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Magnesium Oxychloride Cement-Based Foam Insulation: A Review of Available Information and Identification of Research Needs

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Interim Report

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
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ABSTRACT

This report reviews available information concerning the properties, performance, and use of magnesium oxychloride foam insulation. Laboratory testing was not included in the scope of the study, and data summarized were not developed based on NBS testing. These insulations are produced at the job site from formulations based on the reaction of magnesium oxide and magnesium chloride to form magnesium oxychloride cement. The low-density foams have been available in the U.S. for insulating walls of buildings for about three years.

This review indicates that data are not complete regarding the characterization of this thermal insulation. One density and one thermal resistance value have been reported, in addition to some properties that concern the safe use of the insulation. Additional properties such as composition and structure, durability, effect on other building materials including corrosiveness, heat of combustion, shrinkage, strength properties, and water absorption and moisture transfer, that affect its performance as thermal insulation in buildings, have not been reported in the archival literature. It is recommended that more data be developed through laboratory research and field observations to provide for the characterization of the insulation.

It is also recommended that caution be exercised when applying magnesium oxychloride foam insulation in wall cavities that contain metal objects. The available evidence describing the corrosiveness of magnesium oxychloride products is not definitive. As a matter of caution, the foam insulation should not be installed in wall cavities which have iron, steel, or aluminum objects such as studs, wall ties, or pipes without evaluation of the potential corrosiveness of the foam on such metallic components.

Key words: cement; foam; energy conservation; magnesium oxychloride; performance; properties; thermal insulation; walls.

1. INTRODUCTION

1.1 BACKGROUND

The use of thermal insulation in the exterior walls of residential as well as commercial and industrial buildings is a key contributor to efficient energy use. The construction of energy-efficient buildings not only contributes to the nation's efforts to conserve energy, but also provides a means for the individual building owner to reduce heating- and cooling-energy consumption and save fuel costs. For new buildings, insulation is, in most cases, readily applied during construction before finishing the walls. For existing buildings, the insulation is often retrofitted into a cavity that is hard to access and may contain obstructions. Retrofitting of uninsulated cavities of building walls is difficult and the finished product can only be inspected using an indirect technique such as infrared thermography. In spite of the difficulty and costs involved, the retrofitting of residential building walls has been shown to be cost-effective in many areas of the United States [1].

Foam insulations, which can be applied in-situ, may offer an advantage for retrofitting, because of their ability to be used on irregularly shaped surfaces or in spaces where access is difficult. Polyurethane and urea-formaldehyde foams [2] have been used in the past for retrofitting uninsulated cavities of building walls, but their use has not been without problems. Efforts to insulate the exterior walls of buildings, particularly by retrofitting techniques, has prompted development of some new insulation products. For example, Cartmell and Brown [4] reported on the use of a polyurea cellular plastic for retrofitting. The motivation for developing new insulation products may stem from a variety of factors including cost, improvement of performance properties, and availability of materials having a wide range of applications. Regarding this last factor, some of the presently available insulations have limits to their use. Batt type insulations are commonly used for wood-frame and steel-stud walls of new constructions, while loose-fill materials are commonly blown into uninsulated cavities of existing buildings, as well as some other spaces (e.g., attics) in new buildings.

During the last three years ago, a new low-density (2 lb/ft^3 or 32 kg/m^3) inorganic foam insulation has been available in the U.S. [3]. When the present study began, according to the manufacturer, the production of the insulation was based on magnesium oxychloride cement technology. At the time the present report was being finalized, the manufacturer indicated that changes in foam production have occurred. The manufacturer now states that the current product is referred to in general terms as an oxychloride cement foam insulation, but is more properly described as a calcium magnesium oxychloride silicate composition. The present report addresses the properties, performance, and uses of magnesium oxychloride foam insulation.

As indicated by the manufacturer, magnesium oxychloride foam insulation has been available in about one third of the states from a network of 9 distributors. The insulation has been marketed for use in a variety of building constructions including new and existing wood-frame, steel-stud, masonry cavity walls, and curtain walls, and for filling hollow-cores in masonry walls.

