Magnesium Oxide Panels:

Emergence of a Modern Building Material

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ABSTRACT – This paper provides a fresh perspective on the emergence of magnesium oxide (MgO) as a modern building material. We begin with an introduction to basic material composition. We then describe the primary MgO types and modern practices used in their transformation into composite panels. Next, we examine properties of MgO in panel form. Here, we review its advantages in fire resistance, durability, and lesser-known attributes such as coating and surface bonding. We take a direct approach at ongoing quality concerns, especially those involving weeping, corrosion, and general water resistance. Last, we discuss factors that either hinder or hasten the expansion of MgO panels into new markets. No longer a niche material, MgO has found value in all segments of the construction industry. This positive growth is gaining renewed attention from key industry stakeholders seeking creative new uses of MgO. The world now sees its potential. Though still enigmatic, MgO has emerged as an immensely capable material poised to disrupt the industry for generations to come.

INTRODUCTION

Magnesium oxide (MgO) panels represent composite cementitious materials used as alternatives to conventional products such as gypsum board, plywood, oriented strand board, and Portland cement panels. Magnesium oxide has gained considerable acceptance as a modern construction material due largely to its unique chemical compositions and favored performance attributes such as high strength, dimensional stability, and resistance to fire, water, and biological degradation. Indeed, its attributes have been recognized and refined since the late 19th century. Only now, almost two centuries later, have we realized the potential this material offers.

In this review, we define magnesium oxide panels as a collective of sheathing, panel, or board products comprised of MgO cements – also known as magnesia cements. The term 'Magnesium Oxide Panels' is therefore a general phrase used to reference a myriad of products employing vastly different mineral compositions, additives, and manufacturing processes. The industry has adopted the term 'Magnesium Oxide Sheathing' when referencing its use in wall, floor, or roof assemblies. While both terms could be used interchangeably, the distinction as 'panels' better aligns with existing terminology defined by the International Code Council.

We limit this review to magnesia cements used in the commercial production of panel products. These processes employ reactive MgO, an additional reactant salt, water, and desired additives. Furthermore, magnesia cements are not to be confused with magnesium-enriched Portland cements nor lime cements consisting of binders formed from hydrates of calcium silicate or calcium oxide, respectively. Likewise, we exclude magnesian lime cements or dolomitic lime because calcium oxide still serves as the predominant binder precursor. Magnesium-containing cements have long been conflated with those comprised of purely reactive MgO, giving the impression that MgO reflects a revived ancient material when actually it does not. For example, studies of stuccos and mortars from ancient walls in Europe, China and the Middle East show compositions primarily of calcium oxide with low or immeasurable magnesium content [1-6]. Analogs of modern MgO undoubtedly occurred in ancient times as the means and materials existed in some form, including the ability to calcine. Still, current evidence shows that ancient cements were predominately rich in lime, not MgO.

The forerunner to modern magnesia cement was first described by Stanislas Sorel in 1866 with his invention of magnesium oxychloride [7, 8]. Sorel combined reactive MgO with concentrated magnesium chloride brine, to achieve properties arguably superior to Portland cement. Features of particular relevance included greater compressive strength (>10,000 psi), lower alkalinity (pH 8.5 - 9.5), improved elasticity, and the ability to bind with organic and inorganic additives [9, 10]. Variations soon followed with the emergence of magnesium oxysulfate cement in 1891 [11] and magnesium phosphate cement in 1939 [12, 13]. These variants contained the same general components as their chloride predecessor: reactive MgO, an activating salt, and water. Although each offered something unique, they shared antecedent properties for what would eventually become a reinforced, lightweight cast material – what we recognize today as MgO panels [14] (Fig 1.).

The range of products stemming from these varied compositions are similarly diverse, encompassing common panel products such as wall sheathing, floor underlayment and roof decking to more specialized applications such as sound attenuation panels, fire partitions, and integrated water-resistive sheathing. No longer a niche material, MgO panels have found their way into all segments of the construction industry.

The advantages of MgO are significant. When compared to Portland cement, MgO panels offer greater flexural strength and higher resistance to fastener withdrawal. Fire resistance rivals that of gypsum panels while providing significantly greater impact and water resistance. Unlike wood-based panels, MgO is dimensionally stable when exposed to moisture. And unlike gypsum, it will not disintegrate during freeze-thaw cycling. Magnesium oxide also remains highly resistant to microbial and insect degradation. Hygric properties of MgO panels include high water vapor permeance, efficient drying, with the added benefits of moisture buffering in a manner similar to wood and gypsum. In short, MgO confers the best attributes of each conventional material while offering additional advantages uniquely its own.

Fig.1. Magnesium oxide panels. Shown are three products with thicknesses ranging from 0.25” to 0.75”.

Though its benefits are many, the adoption of MgO paneling has been fettered by challenges. We discuss these at some lengths in this review. They entail factors such as material sourcing, insufficient standards, manufacturing quality, and questionable installation practices. We see these obstacles as normal course in early adoption of new construction materials. Moreover, many of these issues are already well-resolved and the remaining will be sorted out by market demands, ongoing innovation, and education.

Modern pursuits for high-performing buildings favor products that are sustainable, durable, and resilient in response to changing conditions. Materials must be safe and user-friendly. And they must be steadfastly attentive to costs and market demands. In this review, we explore the untapped potential of MgO. We examine how a material so simple in composition and so adaptable in application finds new purpose in modern construction.

MATERIAL COMPOSITION AND REFINEMENT

Raw Material

Production of magnesia-based panels utilizes MgO, a mineral representing the oxidized state of magnesium. Unlike pure magnesium, which is chemically reactive and highly flammable, the mineral form of MgO is extremely stable and fire-resistant – traits that it retains through processing into composite materials.

Although MgO exists naturally in the form of periclase, it is largely obtained from magnesium-rich ores such as magnesite (magnesium carbonate), brucite (magnesium hydroxide), and dolomite (calcium magnesium carbonate). Magnesium oxide is also sourced from seawater and naturally occurring brines as precipitated magnesium hydroxide [9, 10].

Calcining and Reactivity

Magnesium ores are refined through a series of crushings, screenings, and one or more stages of calcination, a process of controlled high-temperature heating to remove impurities and carbon dioxide. The characteristics and reactivity of MgO are largely determined by calcining stages, durations, and corresponding temperatures. Light burned MgO is derived from burning at 700°C to 1,100°C, yielding larger particle sizes and the most reactive in terms of cement hydration. Higher temperatures are necessary to obtain purer, less reactive hard burned MgO (>1,100-1,400°C). Dead burned MgO represents an even higher-grade, less-reactive form obtained with two-stage calcining at temperatures similar to those used in calcining Portland cement (>1,400°C) [9, 10].

Calcining typically yields a fine white or tan powder with purity ranging from approximately 70% to 98%, depending on raw ore source and degree of calcining [10]. Figure 2 depicts light burned MgO originating from calcined magnesite. The homogeneity, purity, and reactivity of MgO have significant influence on the quality of magnesia cements. For example, common mineral impurities such as calcium oxide and silicon dioxide are known to adversely affect mechanical properties and weathering characteristics [15, 16]. Likewise, MgO reactivity alters the rate of dissolution, setting times, water evaporation, and preferred mix ratios. Lowering reactivity reduces MgO levels within hydrating magnesia slurries, leading to higher quantities of unreacted salts and reduced matrix durability [9, 10]. Further irregularity is introduced by the change in MgO reactivity over time as exposure to high humidity and air leads to hydration and carbonation, which ultimately reduces reactivity [17]. Such compounding variables point to the importance of robust quality control inclusive of calcining, material storage, and production.

Fig.2. Calcined MgO originating from mined magnesite.

