral-bonded composites [8].

Cement-bonded low-density products are usually called Excelsior and high-density products are called cement-bonded particleboard or fiberboard. However, Portland cement is the most common mineral binders while gypsum and magnesia cement are sensitive to moisture, and their useability is generally restricted to interior applications. Therefore, the panel materials bonded with Portland cement are considered to be more durable than others. These make cement-bonded products are useful material in both interior and exterior applications [2, 3, 9]. Although, synthetic resin-bonded panels (fiberboards and particle boards) are produced in much higher volumes due to the low cost and wider application areas, especially wood-cement bonded panels present several advantageous properties that make them more competitive for some special outdoor applications.

The general classification of mineral bonded wood composite materials and their commercialized names are briefly given in **Figure 1**. However, much valuable information and some excellent results have been provided on these products could be found elsewhere [2, 3, 8–12].

2. Compatibility of mineral binders with wood

The setting of inorganic binders is the result of a multi-complex chemical reaction causing a succession of crystallization stages. However, the hydration of mineral binder is an exothermic process which is possible to trace the compatibility by monitoring temperature changes. Typically, lignocellulosic have a cellular structure with various inhibitory substances (cellulose, hemicelluloses, lignin, extractives), and some of them dissolve in water and could be disturbed in the mineral binder crystallization [8–11]. Thereby, species compatibility varies with the type of binder and chemical constituents. But the term compatibility usually refers to 'the degree of binder setting after mixing with water and with a given wood in a fragmented form'. The inhibited reactions are generally characterized by;

- Hydration temperature,
- Hydration time,
- Retarding the cure of binders.

As briefly explain introduction section, the woody material can act both as an aggregate and as a reinforcing element in a mineral binder-based matrix system. In either case, the interaction between the binder and the element is very important. Because the particle-matrix interface is the diffusion zone, the matrix phases are connected either chemically or mechanically [8–12]. However, this diffusion region mostly influences the mechanical properties because the interfacial adhesion between particles and matrix characterizes composite materials. During hydration of cement, it created crystals in the contact layer with variable dimensions. But the crystals in the middle layer should be appropriate in the transition layer and resemble should be well bonded to each other. Because of inhibiting constituent presence, the form and dimension of the crystals could be modified. Thereby, some layers of altered crystals cannot be distinguished [9, 13].

However, cement is more sensitive to wood chemical constituents than either gypsum or magnesia cement, in most cases, the hydration times are the longest. Moreover, relative hydration times of gypsum, as also affected by selected wood species while sugars and extractives do not have as much effect on the curing and bonding of magnesia cement. The general comparative hydration properties of selected species with the inorganic binder are shown in **Table 1**.

The compatibility of wood with cement can be strongly influenced by

- Cutting and storage time of woods,
- Water to binder ratio of paste,
- Wood particle size of paste

But the content and type of sugars present in wood have been previously identified as the most critical compounds causing incompatibility, especially in softwoods [9, 13, 14]. Hence, it is very important to supply woody elements with homogeneous physical and chemical properties for the standardization of the manufacturing process.

However, the hydration of mineral binders can be improved by treating the particles or by using some additives. In the most cases, the pre-treatment is necessary, allowing to compatibility with mineral binders to obtain more suitable production [9, 14]. The aging or seasoning of wood and some degree use of chemical agents (i.e. CO_2, $CaCl_2$ and $MgCl_2$) found to be increase certain wood's compatibility with cement [9, 11–14]. The similar approaches could be useful for both gypsum and magnesia cement as well.

2.1 Cement-bonded composite materials

Portland cement is the most common type of binder in mineral based wood composite products. However, it reacts with water in a process called hydration and eventually solidifies into a hard mass. In general, the major ingredients of cement are three complex mixture of tricalcium silicate, dicalcium silicate, and tricalcium aluminate, which comprise more than 87% of the total weight [9, 13].

The advantages associated with wood elements in cement matrix system, include wide variety of species available, low density, high tensile strength, relatively low cost and well-developed technology to supply raw materials from renewable sources [9–11]. However, the use of cement in wood composites is faced with some limitations. One of the major drawback is the vulnerability of natural fibers to decompose in the alkaline environment of cement. In addition, some woods might exhibit incompatibility with cement due to specific chemical structures (sugars and extractives) that retard the cure of cement that impermeable hydrates are formed around unhydrated cement grains, which delay the setting and affect the final strength of the products [8–14]. Therefore, species selection can be important for the effective manufacturing process.

These drawbacks could be solved by several techniques which are effective in removing the detrimental components from wood. These are [9–14];

Wood or chemical	Gypsum	Magnesia cement	Portland cement
Inorganic binder	1.0	1.0	1.0
Glucose (1.0%)	1.20	1.20	Inhibited
Spruce wood	1.33	1.35	1.35
Beech wood	1.46	1.53	2.55

Table 1.
The comparative relative hydration properties (%) [13].