The insulation is foamed-in-place from aqueous solutions at the building site in a manner similar to some plastic foams. The unset foam insulation may be pumped under pressure into closed cavities where access is obstructed and which may be difficult to fill with loose-fill insulation. After application, the foam hardens in place to a self-supporting material.

Because of the potential benefits of having available a new insulation material, the U.S. Department of Energy (DOE) requested that the U.S. National Bureau of Standards (NBS) review the properties, performance, and use of magnesium oxychloride foam insulation. This report presents the results of the review, which was phase I of a study regarding these insulations and identification of research needs. It is intended that, in phase II, field observations and laboratory testing will be conducted to provide needed data concerning the properties and performance of magnesium oxychloride insulations.

1.2 OBJECTIVES

The objectives of this report are:

(1) to describe the process used in the production of low-density magnesium oxychloride foam insulation,

(2) to review available information concerning the properties, performance, and use of the insulation, and

(3) to identify areas where data are lacking regarding the properties and performance, and to recommend needed research for filling in the gaps in this knowledge.

1.3 SCOPE OF THE STUDY

The present study was limited to a review of existing information. No laboratory or field tests were conducted.

Since magnesium oxychloride foam insulation has only been available for a short period of time in the U.S., the information regarding its properties and performance was limited. The major sources of information were: (1) the archival chemical and engineering literature; (2) building research organizations in Canada and France; and (3) literture from and discussions with a manufacturer of low-density magnesium oxychloride foam insulation. During the study, an NBS staff member had the opportunity to observe the production of magnesium oxychloride foam insulation at the facility of a distributor.

2. MANUFACTURE OF MAGNESIUM OXYCHLORIDE FOAM INSULATION

The information provided here is based primarily on that supplied by one manufacturer and the observations of an NBS research staff member during its production. The chemical formulations used in the preparation of the insulation are proprietary. A description of the process for manufacture of low-density foam insulation, based on magnesium oxychloride cement technology, was not found in the archival literature.

The manufacture of the low-density foam insulation involves three major ingredients: an aqueous cementitious slurry, a surfactant (or foaming agent) solution for cell generation, and compressed air. The cementitious slurry consists mainly of magnesium oxide dispersed in an aqueous solution of magnesium chloride. The slurry also contains proprietary additives such as: fillers or extenders, agents to control the rate of chemical reaction (hardening), agents to alter properties of the finished product (e.g., moisture absorption), and colorants. The aqueous cementitious slurry is prepared at the job site, since it has a limited pot life (a few hours) due to the hardening of the magnesium oxychloride cement. The foaming agent solution is also proprietary. It may be prepared in advance of its use, since it has an extended pot life.

The equipment for generation of the foam on site includes a compressed air pump, and a mixing or foaming gun. The foaming agent is first pumped into the gun, where the compressed air mixes with it in an expansion chamber, and expands it into a foam bubbles. Just before the bubbles exit from the nozzle of the gun, they are mixed with the magnesium oxychloride cement slurry, which has been pumped through a separate line into the gun. The foam is then pumped under pressure from the gun. Expansion of the foam is complete at this point and no expansion occurs after installation. Initial hardening of the magnesium oxychloride foam has proceeded to an extent sufficient for it to be self-supporting as it exits the gun. Complete hardening of the cement reportedly occurs a few weeks after application. Hardening depends, in part, on the formulation of the magnesium oxychloride cement and the environmental conditions present in the insulated walls.

When it exits from the nozzle of the foaming gun, the unset low-density foam contains about 50 to 60 percent water by mass. This water has to be released from the wall after application of the foam. Drying may lead to problems such as damage to wood and steel members of the wall, blistering of paint on the outer wall surface, or damage to interior wall surfaces.

3. MAGNESIUM OXYCHLORIDE CEMENT

3.1 CHEMISTRY

Archival literature on the chemistry of magnesium oxychloride cements is limited. The information is important because the production of magnesium oxychloride foam insulation depends in part upon the chemistry of the process. The reaction producing magnesium oxychloride cement from the component materials must be controlled to proceed rapidly and uniformly to provide an acceptable product [5].