Reactant Salts

In addition to reactive MgO, proper setting of magnesia cements requires a chemical reactor. This is typically achieved using reactant salts such as magnesium chloride ($MgCl_2$), magnesium sulfate ($MgSO_4$), or potassium dihydrogen phosphate (KH_2PO_4). The anion of the reactant salt defines the magnesia cement type. In other words, magnesium oxychloride is formed by combining MgO with concentrated brine consisting of water and magnesium chloride ($MgCl_2$). Magnesium oxysulfate is produced similarly using concentrated solutions of magnesium sulfate ($MgSO_4$). A third type of magnesia employs acid phosphate salts such as potassium dihydrogen phosphate (KH_2PO_4) or ammonium dihydrogen phosphate ($NH_4H_2PO_4$). Regardless of magnesia type, the reactant salts, and their mix ratios with MgO, play important roles in magnesia cement properties, stability, and long-term weathering behaviors. Moreover, important manufacturing processes such as casting, set times, and curing are notably influenced by the reactant type [9, 10].

Fillers, Additives and Reinforcements

Magnesia cements are known to receive a great variety of fillers, admixtures, and reinforcing materials [9,10]. These components serve various functions, including weight reduction, slurry modifiers, and improved mechanical properties. Additives such as latexes, fly ash, silica fume, and metakaolin are often used to improve plasticity, crack mitigation, and water resistance [18-22]. Furthermore, foaming agents have been employed to achieve lower densities and higher insulating values [23]. Other additives, including setting retarders, accelerators, and superplasticizers are used to adjust slurry fluidity, component dispersion, set times, volume stability, and general curing characteristics [9,10].

The most abundant components added in commercially available MgO panels include sawdust, perlite, and reinforcing scrims [14]. Sawdust serves principally as a lightweight fine aggregate to reduce panel density. To a lesser extent, it also serves as a binder to improve cohesiveness of the cement matrix. Unlike Portland cements, magnesia cements bind well to lignocellulosic materials and are compatible with their associated extractives such as acids, sugars, resins, and waxes [9, 10]. Despite strong binding characteristics, wood components are known to reduce the mechanical properties of magnesia and other cements [24-26]. Wood also encourages water absorption while retaining moisture over longer periods of time [10]. As a combustible material, wood presents additional considerations for flame spread, smoke generation, and fire classification.

Perlite is comprised of amorphous volcanic glass. While it offers the same benefits as wood, it also suffers similarly regarding water absorption and reduced strength. Wood and perlite are both highly water-absorptive. By competing for available water, they notably influence slurry fluidity and uniformity of cement hydration. These considerations are particularly critical for mixes requiring low water/cement ratios. Furthermore, dissolved unreacted salts absorbed by perlite and wood are subject to leaching [10]. Proportions of these lightweight aggregates are therefore carefully optimized to achieve the desired effects of lighter weight while retaining other preferred properties and durability.

Reinforcing fibers, scrims, and meshes vastly enhance mechanical properties such as impact resistance, flexural strength, and even fastener pull-out resistance. These materials work by transferring stresses to the greater matrix rather than allowing them to propagate and expand locally or discretely. Cracks and impacts are thereby mitigated, preserving cohesiveness and durability. Magnesia cements are well-suited for fiber reinforcements as their lower alkalinity reduces degradation often associated with Portland cements. Current production methods for MgO panels rely heavily on fiberglass meshes placed incrementally within panel depth (thickness). Lightweight fabric scrims are also employed in combination with courser meshes to preserve surface integrity and handling. The use of loose fibers in panel production remains an underutilized approach though their efficacies in magnesium cements have been well-demonstrated [27-29]. Examples of fibers used in MgO include glass, brucite, basalt, carbon, and polypropylene.

TYPES OF MAGNESIA CEMENTS

Current production of MgO paneling utilizes predominantly two magnesia cements, magnesium oxychloride (MOC) and magnesium oxysulfate (MOS). Advances in both technologies are driving innovation, achieving novel formulations, improved durability, and greater consistency. Ongoing research also shows progress for other emerging magnesia, namely magnesium phosphate cements (MPC). Indeed, magnesium oxide represents a highly adaptable medium, accommodating a variety of admixtures, hybridization with other magnesia, and as additives in Portland and lime cements. To say that a magnesia cement is exclusively of one type is not always apparent as combinations in blending are seemingly endless and the specificity of formulations are rarely disclosed.

Magnesia cements represent heterogenous matrixes comprised of amorphous and crystalline structures randomly encompassing their respective fillers [10]. Morphologies vary widely based on magnesia type, compositions, specific hydration products, and curing conditions. Figure 3 illustrates general morphologies of magnesia used in MOC panel production.

Magnesium Oxychloride (MOC)

Magnesium oxychloride, also known as the original Sorel cement, represents the most common type of MgO panel. This magnesia is formed by mixing light burned MgO with a concentrated magnesium chloride brine. The resulting products include hydrates of magnesium chloride, each reflecting different $MgO/MgCl_2$ ratios, reaction temperatures, and microstructure.

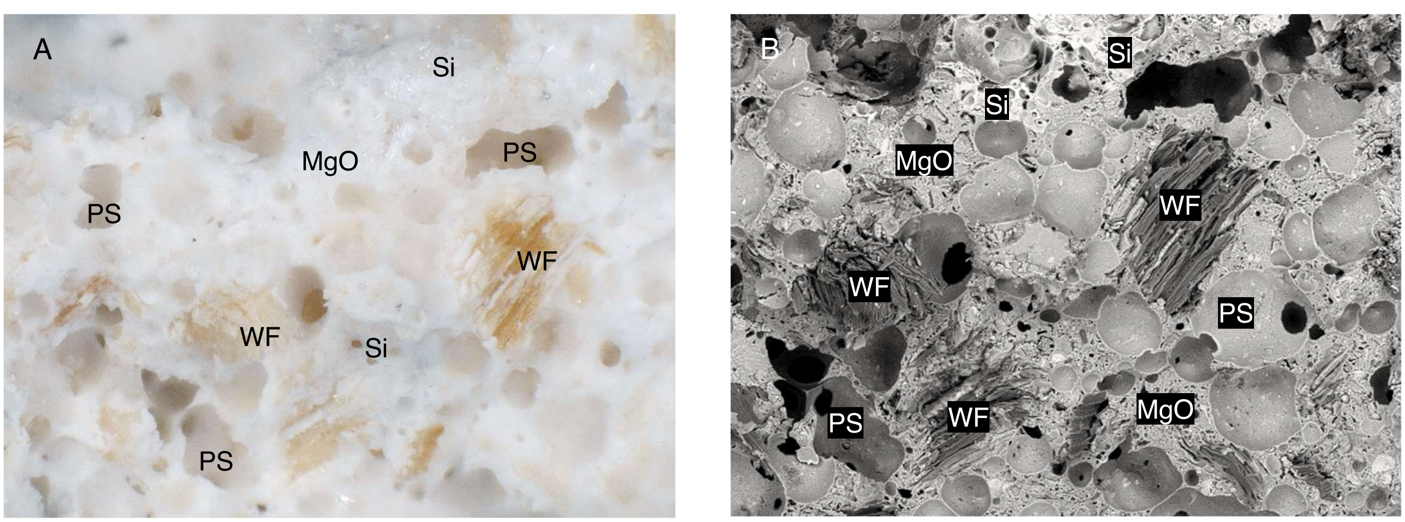


Fig 3. A) Light micrograph of MOC panel illustrating magnesia matrix (MgO), pore structure (PS), wood fibers (WF), and silica-rich regions, likely representing perlite. Scanning Electron Micrograph (SEM) of same panel.

Hydrates of MOC are referenced according to phase composition, or simply "phase"; the most stable being the 3-phase and 5-phase [9,10].

Magnesium Oxychloride

$3MgO + 1\ MgCl_2 + 11H_2O \rightarrow 3Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O$
3-Phase

$5MgO + 1\ MgCl_2 + 13H_2O \rightarrow 5Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O$
5-Phase

The properties of MOC epitomize the advantages of magnesia cements in general, namely high strength, abrasion resistance, fire resistance, and high affinities for additives and reinforcing materials [9, 10]. Refinements in MOC formulations yield performance attributes that far exceed industry criteria for fiber-reinforced MgO panels as outlined by ICC Evaluation Service (ICC-ES) Acceptance Criteria 386 (AC386) [30]. These include properties such as high flexural strength, impact resistance, fastener pull through resistance, reduced water absorption, and dimensional stability.