- Hot water extraction,
- Leaching in cold water,
- Chemical extractions,
- The use of cement curing accelerators like $CaCl_2$, $MgCl_2$ and $CaCO_3$,
- CO_2 treatment,
- Addition of pozzolans such as volcanic ash, fly ash, rice husk ash and condensed silica fume.

2.2 Gypsum-bonded composite materials

Gypsum is a sedimentary mineral and composed of calcium sulfate ($CaSO_4$) and water (H_2O), naturally in a crystalline form known as calcium sulfate dihydrate ($CaSO_4$•$2H_2O$). However, gypsum boards are typically made from a slurry of gypsum, water, and lignocellulosic fibers. Its structure is composed of interconnected needle-like calcium sulfate dihydrate crystals which entangle and rehydrated during the binder curing process (calcination), hardening to create a gypsum network [15]. Because hydrate crystals form in a gypsum-natural fiber network, wood chemical constituents especially sugars or some extractives may retard the hydration of the binder and alter crystalline structures. Typically, gypsum crystals are relatively long and have a hexagonal form, but the retarder chemicals could be influenced, the form and dimension of the crystals are altered [13, 14].

Manufacturing of wood-based gypsum boards required a higher binder (gypsum) than that needed in the bonding of composites with thermosetting resins. However, one of the main drawbacks of gypsum as a building material is its heaviness and brittleness. Hence, these boards do not have strong impact resistance for some building applications. These situations can be partly overcome by combining gypsum with various types of natural fibers (waste paper, agriculture waste fibers) to impinging better mechanical performance [15, 16]. Some advantages and disadvantages of gypsum-based composite materials are given in **Table 2**.

Advantages	Disadvantages
Ease of workability and adhesively attached to many substrates	Dry construction material that sensitive to water or moisture.
Acoustics properties that can be used partitions and floor/ceiling systems for control sound.	Very short period of setting times
Fire resistance material that gypsum could not support combustion	It has very brittle matrixes.
Cost effective manufacturing process and lower CO_2 emission compared to other construction materials (i.e. portland cement)	Water mold damage possible
Lightweight material	Environmentally not sound
The gypsum plaster supply chain has low energy consumption and	Harmful for health produce toxic SO_2 gas
Gypsum board is used to construct strong, high quality walls and ceilings	High wastage in use and manufacturing

Table 2.
Some advantages and drawbacks of gypsum bonded composites.

2.3 Magnesia-cement-bonded composite materials

Magnesia cement-based boards are formed by a chemical reaction between MgO and MgCl2, typically in a weight ratio of $MgO/MgCl_2$ (1.0/2.5–3.5 by weight). This product is quite similar to Sorel cement but has both organic additions (sawdust, wood flour) and inorganic fillers (sand, lime, or volcanic ash) [17]. However, the hydrated product is hard and strong, but the product decomposes over time by contact with water or air at high relative humidity (RH) [17, 18].

The first industrially made inorganic bonded wood composites were magnesia-bonded wood wool boards called the Heraklith boards in Europe and Tectum boards in the USA [13, 17, 18]. Recent studies show that half calcined dolomite can be partially substituted for magnesia. However, it was proposed that wood composites can also be made using a mixture of heavy magnesia and ground dolomite in combination with a solution of ammonium polyphosphate as the binder. The process is further simplified by using caustic calcined magnesia or half calcined dolomite in combination with a sparely soluble ammonium polyphosphate [13].

Fewer boards bonded with magnesia cement have been produced than portland-cement bonded panels, mainly because of cost. However, magnesia cement does offer some manufacturing advantages over portland cement. These are;

- The extractives and chemical constituents in lignocellulosic do not have as much effect on the curing and bonding,

- The magnesia cement is more tolerant of high water content during production.

These open up possibilities to use lignocellulosic not amenable to cement composites, without leaching or other modification, and to use alternative manufacturing processes and products.

In the production of this panel product, wood wool (excelsior) is laid out in a low-density mat. The mat is then sprayed with an aqueous solution of magnesia cement, pressed, and cut into panels. The cure of magnesia binders can be readily accelerated by the addition of heat. Wood-based boards made with this material are therefore compressed in a heated press. As with resin-bonded wood composites, total press time can be reduced by rapidly transferring heat to the center of the board. Steam injection pressing, a process whereby saturated steam is forced into a mat during pressing, is being successfully used to raise the center-line temperature of resin-bonded boards to curing temperatures in less than a second [13, 18, 19].