Magnesium oxychloride cements were first described by Sorel [6] over one hundred years ago and are often referred to as Sorel cements. They are prepared by the addition of magnesium oxide to a solution of magnesium chloride. At temperatures between 20 and 100 °C (68 and 212 °F), two major ternary phases are formed during the reaction [7,8]:

$$5Mg(OH)_2 . MgCl_2 . 8H_2O$$

$$3Mg(OH)_2 . MgCl_2 . 8H_2O$$

These two phases are often called the 5-form and the 3-form, respectively. The chemistry of the reaction was reviewed and investigated in 1955 by Demediuk et al. [7], who indicated that the reaction between magnesium oxide and magnesium chloride was complex. They proposed that the reaction proceeded through the formation of a complex (unidentified) ion that subsequently reacted with magnesium hydroxide, formed by rapid hydration of magnesium oxide, to yield amorphous (noncrystalline) oxychloride gels which in turn slowly crystallize.

Demediuk et al. [7] also reported on the phase equilibria for the reaction. In the case they studied, the amount of the magnesium oxide was low in relation to that of magnesium chloride. They reported that, for a given quantity of magnesium oxide, the 3-form predominates at higher concentrations of magnesium chloride, while the 5-form is predominantly produced at lower concentrations of magnesium chloride. They also indicated that, at the lowest concentrations of magnesium chloride used, magnesium hydroxide was the major crystalline phase produced.

In 1976, Sorrell and Armstrong [8] re-examined the phase equilibria of the process, particularly with regard to the reactivity of the magnesium oxide. They indicated that the magnesium oxide must be sufficiently reactive to be rapidly dissolved by the magnesium chloride solution to form a solution that rapidly gels and then crystallizes. They described reactive magnesium oxide as having relatively small crystallite size and narrow size distribution, and a low state of aggregation. It was found [8] that, when the magnesium oxide was reactive, the magnesium oxychloride reaction was uniform and rapid (complete in 4 days). When the magnesium oxide was not reactive, it was slow to dissolve, the reaction with magnesium chloride was also slow (incomplete after 2 weeks), and compositional gradients occurred through the product. For example, they demonstrated that when the reaction was slow, water evaporated from the free surface of the reaction vessel, resulting in incomplete formation of magnesium oxychloride at that location. Also, unreacted magnesium chloride migrated to the free surface where it precipitated.

3.2 USES OF MAGNESIUM OXYCHLORIDE CEMENT

Magnesium oxychloride cement has been reported to have engineering properties desirable for certain specific applications [9]. The density of the cement in applications other than foam insulation is considerably greater than 2 lb/ft^3 (32 kg/m^3). The compressive strength and hardness of the hardened product are usually greater than those properties of normal (portland) cement pastes [9]. During production, its rate of strength gain is relatively rapid, although the rate of reaction may be retarded by the addition of additives. In addition, magnesium oxychloride cement is compatible with a wide variety of granular, mineral, vegetable, and polymeric fillers, and does not produce alkaline attack on glass [9]. Two limitations of using magnesium oxychloride cement are that it is attacked by water and has a corrosive action on iron products [10,11]. These two references did not discuss corrosive action towards other metals.

The main use of magnesium oxychloride cement has been as a flooring material with inert fillers and pigments to provide color [10,11]. As a flooring material, the product is hard and strong, but must be protected from water. This is reported to be accomplished by polishing with wax in turpentine.

A 1965 British Standard Code of Practice for in-situ floor finishes included reference to magnesium oxychloride cement flooring [12]. This document indicates that the product is suitable for industrial, commercial or domestic use, and has good durability. It also recommended that the flooring not be used where it may be exposed to high humidity or damp conditions. A noteworthy guideline in the Code of Practice advises that metalwork, such as gas, water, and electrical services in contact with magnesium oxychloride flooring, is liable to corrode. The Code of Practice thus recommends that the metalwork should be isolated from the flooring or protected by a coating of asphalt or coal tar. In this regard, one reference [10] has stated that iron pipes passing through such flooring are subject to the corrosive action of the cement. Another reference [13] pointed out that magnesium oxychloride compositions used in flooring stimulate corrosion of aluminum under moist conditions.