Drawbacks to chloride technologies center around concerns regarding hydrate stability and water resistance. Both matters are derived from inconsistencies in mix design, unreacted $MgCl_2$, and the inherent instability of primary hydrate phases under prolonged contact with bulk water [9,10]. Furthermore, unreacted $MgCl_2$ leads to water adsorption, droplet formation, and subsequent efflorescence following evaporation from cement surfaces. This phenomenon actually involves multiple processes including deliquescence, dehalogenation, and efflorescence and are collectively referenced as "weeping" or "crying". The detrimental effects of weeping boards have long been known and are perhaps best documented from European accounts of unprotected panels installed in humid climates [31-34]. Degradation likely involves dissociation of the 5-phase hydrate and the ensuing formation brucite, hydromagnesite, and $MgCl_2$. Degradation of contacting metal is also reported as the presence of excess free chlorides leads to premature corrosion [10].

Matters regarding free chlorides, "weeping", and corrosion are resolved through greater attention to mix design and production control. Additives such as phosphates and reactive silicates are also suggested in these pursuits [9, 10]. Concerns of hydrate stability, and specifically 5-phase disassociation, stem largely from civil applications where materials are routinely, or even continuously, exposed to water. This contrasts with its uses on buildings, which are limited to transient moisture and above-grade applications, conditions for which oxychloride panels are well-suited.

Magnesium Oxysulfate (MOS)

Developed in 1891, magnesium oxysulfate cement offered an early variant to Sorel's oxychloride. Its core formulation employs magnesium sulfate as the reactant salt in lieu of magnesium chloride. Similar to its MOC predecessor, oxysulfate cement is formed by combining light burned MgO with its respective reactant brine, yielding two stable hydrates of magnesium sulfate [9, 10].

Magnesium Oxysulfate

$3\ MgO + 1MgSO_4 + 11H_2O \rightarrow 3Mg(OH)_2 \cdot MgSO_4 \cdot 8H_2O$
5-1-3 Phase

$5\ MgO + 1MgSO_4 + 7H_2O \rightarrow 5Mg(OH)_2 \cdot MgSO_4 \cdot 2H_2O$
5-1-7 Phase

Magnesium oxysulfate offers two primary advantages over its MOC counterpart. These include improved fire resistance and reduced corrosivity to contacting metals. Although both MgO types are inherently fire-resistant, MOS cement exhibits significantly less mass loss at temperatures exceeding 400°C [10]. Therefore, fire performance of MOS cement has long been favored for fire-resistant applications such as wood wool insulation boards [10].

As previously discussed for MOC cement, metal corrosivity is largely attributed to free chloride levels due to unreacted $MgCl_2$ and the concomitant effects of deliquescence, dehalogenation, and efflorescence [35]. Although MOS cements will degrade under prolonged exposure to water, its dissociated salt, magnesium sulfate, is notably less corrosive than magnesium chloride.

The mechanical properties of MOS cements are generally regarded as inferior to those of MOC [9, 10]. This is especially true for weathered products which undergo binder disassociation to form insoluble magnesium hydroxide. Likewise, MOS panels have shown dimensional instability when exposed to 90% relative humidity for prolonged periods. Furthermore, dimensional changes in two MOS products were greater than those observed in fiber cement, plywood, and OSB [36-38].

In recent years, modifications of MOS cements have offered considerable improvements in water resistance and general mechanical properties [20, 39, 40]. These modified oxysulfates are collectively referred to as Basic Magnesium Sulfate Cement (BMS) and are characterized as having higher $MgO/MgSO_4$ ratios, admixtures, and an improved crystalline morphology that favors the 5-1-7 phase. The BMS cements rely principally on admixtures to achieve their desired effects. Examples include potassium phosphate, sodium malate, phosphoric acid, citric acid, tartaric acid, and amino trimethylene phosphonic acid.

Panel production utilizing MOS cement shows growing use of BMS technologies.

By appearance, oxysulfate panels are indistinguishable from those derived from oxychloride formulations. The use of scrims, meshes, and fillers are similarly unchanged from those traditionally used for MOC. This has given rise to a great deal of confusion regarding MgO variants since toll manufacturers and their resellers do not always openly divulge MgO type. Nonetheless, there are two camps now deeply entrenched in global MgO markets – one favoring the traditional chloride panels and the other embracing magnesium oxysulfate. Developing standards may eventually negate these opposing viewpoints as MgO type is inconsequential under common acceptance criteria.

Magnesium Phosphate Cements (MPC)

Recently emerging is a third type of magnesia cement employing phosphoric acid or acid phosphates as hydration activators. These reactions are rapid and exothermic, giving rise to high amounts of heat with set times measured in mere seconds or minutes [9, 10]. Practical commercialization of MPC cements employ two strategies to overcome these challenges: 1) use of less reactive dead burned MgO, and 2) use of various set-retarders [10]. The first solution is advantageous as using dead burned material confers greater purity (>98%) as compared to light burned MgO (70-84%). The second strategy also shows promise as retarders effectively extend set times without deleterious effects to the cement matrix.

The potential of magnesium phosphate cements is worth the challenge as their properties are arguably superior to those of magnesium oxychloride and magnesium oxysulfate. In short, MPC cements may have all the benefits of MOC and MOS without the concerns of corrosivity, poor water resistance, and hydrate instability.

Hydration products of MPC depend on the reactants. The use of concentrated phosphoric acid alone, though effective, is violently reactive and impractical for large scale production [10]. Attention has therefore focused on acid phosphates salts such as ammonium dihydrogen phosphate ($NH_4H_2PO_4$) or potassium dihydrogen phosphate (KH_2PO_4), the resulting products being struvite and k-struvite, respectively. Additional hydration products are formed depending on the employed activators, reaction rates, and general matrix conditions. However, these products are typically transitory in nature; or they comprise minor proportions of the overall matrix [9, 10].

Magnesium Phosphate Cements

$MgO + NH_4H_2PO_4 + 5H_2O \rightarrow NH_4MgPO_4 \cdot 6H_2O$
struvite

$MgO + KH_2PO_4 + 5H_2O \rightarrow KMgPO_4 \cdot 6H_2O$
k-struvite

The predominant products struvite and k-struvite show high stability in water, including intermediate periods of full submersion [10]. These findings confer high confidence for MPC in exterior applications where MOC and MOS have previously suffered.

Commercial development of MPC strives to overcome the challenges of short working times and the explicit requirements for admixtures to hinder its reactive tendencies. Another constraint involves the tensile strength of MPC, which is notably lower than that of MOC and MOS [10]; however, admixtures in combination with fibers and reinforcing meshes show promise in achieving panels having equal or greater attributes.

MANUFACTURING

The following discussion offers an overview of panel manufacturing and quality control procedures. Although practices vary considerably according to MgO types, and their proprietary methods, the general concepts remain largely the same. Manufacturing facilities also vary widely in size, modernization, and automation. In China, modern facilities show production capacities ranging from 1,000 to over 3,400 sheets per day. These higher quantities are achieved through increased levels of automation, including automated metering, mixing conveying lines, unloading, and stacking systems. The best facilities also give considerable attention to panel curing, which requires specific setpoints for temperature and humidity.

Mixing

Development of MgO cements has placed much emphasis on dry-mix applications where dry components, including admixtures, are premixed and packaged for onsite use. Panel manufacturing lacks these constraints as mixing occurs at the production facility using pre-staged raw products procured in bulk. Production is still built around a specific mix design with respect to formulation, sequence of dry and wet components, rate and manner of introduction, and preferences for component preconditioning. These variables are optimized to achieve high efficiencies and consistencies not attainable in field applications.

Calcined MgO is typically combined with other dry materials such as wood, perlite, fibers, and preferred dry admixtures. This pre-blending assures more uniform distribution prior to introduction of the reactant brine. Where water content is more critical, fillers may be pre-wetted to improve fluidity and mix consistency. Panel production employing MOC and MOS cements introduce the reactant salt as pre-mixed brine solutions. Dry and liquid portions are then combined in hoppers and agitated to desired consistency. It is important to note that panels are generally produced with more than one slurry type – one is more fluid and serves as the base material; the other has a medium consistency and serves as the primary panel matrix. Mixed slurries are staged in collection bins prior to being sequentially released on to casting molds.