However, the addition of fluorine anhydrite has been caused by the modification of wood–magnesia bonding mechanisms that affect the stabilization of creeping deformations of the products. The fluorine anhydrite intensifies the processes of caustic magnesia solidification and causes the formation of thick structure in the wood–magnesia panel products [19].

3. Properties of mineral bonded composites

Typically, there are two types of water (free and chemically bound) in mineral bonded boards. This is important because it contributes to the fire resisting behavior. Hence, when exposed to fire, these materials undergo reactions in which the water is gradually driven off at temperatures above 100°C. However, considerable high-level heat energy is required to evaporate the free water and for the chemical reaction to release the water in the crystal structure. Moreover, those have also usually low heat transfer coefficients and are capable of quick release of the humidity.

However, wood-cement bonded composites have become environmentally benign sustainable materials for the constructions due to reducing material costs by combining a lower cost material [9, 20]. Hence, these products have very good dimensional stability, high fire resistance properties, and impart additional energy absorbing capacity to the matrix system. The wood cement composites typically show improved ductility, flexibility, and crack resistance when compared to neat cement concrete [9–12]. In addition, besides being high strength properties, these products could be provided well protection against decay and insect attacks as well [21, 22].

The mechanical properties of gypsum base panels are closely correlated with panel porosity, water/gypsum ratio, network structure, intercrystalline interaction, crystal sizes, and aging time. Although the hydrated gypsum and magnesia bonded boards are hard and strong, the product decomposes over time by atmospheric effects at high relative humidity (RH) [17]. Hence, the gypsum and magnesia bonded boards are not recommended as sheathing in exterior facades or any other application where the boards are in contact with a moist climate. In contrast, the cement-bonded boards showed excellent dimensional stability and only a slight reduction in mechanical properties after outdoor exposure for years, greatly outperforming other wood-based panels.

The modified magnesium polyphosphate-bonded particle boards are some similar properties to those obtained with magnesium sulfate while shrinkage decreases due to carbonization of wood–magnesia matrix, and the density, strength, and water resistance increases [13, 19].

There are numerous studies for determining the suitable board configurations on the end-use applications. But many properties such as; strengths, fire resistance, sound absorption, and insulation behaviors of panels, are primarily influenced by the density of the product and the binder/wood ratio. **Tables 3** and **4** show the general and physical comparative properties of mineral-based wood composite materials.

The cement-cellulosic substrate matrix is a complex system that can be given different properties and the resulting products can be used for a broad variety of applications. However, cellulosic fibers are well bonding ability to each other. Especially well-fibrillated fibers are more flexible and have a higher area available for bonding. This is possible by using refiners which are breaking the primary wall and the fibrils from the secondary wall will stick out. This will increase the surface area for bonding and therefore increase composite strength. The results presented in **Table 4** support this hypothesis.

	Gypsum boards	Wood-cement boards	Magnesia boards
Water resistance	+	+++	+
Fire resistance	+++	+++	+++
Fungal/mold/termite resistance	++	+++	++
Acoustic insulation	+++	++	++
Lightweight	+++	+	+
Nail holding capacity	+	+++	+++
Workability	+++	++	++
Durability	+	+++	++

Table 3.
General Properties of mineral bonded boards composites [9–12, 19, 23].

Wood composites	Density (kg/m^3)	Binder/wood ratio	MOR (MPa)	IB (MPa)
Cement-bonded particleboards	1000–1350	2.9	6.0–15	0.4–0.6
Cement-bonded fiberboard	1000–1350	10	12–20	0.8
Gypsum- bonded particleboards	1000–1200	4.0	6.0–9.0	0.3–0.6
Gypsum- bonded fiberboards	900–1000	5.0 to 6.0	4.0–7.0	0.3–0.5
Magnesia-bonded particleboard	900–1250	1.5	7.0–14	0.4–0.6
Magnesia-bonded fiberboard	700 to 1100	5.0	8.0 to 10	—

Table 4.
Comparative physical Propoerties of mineral bonded boards boards [23].

4. Uses of mineral bonded composites

An acceptable property from mineral bonded panels is dependent on both the type of the binder and wood properties. All these materials are considered non-toxic yet and commonly referred to as being virtually incombustible. Due to very high dimensional stability and physical properties, the cement-bonded products could be useful for many external applications including; exterior siding, agricultural buildings, pre-fabricated structures, mobile buildings, roofing, flooring, industrial and exterior domestic cladding, tunnel linings, highway sound-barriers, fire-barriers and paving tiles. However, the low-density cement-bonded boards (Excelsior) could be used for high-performance applications and improved acoustic and damping properties such as; fire-resistant, sound-absorbing walls, ceilings, and thermal insulation panels [24]. But it is important to note that the utilization of cement-bonded composites is highly dependent on construction techniques, esthetics, safety and energy regulations, and all the other underlying factors which determine public acceptance of a product. The vast literature on cement bonded-wood-based composites, their properties, and manufacturing variables could be found elsewhere [9, 20]. **Table 5** shows comparative use ability and **Figure 2** shows some examples of mineral bonded composites.