Another use of magnesium oxychloride cement has been as decorative interior plasters and exterior stuccos [8,14]. It has been reported [8] that exterior applications have encountered such problems as dimensional instability, lack of resistance to weathering, and release of corrosive solutions. Sorrell and Armstrong [8] have discussed the weathering characteristics of magnesium oxychloride cement. They indicated that both the 3-form and 5-form phases are unstable in water and dissociate to magnesium hydroxide (which is not a strong binder) and magnesium chloride (which can leach from the cement as a corrosive solution). However, the stability of the cement for exterior applications is enhanced by two reactions which occur in service [8]. First, the cement reacts with atmospheric carbon dioxide (CO_2) to produce a magnesium chlorocarbonate, $Mg(OH)_2.MgCl_2.2MgCO_3.6H_2O$. This chlorocarbonate tends to protect the surface of the cement from rapid attack by water and slows the leaching of magnesium chloride. Second, as water slowly leaches magnesium chloride from the protected surface of the cement, insoluble hydromagnesite ($4MgO.3CO_2.4H_2O$) is formed which stabilizes the stucco.

In a test related to the weathering characteristics of magnesium oxychloride cement, Demediuk et al. [7] exposed both the 3-form and 5-form phases to air, a CO_2 atmosphere, and a CO_2-free atmosphere at various relative humidities. In air at 65 percent relative humidity, they reported little change in either form. In the CO_2 atmosphere, magnesium chlorocarbonate was formed at a rate which increased with relative humidity. In CO_2-free atmosphere at 95 percent relative humidity, both forms were unstable and magnesium hydroxide and magnesium chloride were produced. A minimum level of relative humidity, above which the magnesium oxychloride phases became unstable, was not reported.

Magnesium oxychloride has been described as having excellent fire resistive properties and has been used for over 25 years as a fireproofing coating material for structural steel in building constructions [15,16]. When applied as a fireproofing, its density may fall within the range of 20 to 80 lb/ft^3 (320 to 1280 kg/m^3) depending on the product [17]. Its fire resistance is due to water of hydration being released as vapor when the material is exposed to fire, and heat being absorbed. Depending on the form of the magnesium oxychloride cement, the water of hydration accounts for approximately 35 to 40 percent of its mass. The chemically-bound water is released at temperatures in the range of 350 to 550 °F (177 to 288 °C) [16].

As with other uses of the cement, a limitation to its use as fireproofing on steel is its corrosiveness [16]. Protective measures against corrosion of the steel are required. For example, one manufacturer recommends priming steel before application of the magnesium oxychloride fireproofing. Another limitation for use as a fireproofing material has been the effect of weather conditions during application. Such factors as humidity, temperature, and wind can influence and alter the chemistry of the hardening reaction [15]. In particular, if the water present during application dries too fast (e.g., hot, dry weather), the setting reaction may be incomplete and yield some magnesium hydroxide and unreacted magnesium chloride.

4. PROPERTIES OF MAGNESIUM OXYCHLORIDE FOAM INSULATION

One finding of the review on magnesium oxychloride foam insulation is that little information is presently available regarding its properties and performance. This was not unexpected, since the use of magnesium oxychloride cement as thermal insulation is a relatively recent development. No descriptions of the properties and performance were found in the archival technical literature. The data that have been summarized here (table 1) were made available from one manufacturer that sponsored testing at independent laboratories during the development and marketing of its product [18-25]. It must be emphasized that none of these data were developed based on NBS testing.