Casting and Curing

Slurries are often cast on to plastic casting sheets that are pre-coated with a release agent. Fabric scrims and reinforcing meshes are also unrolled and laid into each cast in their preferred sequence and corresponding slurry type. Each step occurs along a single automated conveying line. Casting employs sheets that are slightly oversized to accommodate edge trimming and sizing after final curing.

Critical factors in panel manufacturing include conditions and timing of MgO curing. For example, curing of MOC and MOS panels usually involves a two-step process – the first is conducted while still on the cast sheet at elevated temperatures and low relative humidity (<50%). This cure is achieved over a period of approximately 12 hours. The second stage follows removal of the mold and involves 14 to 28 days under controlled temperature and humidity.

Edges of cured panels are cut to achieve desired finished sizes. A common size is 4' wide x 8' long x ½" thick. Other thicknesses are available ranging from ¼" to 1" and lengths to 9' and 10'. After trimming to preferred size, panels are sanded to achieve uniformly flat planes.

Packaging and Shipping

When fully cured and rid of remaining moisture, each MgO panel can weigh between 60 to 120 pounds depending on density, fillers, thickness, and added reinforcements. Individual panels are stacked on pallets and prepared for shipment by land, rail, or sea. As with other cementitious materials, MgO pallets are heavy, resulting in relatively short pallet stacks of approximately 50 to 60 panels of ½" material. Reduced stack heights are also necessary to accommodate lifting and dimensional constraints of common shipping containers (Fig. 4).

Fig.4. Palletized MgO showing panel edge orientation to accommodate oversea transport in shipping containers. Panels are typically re-palletized prior to distribution.

Quality Control

Like many building products, MgO paneling is not immune to quality concerns. Without exception, notable failures have involved poor quality material or quality issues combined with improper use [31-34]. Of those pertaining to quality control, virtually all aspects of manufacturing, from raw material sourcing through shipping and storage, are brought into play.

Quality begins with the MgO itself. Its homogeneity, purity and reactivity are of immense importance as MgO/salt ratios and hydration products stem from the reacting binder. When exposed to ambient air, calcined MgO is subject to hydration and carbonation with subsequent change in reactivity over time [17]. Therefore, chemical reactivity of refined MgO should be monitored throughout its storage life [10].

Curing represents another determining factor in quality and panel consistency. These conditions are not prescribed by performance standards as curing represents highly specific and proprietary processes that depend largely on the type of MgO slurry as well as its unique formulation. Some panel manufacturers have been known to cure their MgO in unconditioned, exterior environments for very short periods of time – often in as little as a few days. Such lapses in controls can cause significant problems with material properties. These issues are compounded by changing seasonal weather. In some cases, poorly manufactured MgO panels arrive with several inches of water in the bottom of the container with panels fused together through chemical reactions spurred by excess water.

As with any engineered material, performance of MgO paneling hinges on demonstrable quality monitoring – or the ability to meet best practices and applicable standards with consistency. The central premise is to demonstrate ongoing compliance with performance criteria originally conveyed by the rigors of code acceptance. For MgO paneling, these minimum criteria are established by AC386 or product-specific evaluation reports and listings. Quality manufacturing practices should therefore align with these key performance benchmarks.

It is worth noting that many of the MgO panels on the market today originate from China and are imported by contract manufacturers in the country of destination. These materials may or may not conform to the quality demands claimed by the reseller. Alternatively, the product itself may undergo changes during shipping and prolonged storage. It is therefore incumbent upon the contract manufacturer to maintain a robust quality monitoring program as verification to those offered by the toll processor. Though seen by many as overly burdensome, this 'trust but verify' approach addresses many of the lingering skepticisms of MgO panel quality. More importantly, it protects the supply stream of products distributed within the importing country.

In Table 1, we list minimum performance testing as a basis for quality monitoring of MgO paneling. These procedures should be performed on a batch basis involving materials selected at random from each batch. Further periodic testing is recommended to verify board composition by means of Fourier Transform Infrared Spectroscopy (FTIR). Fire properties should also be periodically verified via cone calorimetry (ASTM E1354). Further program requirements include corresponding document control, instrument calibration, and requirements for packaging and storage as outlined in each manufacturer's listing and/or report.

Table 1. Minimum performance testing as a basis for quality monitoring of MgO paneling.

Property	Method
Density	Mass/volume ratio
Flexural Strength	ASTM C1185
Fastener Withdrawal	ASTM D1037
Moisture Absorption	ASTM C1185
Moisture Movement	ASTM C1185
Moisture Content	Percent moisture loss
Free Chloride Ion Content	Titration (Mohr's method)
Halogen Resistance	90% RH, 72 hours
Dimensions and Tolerances	ASTM C1185/ASTM C1186

PROPERTIES OF MAGNESIA PANELS

Below we describe key properties of MgO with relevant comparison to other panel types. As previously discussed, the properties of MgO panels vary considerably from one manufacturer to another; and similarly, they vary between formulation types and intended uses. The following pertains to prevailing products having demonstrable quality control and adherence to the strictest industry standards.

Fire Resistance

Perhaps the best known benefit of MgO paneling is its resistance to fire. Magnesia cements are inherently fire-resistant imparted by their low thermal conductivity, heat mitigation by crystalline and free water, transpiration processes, and high heat reflectance [10]. Fire resistance of MgO paneling is comparable to that of gypsum panels and is classified as a nonflammable Class A fire-resistant material. When tested in accordance with ASTM E84, MgO panels do not burn at temperatures up to 800°C (1,472°F). Furthermore, MgO paneling shows no flame spread at 1,200°C (2,192°F). Such attributes are advantageous when using MgO as a non-combustible material per ASTM E136 or as part of a fire-rated assembly when applied to criteria outlined by ASTM E119. Magnesium oxide panels are also routinely incorporated into a great variety of assemblies where combustible materials require NFPA 285 compliance.

In addition to fire resistance, MgO panels will not produce toxic fumes or smoke when exposed to high heat or flames. Instead, panels char and absorb large amounts of thermal energy thereby contributing to delay in fire and smoke spread (Fig. 5).

Fig.5. Charing and zero flame spread of MgO paneling following ASTM E2768 or extended ASTM E84 30-minute testing.

Strength & Impact Resistance

The mechanical properties of MgO panels are on par with engineered wood while well-exceeding those of gypsum-based products. The attributes of MgO panels are owed largely to their extremely strong and durable cementitious matrix that outperforms conventional Portland cement under compressive and tensile stresses [9, 10]. Reinforcing fibers, scrims, and meshes further enhance its flexural and plastic properties, offering extremely high resistance to shear, impact, and bending (Table 2).

The dense and cohesive matrix of MgO paneling serves as an ideal fastener base. Single fasteners within half-inch MgO have been shown to hold greater than 350 psf in shear while providing a withdrawal strength of more than 150 lbs of force. This performance is further enhanced in cases where MgO panels are bonded to other materials such as Structural Insulated Panels (SIPs) or Structural Insulated Sheathing (SIS). These properties enable cladding to be directly fastened to the MgO panel without explicit need to tie back to framing members. At half-inch thickness, MgO serves as a suitable fastener base for most cladding types or their corresponding attachment systems.

Table 2. Strength properties of MgO panels*.

Property	Performance
Density	1,000 - 1,250 kg/m^3
Flexural Strength – machine direction	13 - 30 MPa
Flexural Strength – cross direction	13 - 22 MPa
Fastener Withdrawal Force	80 – 150 N/mm
Compressive Strength	20 - >40 MPa
Impact Strength	5 - >20 kJ/m^2

*Values reflect performance ranges for 12 mm (1/2”) panels as produced by various manufacturers having different formulations and MgO types.

Water Resistance

We refer to ‘water resistance’ as a material’s ability to remain durable and substantively unchanged in response to bulk water. This requires three important attributes: reduced water absorption (wetting), effective desorption (drying), and a matrix that remains reasonably stable over repeated wetting events. Magnesium oxide panels are designed to accommodate repeated water exposure as encountered over the course of construction. They also withstand transient moisture cycling under normal service conditions. But as with other materials, there are limits. Most magnesia cements are not intended for applications involving continuous water exposure or prolonged water immersion. Such conditions will cause the cement to disassociate, leading to leaching and matrix instability [9, 10]. The intended exposures are those that are transient, non-immersive, and concealed or otherwise protected from the elements.