The gypsum-based composites are a well-known low-cost material and frequently used to finish interior wall and ceiling surfaces that are often called drywall, wallboard, or plasterboard [20, 25]. Thereby, these materials could be useful for both residential and non-residential construction applications. However, the paper-faced gypsum boards have been widely used since the 1950s for the interior lining of walls and ceilings which are appropriate to fire ratings [20]. The paper-faced gypsum boards also find use areas as exterior wall sheathings. The facings of drywall and gypsum sheathing panels are adhered to the gypsum core, providing the panels with impact resistance, and bending strength, and stiffness. An alternative to adhered facings is to incorporate lignocellulosic fiber (typically recycled paper fiber) in the gypsum core to make what is termed fiber-reinforced gypsum panels. Moreover, the gypsum sheathing panels are primarily used in commercial construction, usually over steel studding, and are distinguished from gypsum drywall by their water repellent additives in the paper facings and gypsum core [8, 15, 20]. It has already well established that natural fiber-reinforced gypsum panels (wood fibers) are typically stronger and more resistant to abrasion and indentation than paper-faced drywall panels and also have a moderate fastener-holding capability [8, 20, 25]. Although gypsum-based boards have usually been marketed for use as interior finish panels (drywall), some hydrophobic additives can provide a certain level of water resistance, for use as sheathing panels, floor, or roof

	Cement bonded composites	Gypsum bonded composites	Magnesia bonded composite
Exterior and partition walls	+++	+	+
Coating of the wall	+++	+++	++
Acoustic and thermal insulation	++	+++	++
Decoration	++	+++	++
Flooring	+++	+	++
Large size prefabricated elements	+++	+	++
Roofing, shingles and shade	++	++	++
Ceilings and architraves	++	++	++
Fire resistant construction	+++	+++	+++

Table 5.
General uses of mineral bonded composites (+: low level; ++: medium level; +++: high level).

Figure 2.
The uses of mineral-bonded composites in some applications.

underlayment, or tile-backer boards. In addition, the gypsum-based panels have a low thermal coefficient and low solid contents that these properties are good for insulating against heat and sound while the mechanical strength of the gypsum-based composites is still retained [8, 9, 16, 20].

Although composites bonded with magnesia cement are considered water sensitive, they are much less so than gypsum-bonded composites. One successful application of magnesia cement is a low-density panel made for interior ceiling and wall applications. However, the gypsum and magnesia-based wood composites have also presented high dimensional stability and resistance against biodegradation while well fire resistance and some level sound insulation properties. This is attributed to the lower content of organic matter and the crystal water in the binder. These special properties make these products could be useful for a wide variety of purposes in construction applications. Thereby, the low-density products could be useful as interior ceiling and wall panels while high-density panels could be used as complete wall and roof decking systems. Moreover, exterior-type panels are coated with stucco, and the interior is a gypsum board. These are also useful for decorative and sound barrier purposes in constructions [22, 26].

However, high-density magnesia and/or Portland cement-bonded boards can be used as flooring, roof sheathing, fire doors, and load-bearing walls. But complex shapes, such as decorative roofing tiles or non-pressure pipes, can be molded or extruded as well. The largest volume of cement-bonded wood-based composite materials manufactured in North America is fiber (pulp)-cement siding [27]. Moreover, cement-bonded panels can be used as low-cost housing systems in developing countries such as; rural prefabricated structures, mobile homes, structural insulation panels so on [9].

The Magnesia and gypsum boards might also be used outdoors but must be protected from direct exposure to the weather because of sensitivity to moisture.

5. Conclusions

The markets for inorganic-bonded wood composites vary throughout the world. However, there is a great potential for the use of wood species to make mineral-bonded composites. Substantial markets for these panels have been developed for various construction end-uses (i.e. sheathing and siding) with insulation partitions. These products may provide an option for using lignocellulosic residues for improved properties like fire and sound insulation characteristics and hence can be used as wall covering and filling material in the constructions. Moreover, inorganic-bonded boards could be adapted to the wood frame construction techniques used for residential housing.

The use of mineral-bonded composites is highly dependent on building codes, safety and fire regulations, construction techniques, esthetics, availability of materials, and all the other underlying factors which determine public acceptance of a product. However, cement-bonded wood composites (WBC) have been taken as very stable dimensionally when subjected to outdoor applications. However, gypsum boards are commonly used as a lining material in walls, ceilings, and wall partitions.

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