A major observation from table 1 is that, at a dry density of 2.1 lb/ft^3 (33 kg/m^3), the reported value of thermal conductivity for a foam specimen was 0.257 $Btu.in./h.ft^2.°F$ (0.0371 W/m.K) [19]. The mean temperature of the specimen during the test was not reported. The value of thermal conductivity (table 1) is comparable to those of other insulations commonly used for walls of buildings. For example, Weidt et al. [26] have reported that the thermal conductivities of a number of loose-fill mineral-fiber and cellulosic insulations removed from the walls of retrofitted residences averaged about 0.26 and 0.28 $Btu.in./h.ft^2.°F$ (0.038 and 0.040 W/m.K), respectively. It would be desirable to have thermal conductivity values for a range of densities over which the foam may be applied and also for various mean temperatures.

The other properties of the foam for which tests have been conducted concern behavior on heating, flammability, release of formaldehyde, presence of metallic elements in the foam, and constituents of smoke (table 1). These tests in general relate to the safe use of the foam. For example, four of the test reports cited [18, 21-23] in table 1 concern the release (offgassing) of formaldehyde. These tests may have been conducted because of current concerns regarding the release of formaldehyde from building materials and its resulting effect on indoor air quality. The results of the tests cited indicated that formaldehyde was not detected. As is also evident from table 1, values of flame spread, smoke density, and fuel contribution measured according to the ASTM E 84 tunnel test procedure were found to be zero [20].

The results of the ash content test (table 1) appear to contradict evidence given in the literature concerning the loss of water of hydration from magnesium oxychloride cement during heating. The test report [18] indicated that the ash content of a foam specimen on heating for 24 hours at 700 °F (371 °C) was 98 percent. The temperature at which the ash test was conducted was at the limit of thermal decomposition of the product. It has been reported [15] that magnesium oxychloride begins to decompose significantly between 770 and 1000 °F (371 and 538 °C). However, the temperature of this ash test was considerably greater than the temperature range of 350 to 550 °F (177 to 288 °C) over which the water of hydration is reportedly released from magnesium oxychloride cement used as fireproofing for steel [16]. In addition, Cole and Demediuk [27] have indicated that all forms of magnesium oxychloride dehydrate upon heat treatment to form anhydrous phases. They presented thermogravimetric analysis results over the temperature range of 68 to 932 °F (20 to 500 °C). Mass loss began about 212 °F (100 °C). The 3-form and 5-form cements lost approximately 25 and 35 percent of their mass, respectively, when heated to about 572 °F (300 °C). Mass loss continued when the temperature surpassed 572 °F (300 °C). Thus, on the basis of this literature data, the ash test (table 1) of the magnesium oxychloride cement insulation would have been expected to yield a much lower ash content. Reasons for this apparent contradiction have not been investigated.

5. DISCUSSION

5.1 CHARACTERIZATION OF THE INSULATION -- RESEARCH NEEDS

As with most new building materials, magnesium oxychloride foam insulation has been introduced into the market with little service life history. The characterization of a thermal insulation should consider a number of properties in addition to those given in table 1. To assist in the review of available information, a preliminary list of performance characteristics for in-situ foam insulations was prepared. The list of performance characteristics is given in table 2 along with a comparison of the information available on the properties and performance of magnesium oxychloride foam insulations. The comparison of available information with the preliminary list of performance characteristics is based on the information provided in table 1. As is evident from table 2, little data have been published regarding many of the performance characteristics of these insulations.

Research is needed to provide data concerning these performance characteristics. This section of the report focuses on the following properties (which are discussed below): composition and structure, durability, effect on other building materials including corrosiveness and fungal growth, heat of combustion, shrinkage, strength properties, and water absorption and moisture transfer.

- Composition and Structure. During the present study, reports were not found in the archival literature characterizing the chemical composition of the foam insulation. In addition, the cellular structure (e.g., cell size and nature) of the foam insulation has not been described.

- Durability. This is the capability of the material to maintain its serviceability over a specified time [28]. For magnesium oxychloride foam insulation, little data are available regarding durability. Observations of older foams in service have not been made. Characterization of foams removed from walls of buildings should be made to assist in assessing their durability.