As a cementitious material, MgO will absorb water. But, in terms of hygric performance, it behaves more like gypsum rather than wood. This is true for its water sorption characteristics as well as its ability to dry. For example, water absorption following two-hour immersion is typically less than 10% (M%). Gypsum panels exhibit similar water absorption for the same period. In contrast, wood-based panels show notably higher water absorption, typically well in excess of 20%. Even more telling is the ability to dry. In Fig. 6 we show simulated drying of panels initially held at their respective free moisture saturation and maintained under isothermal conditions for 30 days. Both MgO and gypsum show effective drying, requiring approximately four days to reach equilibrium. In contrast, drying of plywood and OSB require considerably longer periods, approaching 25 days.

An important distinction of MgO paneling is its ability to retain its mechanical properties when exposed to water. For example, prior findings have shown that flexural strength of MgO is minimally changed when exposed to 25 cycles of water immersion and drying. By comparison, bending strengths of OSB and plywood were reduced by 40% and 9%, respectively. Gypsum panels lost 36% to 52% of their flexural strengths when subjected to the same wetting-drying cycles [31]. These results agree with our ongoing studies of MgO, which show no appreciable reduction in flexural strength following routine weathering.

Exposure ratings for MgO panels are product-specific, but most accommodate a period of at least three months. Beyond this period, they should be protected from the elements whether by sheltering or by application of an approved underlayment or water-resistive barrier.

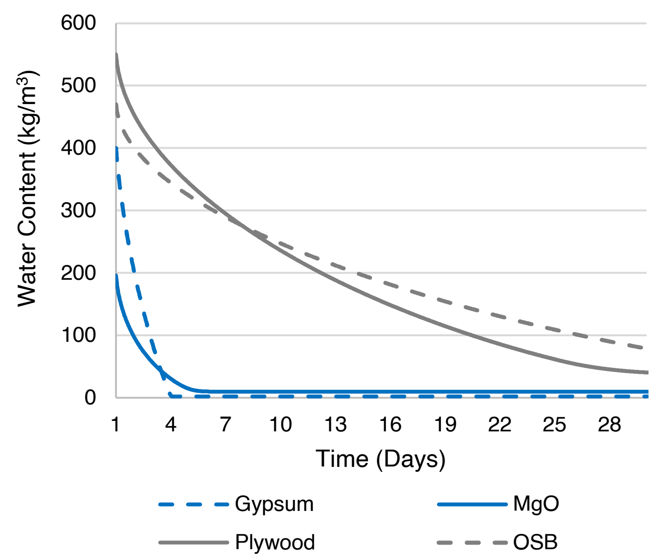


Fig.6. Simulated drying of panels initially held at their respective free moisture saturation and maintained under isothermal conditions for 30 days (20°C, 50% RH).

Other Hygric Behaviors

Magnesia panels are hygroscopic, which means they readily adsorb moisture from the ambient air. This is also true for other panel types as their water contents will approximately double when relative humidity changes from 50% to 80%. For MgO, this same change results in a four-fold increase. But, as previously shown, MgO also dries efficiently – similar to gypsum and notably better than wood. Moreover, MgO paneling is vapor permeable, having a perm greater than 10 at half-inch thickness.

The combined features of being hygroscopic and vapor permeable aid in moisture transport and subsequent release to its interfacing components. As a result, moisture is safely stored, transferred, and released in response to prevailing vapor gradients. The hygric properties of MgO panels offer what is arguably an ideal construction material. This opinion runs counter to prior accounts of 'weeping' and degradation of panels exposed to high humidity [31-34]. The importance of this matter deserves further explanation as ongoing misinterpretation dissuades acceptance of what are highly predictable and stable materials. Though weeping is not exclusive to magnesium oxychloride; for the purpose of clarity, we have focused our attention on this MgO variant.

The production of panels under poor quality control may give rise to unreacted magnesium chloride ($MgCl_2$). This is often referred to as free chlorides. Unstable panels under prolonged water exposure can also form chlorides via decomposition to $Mg(OH)_2$ and $MgCl_2$ [10]. Regardless of their origins, chlorides will dissolve in water derived from the ambient air. But the hygric nature of the panel itself is not the problem as any hygroscopic material will reach its saturation point when left at sufficient humidity for sufficient time. The problem stems from the fact the $MgCl_2$ is highly deliquescent – it adsorbs water vapor very aggressively, dissolving into it and forming saline solutions – even while the surrounding matrix is held below its saturation point. In other words, $MgCl_2$ is significantly more hygroscopic than the cementitious matrix. And unlike the hydrated products, unreacted $MgCl_2$ dissolves in water, effectively lowering the equilibrium moisture content of the greater panel. Saline droplets are ultimately expressed on panel surfaces; and there they remain while the concentrated brine hinders evaporation of the captured water portion. As vapor pressures change, the entrapped water will evaporate, leaving its dissolved salt behind. The process of deliquescence (i.e. 'weeping' or 'crying') works in tandem with efflorescence and dehalogenation as salts are transported in solution and ultimately expressed on panel surfaces (Figs. 7-8).

Weeping has been best documented for oxychloride panels [31-34, 36-38]; however, the condition may occur in any material having high amounts of unreacted deliquescent salts, including magnesium oxysulfate. Greater prevalence with $MgCl_2$ reflects its heightened affinity for water when held at 34% relative humidity. For $MgSO_4$, its deliquescence relative humidity is 92.7%. In other words, the salts will begin to dissolve in water above their respective deliquescence thresholds. Whether weeping follows depends on several factors – most important of these are salt levels, phase stability, and moisture conditions. Under proper quality control, MgO panels reflect predictable and stable salt ratios. Defects associated with weeping are entirely avoided.

Figs. 7-8. Weeping of MgO panel at elevated relative humidity (Fig. 7). Salt crystals corresponding to evaporated weep droplets (Fig. 8).

Corrosion Properties

Magnesia cements are neutral to alkaline having pore solutions within a pH range of 7 to 13, depending on MgO type. Within this range, MgO binders exhibit the ability to form passive films that prevent or minimize the corrosion of metals [10]. This accommodates direct contact with common construction materials such as steel studs, metal flashings, cladding attachment systems, and a great variety of corrosion-resistant fasteners.

Our ongoing research of MgO and other panel materials confirms the role of passive films and patination in protecting fastener surfaces. For example, zinc-coated fasteners maintained for over one year in continually wetted MOC panels show uniform patination at fastener interfaces (Fig. 9). Zinc patination follows a predictable path where a thin layer of zinc oxide is formed when exposed to air; transforming to zinc hydroxide and ultimately zinc carbonate upon exposure to wetting and drying. This thinly formed layer is passive and stable, protecting the fastener's underlying metals from corrosion. The chemistry of MgO is highly suitable to patination and there are no known accounts of MgO panels inhibiting its formation.

We have also examined the effects of wetted MOC panels on other fastener coatings, including ceramic/zinc and epoxy-coated fasteners. Continuous wetting over the course of one-year revealed passive protection with macroscopic corrosion present in less than 4% of tested specimens. The affected fasteners also showed reduced abrasion resistance, suggesting that fastener coating plays a greater role than substrate chemistry. Ongoing studies have so far shown no significant differences when comparing fastener corrosion in MgO versus other panel types. Methodologies for such comparative work warrant further development and inclusion within existing acceptance criteria (AC386).

Dimensional Stability and Freeze-Thaw Resistance

Magnesium oxide remains dimensionally stable in response to repeated wetting and freeze-thaw cycling [36]. This attribute is quite unlike other panel materials. For example, durability studies show negligible change in MgO panel thickness when subjected to 25 cycles of wetting and drying (0.1-0.4%). Plywood and OSB exhibited the greatest expansion at 5.1% and 38%, respectively. In comparison, expansion of gypsum panels ranged from 0% to 1.3%. The same panels were subsequently exposed to 25 freeze-thaw cycles, revealing once again the high dimensional stability of MgO as compared to plywood, OSB, and gypsum – the latter disintegrating after freeze-thaw cycling [36].

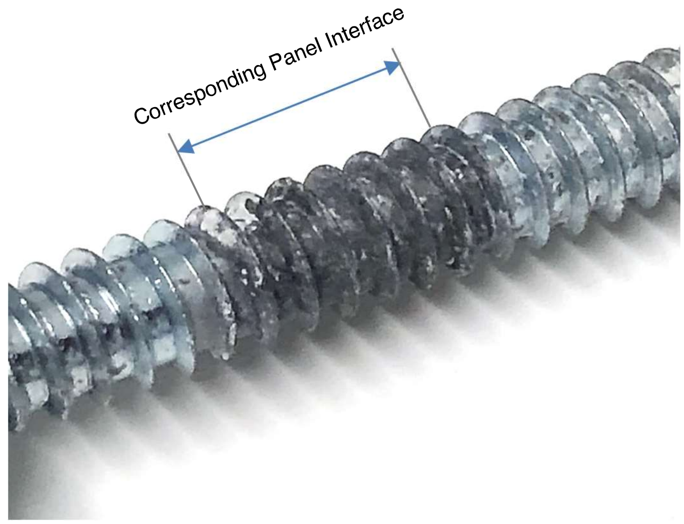


Fig.9. Patination of zinc-coated fastener installed within continually wetted MgO paneling for over one year. Patination occurs discretely at panel interfaces.

Insect & Microbial Resistance

Magnesium oxide exhibits high hardness and exceptional abrasion resistance [9, 10]. These attributes are essential in deterring wood-boring insects such as termites, beetles, and carpenter ants. Though some formulations incorporate wood or other biodegradable fillers, the employed fractions are quite low, typically comprising less than 5% by weight. Furthermore, wood fractions consist of small particle sizes (200-400 μm), dispersed throughout the cementitious matrix, and encapsulated by it. In short, the hardened MgO matrix is unsuitable for insect boring and its limited nutritive components are inaccessible.

Magnesia-based panels are also highly resistant to microbial growth, complying with all commonly used methods for determining microbial resistance (e.g. ASTM G21, ASTM C-1338, ASTM D-3273, and ASTM D-5590). Although microbes will proliferate on MgO surfaces prone to prolonged wetting or leaching of organic extractives, the MgO itself does not serve as a bio-nutritive material.

Surface Coating & Adhesion Bonding

An essential need for panel materials is the ability to receive and bond well to coatings and adhesives. As typically manufactured, the front and back surfaces of MgO panels have very different textures; and each has its own attributes with respect to bonding. The smooth face is formed when cast and initially cured against plastic molds. In some panels, this surface appears glossy or even polished. The opposite face is roughened by sanding to achieve a flat and parallel plane from what was originally the upper surface of the casted panel. Though precise textures vary by manufacturing process, most casting methods consistently impart this two-sided appearance.

The smooth face is typically intended as the exterior surface, and the face to which bonding is generally required. To those unfamiliar with MgO, the smooth face would appear problematic. But, in fact, it yields better bond strengths due to its high intermolecular bonding and microporosity. These attributes offer high surface energies like those of glass, porcelains, and metals. Indeed, our evaluations show that adhesives bond better to MgO than to glass, PVC, and anodized aluminum – even under full water immersion. Similar results are achieved with other building materials. For example, comparisons of acrylic and hybrid butyl tapes show consistently higher peel resistances when bonded to MgO panels (Fig. 10). Adhered water-resistive barriers employ similar adhesives, and these also bond extremely well to MgO – notably better than to gypsum facers and wood panels.

The sanded or rough face of MgO paneling is typically the one that interfaces to studs, trusses, joists, or other attachment substrates. It also offers quality bond surfaces for various types of tapes, sealants, and construction adhesives. In Fig. 11, we compare bond strengths of six subfloor adhesives used in bonding OSB and MgO to wood trusses. Regardless of adhesive type, bond strength is consistently higher on MgO surfaces.

The smooth and uniform face of MgO paneling is particularly well-suited for coatings. It lacks the surface irregularities and face checking of OSB and plywood. Magnesium oxide is therefore more easily coated to desired thicknesses with less product and greater continuity. When compared to glass facers of gypsum panels, MgO shows improved coating characteristics and better overall adhesion. This is especially true for products prone to high gypsum bleed-through or embedded gypsum dust due to handling and stacking.

Problems associated with bonding to MgO are generally the same as those plaguing other panel types. Care must be taken to avoid applications over wet or damp panels, which are difficult to detect visually. Acrylic coatings are particularly fastidious as most of these products show high water absorption. This leads to water transfer to its panel substrate and ultimately failure of the coating itself. Likewise, low-quality tapes and flashings may not perform substantively better on MgO. Furthermore, the adhesion and stability of tapes and liquid flashings at high temperatures is taken for granted. Many of these products do not perform as claimed; or their application limits at high temperatures are not clearly stated. Additional adhesion problems arise from surface dust derived from handling or cutting.

Magnesium oxide panels also possess some unique challenges. For example, the smooth face of some products may show high surface porosity. Though this is not a concern for viscous coatings such as silicones and polyethers, continuity and adhesion may suffer with acrylics due to their poor bridging ability and propensity to absorb water. Occasionally panels may contain residual release agents used in casting. In such instances, bonding may be altogether prevented. Lastly, rough surfaces often exhibit partially exposed reinforcing meshes due to variations in mesh placement. These too may pose challenges for adhesion and permanent bonding.

Fig. 10

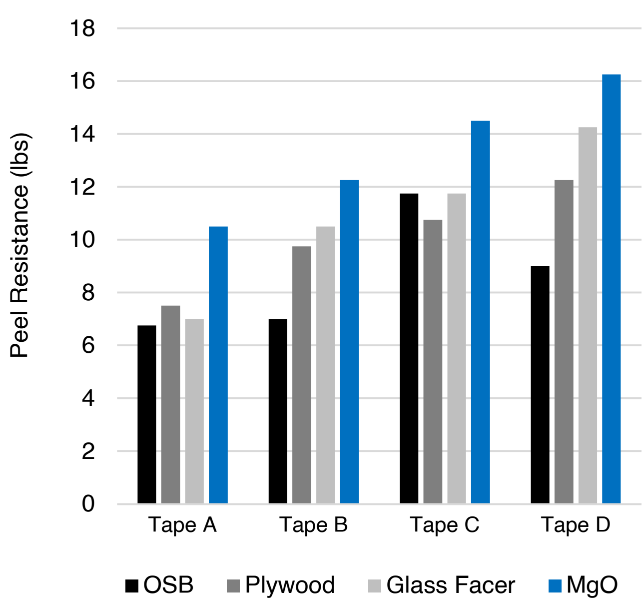
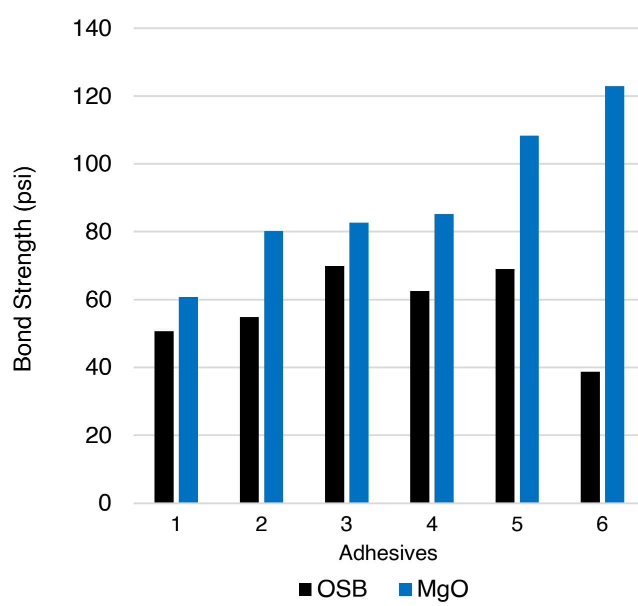


Fig. 11



Figs. 10-11. Peel resistance of tapes applied to various surfaces (Fig. 10). Bond strength of construction adhesives used to bond OSB and MgO to wood framing (Fig. 11).