  With regard to durability, the temperature and humidity conditions, as well as moisture exposure conditions, in service are considered important. Some literature citations [8,10,11] have indicated that magnesium oxychloride cements may have poor resistance to water, and another reference [7] suggested that they may undergo decomposition when exposed to high relative humidity (95%). Although in normal conditions encountered in wood-frame and steel-stud building use, wall insulation is not expected to be in contact with liquid water, high humidities or moisture vapor driven through walls may be experienced depending on factors such as the season, geographic location of the building, location of vapor retarders, and occupancy. The moisture drive may result in accumulation of moisture in the foam insulation. In addition, masonry cavity walls normally provide for drainage of water which penetrates the outer layer. Water penetration of the outer layer would be expected to place the foam insulation in contact with water. Also, the presence of the insulation in the cavity wall may hinder the drainage of water from the cavity. The results of the study did not uncover reports describing the performance of the insulation under conditions of use in walls.

As previously described, other applications of magnesium oxychloride cement including flooring, stucco, and fireproofing have been available for a long time. Although these applications have generally had success, they have not been trouble-free [7,8,10,11,15,16]. Such experiences indicate the importance of understanding the factors that affect the durability of the insulation.

- Effect on Other Building Materials. The addition of thermal insulation to walls of buildings should not make the wall components more susceptible to deterioration over time than they would normally be in the absence of the insulation. Factors that need to be characterized include: corrosiveness, effect on fungus growth, and effect of moisture on other materials, e.g., wood.

Special mention should be made of the findings of the present study with regard to the corrosiveness of the foam insulation. The study results regarding the corrosiveness issue are not definitive. Corrosiveness tests of foam conducted by independent laboratories on iron, steel, and aluminum, as well as other metals, were not found. It is important to assess corrosiveness. One piece of manufacturer's literature on the insulation states that the product "when cured, has a neutral pH, minimizing the potential of corrosion." Conversely, some literature citations [8,10,11,13,16] have reported that magnesium oxychloride cements are corrosive to iron and steel, and that the cement flooring stimulates corrosion of aluminum. As previously mentioned, the British Code of Practice on in-situ floor finishes indicates that magnesium oxychloride cement flooring states that metalwork should be isolated from the flooring or protected by a coating of asphalt or coal tar. Also, when magnesium oxychloride cement is used as a fireproofing on steel, protective measures against corrosion such as priming the steel before application of the fire-proofing are required. Because of the inconclusive evidence on the corrosion issue, caution should be exercised in applying the foam insulation in wall cavities that contain metal objects. The corrosiveness of the foam towards metal objects present in the walls to be insulated should be evaluated before application of the foam insulation.

The presence of water in the freshly-applied foam raises the issues concerning fungal growth. Although the inorganic foam may not provide a food for fungus, characterization is needed to assure that proprietary additives in foam, along with the water, would not initiate fungal growth in the insulated wall.

- <u>Heat of Combustion.</u> An advantageous factor affecting the performance of magnesium oxychloride foam for many insulation applications is its inorganic nature and related combustibility properties. Measurement of heat of combustion may be used to demonstrate low combustibility.

- <u>Shrinkage.</u> Shrinkage of a foam insulation after application leads to gaps that provide unwanted heat flow paths. Magnesium oxychloride foam insulation undergoes some shrinkage after application, as observed (by one of the authors of this report) in unclosed, simulated wall cavities. Manufacturer's literature states that shrinkage is less than 1 percent. The extent of shrinkage that occurs in walls in service was not found in the archival literature. Both laboratory and field tests on shrinkage are needed. Factors that may influence shrinkage such as time, foam density, foam composition, and environmental conditions (temperature and humidity) have not been investigated.

- <u>Strength Properties.</u> Magnesium oxychloride foam insulation should have sufficient compressive strength to support itself in the wall. During this study, some evidence was found that the foam can support itself without collapse. Two samples, applied in 8 ft (2.4 m) high simulated wall cavities and reportedly about 1 year in age, were observed to be intact at the facility of a distributor. Further data, particularly from field observations, would be useful.