Ease of Installation
Panels distributed within the United States are most commonly sized as 4' x 8' x 0.5" sheets. Manufacturers also offer other conventional thicknesses, including 0.25", 0.375", and 0.75". At typical half-inch thickness, panels weigh approximately 25-35% more than gypsum but remain easy to handle and install. Cutting, drilling, shaping, and fastening require no special tools or equipment. Moreover, panels of MgO can be scored and snapped from the smooth side, and edges can be routed flush or shaped using a standard carbide cutting tool.

Fastening reflects manufacturer-specific requirements for respective panel size and intended application. Installation instructions are very similar to those for other panel types. When nailed, corrosion-resistant, ring-shanked nails are commonly used and sized to penetrate to required substrate depths. MgO paneling also accommodates a wide variety of corrosion-resistant screws.

Health and Safety
Magnesium oxide is fundamentally free of harmful additives. It contains only trace amounts of silicas, if any, and is free of asbestos, formaldehyde, and volatile organic compounds. This makes MgO, and its associated dust, far less hazardous than comparable materials. Cutting requires no specialized Personal Protective Equipment (PPE), though eye protection, dust masks, and gloves are recommended as a matter of general safety precautions.

HOLDBACKS FOR EXPANSION TO NEW MARKETS

Even with its wealth of unique performance attributes, MgO panels are not immune to resistance and criticisms stemming from unfamiliarity, competing interests, and quality concerns. Magnesium oxide is a new material, and it will simply take time to garner its due acceptance. In many respects, its use is ahead of the curve prompted by the fact that it addresses so many needs. Though its obstacles are few, they nonetheless require a directed and introspective approach.

Below we discuss some of the primary holdbacks to the expansion of MgO into new markets. They center around three key issues: costs and supply chain constraints, nonuniformity of quality, and research voids. Progress with these dilemmas will pave the way to new expansion, as we discuss in the proceeding sections.

Cost Parity and Supply Chain Constraints
Products distributed within North America are sourced primarily from China. This obviously presents additional costs for shipping as well as concerns regarding stable supply chains and associated logistics. For the past two decades, this cost parity has been offset by rising costs of other panel materials; hence, a foothold was gained when MgO was adopted as a replacement. Cofactors included tremendous change in North American building standards, namely those concerning fire resistance for which MgO so aptly imparts. The fundamental unknown is whether the current market paradigm is sustainable – the one that has toll manufacturers in China producing the board and contract manufacturers in North America importing, labeling and distributing it. The underlying premise is that existing attributes of MgO will justify these additional costs.

The fact remains that costs drive the industry, and nothing substantively happens without consideration for them. Therefore, the current cost parity must ultimately shift to a cost advantage by producing MgO within North America. This is currently unfolding as limited production has already commenced in the United States. As production scales up, so too do the potentials for lower costs and broader expansion into North American markets.

Unstable supply chains also hinder expansion. Recent projections show demand will very soon outpace China's production capacity, which may result in longer lead times or adoption of panels having lesser quality. The supply of inferior products is seemingly endless, and their producers are all too willing to unload them to importers who have little regard for standards and quality control. With North American standards well in development, strategic positioning is underway. Alignments with the best manufacturers, and the highest quality products, will soon be highly coveted.

Quality Concerns
Global demand for MgO panels also relies heavily on products manufactured in China, where raw minerals are readily available and where a large manufacturing industry has developed. There is a prevailing notion that Chinese manufacturers consistently abide by strict quality control – that the products originating from their shores are uniformly stable and reliable. Unfortunately, this is not the case. While some manufacturers produce sheets of exceptional quality, others do not. From this disparity arose supply chains infiltrated with inferior panels. These products found their way to early adopters in Europe, Australia, and to a lesser extent North America. From there, problems soon followed [31-34].

In all instances, reports implying MgO as inherently flawed involved demonstrably defective products applied without water-resistive barriers and in demanding coastal climates. Such failures were therefore predictable. But in their wake emerged a legacy of negative perception that continues to thwart the industry. Much of this criticism originated from stakeholders in product categories that MgO seeks to displace. Further discord emerged from within as diverging interests of sulfate-based technologies were pitted against their chloride counterparts. The fact that defects disproportionately involved MOC panels was used as leverage to gain market share from a more entrenched oxychloride industry. Promotion of 'chloride-free' panels (i.e. oxysulfate) is now common but ignores the fact that oxysulfate panels under the same quality problems show the same or greater flaws. Ultimately, this wrangling serves only to taint the market further, causing confusion and angst amongst potential adopters.

We have previously discussed the technical rationale for these concerns, which centered around weeping, corrosion, and general water resistance. All three issues are very much related. They indicate poor stability arising from aberrant formulation and questionable curing practices. Collectively, they reflect fundamental lapses in quality control (QC). Compounding this was the fact that early importers of these low-quality boards did not fully understand the specialized characteristics and usage specifications of MgO paneling. Moreover, early end-users installed MgO panels in locations or in ways that were not fully tested at the time and are not recommended by today's standards.

Research Voids

The MgO panel industry is still in its infancy, and much of what is known was derived from MgO cements used in civil applications. Published research on the properties of MgO paneling is therefore scant or otherwise shielded by trade secrets. This leaves little for those seeking unbiased information. Ultimately, the world needs to know how MgO behaves in panel form. Properties concerning flexural and compressive strength, fastener holding capacities, and impact resistance all warrant further study and better disclosure.

Knowledge gained and shared will only serve to facilitate the advancement and adoption of MgO paneling. In lieu of performance standards or third-party testing, research findings remain the only means for evaluation by potential end-users. And often third-party research is preferred as meeting minimum criteria does not show the full breadth of a material's capabilities.

Research also plays a vital role in standards development. Methods, performance criteria, and even preferred QC procedures stem from that which is known and shared. For this reason, standards around MgO paneling will see significant change even as they only begin to emerge. In other words, existing standards reflect a vast information void, and standards currently under development are only marginally bolstered.

Limited research arose from quality concerns regarding MgO weeping, corrosion, and general water resistance. Even fewer studies compared MOC and MOS properties or the tremendous variability seen in manufactured products. Likewise, very little advancement has been made in comparing the properties of MgO to those of other panel types. Comparative studies are highly relatable to end-users, and they are critical in placing the performance attributes of MgO in proper context. Such work merits considerable expansion; not only for the purpose of curtailing quality concerns, but also out of sheer need for greater understanding of MgO's traits when used as panels.

DRIVERS FOR EXPANSION INTO NEW MARKETS

The MgO industry is poised to vastly expand market share within the U.S., North America, and beyond. Below we discuss key factors that will guide these efforts. Drivers for expansion mirror the concerns that hinder MgO. They also reflect enthusiasm and keen interest in a material that holds much promise.

Two-Tiered Quality Control

As previously discussed, North American markets are currently dominated by products originating from China. These supply streams have wide variances in quality – often on a batch basis. Until resolved, quality concerns will continue to hinder expansion of MgO on the magnitude that it seeks. Resolution is best achieved through a two-tiered system whereby importing resellers maintain independent quality programs as outlined elsewhere in this review. Adoption of such practices has proven instrumental in protecting supply streams and assuring end-users of attained quality.

Further opportunity awaits a tandem approach bookended by two-tiered QC with performance criteria having higher predictive value. As such, it deserves mentioning that QA/QC and acceptance criteria are separate and distinct, the latter establishing quality goals for the purpose of code acceptance, the former verifying achieved quality on a batch-by-batch basis. The goal is the same, but the means differ.

North American Manufacturing

North American production will further assuage concerns over costs and quality of foreign-made panels. To this end, production in North America is now underway. Though capacities are constrained and niche-driven; grandeur, larger-capacity facilities are imminent. These will embrace the very best of China's modern MgO manufacturing while establishing sole autonomy over all facets of production and cost controls. Domestic manufacturing also consolidates quality assurance under a single domain where arguably it is better managed. Interdisciplinary collaboration, research, and new product development will spearhead innovation and hasten pursuit of new applications. Also awaiting is the vast opportunity to compete as global toll processors.

Research & Education

By the mid-2010s, world-wide research of MgO paneling was well underway. Most of these early efforts focused on criteria development to ensure that imported material met minimum quality standards. Outcomes from this work included AC386 and product registration under the Canadian Construction Materials Centre (CCMC). These efforts also prompted the ongoing development of ASTM standards.

With standards development now on course, the industry turns its head to ambitious research initiatives. This research is long overdue and will vastly expand the industry's knowledgebase. It will also spur new thinking and collaboration between key industry stakeholders.

Market expansion will also follow renewed emphases on industry education. There are several needs here. One of the most pressing pertains to past uses of unprotected MgO paneling. As is customary for other panel materials, MgO must be protected with an approved water-resistive barrier (WRB) or roof underlayment. Alternatively, it must be part of an unexposed, protected assembly. The emergence of products having claims of water-repellency, whether innately or by addition of repellant materials, serves only to confuse the industry and belies further adoption. The implied notion here is that protection is not required. We oppose this view and feel strongly that MgO panels must be protected by an approved WRB or underlayment. Moreover, should future technology demonstrate efficacy as an integrated or integral WRB panel, then products should be evaluated as such – not merely as MgO paneling.

Lastly, research and education will serve pivotal roles in ongoing standards development. Current performance criteria initially established by AC386 require notable revamping. Matters of particular importance include corrosion effects, strength properties, and fastener use. Much of this work is being led by organizations in North America, including the newly formed Magnesium Oxide Building Products Association (MgOBPA), industry stakeholders, and academia.

International Standards

As with other building products, market expansion depends on availability and industry support of strong certification and testing standards. Historically, the first standards for MgO panels originated from China, which still provides most of the manufacturing and distribution activity to global markets. Manufacturing and performance criteria established by the China Magnesite Materials Association (CMMA) have been largely adopted by other certification programs in North America, Europe, and Australia. From these arose the foundation for formal acceptance criteria and the ongoing development of international standards.

More recently, Canada and the U.S. have placed renewed emphasis on standards to support expansion of MgO panels in North American markets. For example, the International Code Council Evaluation Service (ICC-ES) has already issued Acceptance Criteria AC386. These criteria were built largely off ASTM standards for gypsum and Portland cement boards. Further refinements are proceeding with two approved changes in the previous twelve months. Others have been recently adopted including those pertaining to corrosion testing requirements and applicable fastener use testing.

ICC-ES Acceptance Criteria 530 (AC530) was published in 2022 detailing factory bonded MgO panels with a WRB overlay. This standard provides guidance to manufacturers and specifiers alike for intended use and minimum performance requirements. Likewise, development is underway on further acceptance criteria for Structural Insulated Sheathing (SIS) that integrates MgO panels in combination with insulation and an integrated air and water-resistive barrier.

Standards are also under development by ASTM International, specifically the ASTM E06 Committee on Performance of Buildings. Priority will likely be given to two standards, the first being a purity standard that establishes material composition requirements for MgO powder supplied to manufacturers here in North America. The second standard entails separate specifications for use of MgO panels in common applications. Though still under development, these purity and specification guidelines bolster confidence that future supply chains will be protected and products will be properly used.

During the summer of 2023, the American National Standards Institute, Inc. (ANSI) announced a new Project Initiation Notification System (PINS) for MgO panels: Standard for Classification of Magnesium Oxide Boards in Building and Construction. This project is sponsored by the International Code Council (ICC) and is directed at building materials showing high growth potential yet greater need for performance standards.

Availability of Raw Material

A foundational basis for expansion into new markets rests with the availability of raw products necessary for panel production. Magnesium oxide is principally derived from magnesite, which exists worldwide with an estimated global reserve of approximately 13 billion metric tonnes [10]. The most commonly used reactant salts, including magnesium chloride, magnesium sulfate, and monopotassium phosphate are also widely accessible. These salts originate from brine deposits, desalination processes, or vast infrastructures dedicated to the agricultural industry. Additional components such as additives, sawdust, perlite, reinforcing fibers and meshes are all readily available throughout North America and greater global markets.

New Applications

Wide acceptance of MgO paneling has been largely driven by increasing demand for fire-resistant materials. Conventional approaches employ exterior gypsum panels in combination with at least one layer of interior 5/8" Type X gypsum. Although this satisfies fire requirements, gypsum is not a structural panel. Likewise, fire-resistive plywood provides structural benefit, but it is too combustible to meet stringent requirements in Types I and II construction under the International Building Code (IBC). This alone has thrusted MgO onto the stage of mainstream products. And justifiably so as it offers unmatched design flexibility, improved constructability, and greater ease in meeting code requirements.

Changes in energy codes have also created immense demand for insulated panels to meet new requirements in thermal performance. Early adopters were quick to recognize the potential of integrating MgO into insulated panel systems. Today we see MgO panels incorporated into Structural Insulated Panels (SIPs) and in several types of Structural Insulated Sheathing (SIS). Its use as SIS panels is particularly noteworthy as MgO attains the desired fire ratings while also playing key roles in the panel's hygric properties. Further combining a factory-applied coating achieves an integrated WRB panel with exceptionally high R-values, true thermal continuity, and robust moisture performance [41-43]. Synergies such as these will break new ground for MgO panels – applications where smart integration with novel function offset cost parities of the panel alone.

Active pursuits also seek greater impact resistance with MgO paneling. By meeting requirements for debris impact, conventional concrete walls are replaced with a more design-flexible framed assembly. The implications here are monumental as cost parity is truly transformed into cost advantage with applications well beyond hurricane prone regions.

Products are already on the market today employing MgO panels as cladding systems. Advancements with novel coatings and integral protection systems show great promise, potentially catapulting MgO into markets currently dominated by wood composites, plastics, and fiber cement. As with MgO paneling, demand will grow when the attributes of these products are demonstrably better than those they seek to displace.

Opportunities also await application as a potential sustainable material. Production of MgO panels is usually seen as less energy intensive than comparable products such as Portland cement [44-45]. The bulk of MgO paneling is comprised of natural material with high potential for incorporating recycled content. As a waste product, MgO is biodegradable and recyclable. Factors such as molar ratios of MgO formulations and calcining conditions serve as critical determinants of MgO's true sustainable traits. Though there is promise here, further work is necessary to better define it.

Applications beyond flat structural panels will no doubt drive additional niche use. These, in turn, will yield further recognition of MgO as a highly adaptable building material. For example, MgO is aptly suited for aerated foam applications whether cast in panels, forms, or sprayed in place. The potential here is to serve as a lightweight non-combustible layer, insulation, or as an integral non-combustible panel. Similarly, its ability to be cast or extruded into complex forms makes it a suitable replacement material for masonry units and three-dimensional printing of ornamental features, facades, or even whole buildings.

Further promise awaits novel MgO types that embrace hybrid formulations, creative admixtures, and entirely different technologies. Some of these are known, and some still await creative thought and serendipity. The aim – to achieve highly stable, hygric-friendly applications that remain fire resistant, corrosion resistant, and structural. If such a panacea of building materials is possible, then MgO deserves fitting consideration. What we currently see as a simple planar commodity will soon morph into forms and functions not yet imagined.

SUMMARY

Magnesium oxide panels represent light-weight cementitious composites having broad application in floor, wall, and roof assemblies. Their emergence reflects unique properties that fit neatly into growing demands for fire resistance, improved strength, and greater durability. The industry's view of MgO panels is changing from enigmatic material to highly adaptable engineered products with unparalleled potential for all building types.

Key hurdles to market expansion include quality control and costs of products historically manufactured in China. This paradigm is now shifting. Domestic production is aimed squarely at innovation, product consistency, and cost structures better aligned with conventional panel products. Rapidly evolving standards have fostered proper use and code acceptance. And new priorities promote even greater rigor in performance testing. Acceptance is further bolstered by key stakeholders committed to advancing research, education, and novel applications. Magnesium oxide panels have emerged as aptly suited and uniquely poised for industry change.

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