  The foam insulation should also have sufficient strength to prevent deterioration by vibration and other movement during service. The observation of some samples demonstrated that the foam insulation is friable, as indicated by the relative ease with which it could be damaged by handling or rubbing. Although the foam is used in closed cavities in service (and thus protected from mechanical damage), the effect of building vibration and similar actions on the integrity of the installed foam should be ascertained.

- <u>Water Absorption and Moisture Transfer.</u> Water absorption of an insulation under various conditions of use influences its thermal conductivity and may also affect its durability including freeze-thaw resistance. Magnesium oxychloride foam insulations have not been characterized with regard to water absorption over the range of moisture conditions that may be encountered in service. Data are also not available describing the effect of absorbed moisture on the thermal conductivity of the insulation. Reports on the permeability of the insulation were not found during the study.

5.2 STANDARDS

A consensus standard specification for magnesium oxychloride foam insulation is not available. Standard specifications for thermal insulations include requirements concerning thermal resistance, fire and other safety factors, and quality [29]. If magnesium oxychloride foam insulation is to be used commonly for insulating the walls of buildings, then the industry including users may consider that a consensus standard specification should be developed. The development of any standard should consider the performance characteristics listed in Table 2.

5.3 CONTROL OF APPLICATION

Magnesium oxychloride foam insulation is generated on site at the building to be insulated. Thus, factory-conducted quality control techniques are insufficient for this material. Moreover, the environmental conditions at the job site are not controlled, but vary depending upon the locale and season of the year. The satisfactory performance of magnesium oxychloride foam as an insulation depends not only on the properties of the material but also on its proper application. For a material that is produced on site, improper application may result in installation defects such as incomplete cavity fill or damage to walls, and can produce an insulation having less-than-acceptable material properties. It is noted that the manufacturer of the insulation has available an application manual for foam installation [3].

Guidelines for assuring proper application should consider both the quality control of the foam installation and the quality control of the component materials used in foam production. The literature review of magnesium oxychloride cements indicated that proper control of their production is a necessity if the material is to perform satisfactorily. Attention should be paid to the preparation of the reactant solutions, as well as the reactivity of the magnesium oxide [5,7,8].

Environmental conditions during application of magnesium oxychloride cement can also affect the quality of the finished product [8,15]. As was mentioned, experience with magnesium oxychloride fireproofings for steel indicated that their application under conditions favoring rapid drying resulted in unsatisfactory products. For the magnesium oxychloride foam insulation, the effect of environmental conditions during application on the quality of the finished foam was not found in the archival literature. The manufacturer indicates in a product brochure that the foam application "is an all weather process provided that the temperature of the component products is between 40 and 70 °F (4 and 21 °C) at the time they are delivered to the application gun."

6. SUMMARY AND RECOMMENDATIONS

This report reviews the very limited amount of available information concerning the properties, performance, and use of magnesium oxychloride foam insulation. The information reviewed is not based on data developed by NBS. The foam is produced on site from formulations which are based on the reaction of magnesium oxide and magnesium chloride to form magnesium oxychloride cement. The foam has been available in the U.S. for insulating walls of buildings for approximately three years. It is being offered for both new and existing constructions including wood-frame, steel-stud, and masonry walls.

This review indicates that data regarding the characterization of the foam as thermal insulation are not complete. Data are lacking regarding many of the performance properties of the foam, and research is needed to provide such data. In this regard, some data have been reported from independent testing laboratories that address one value of density and thermal resistance, and safety-related parameters such as behavior on heating, flame spread classification, release of formaldehyde, heavy metals in foam, and smoke characteristics. Other properties that affect the performance of the foam as thermal insulation have not been well documented. Such properties include composition and structure, durability, effect on other building materials including corrosiveness, freeze-thaw resistance, fungus resistance, heat of combustion, shrinkage, strength properties, temperature and humidity resistance, water absorption and resistance to water penetration.

Since the insulation has only been available for a relatively short period of time, a standard specification and standard practice for application have not been prepared. Some documents from one manufacturer are available [3]. The manufacturer's documents could provide the starting point for consensus standards development, particularly with regard to application. However, data on foam characterization would need to be developed through research to provide the technical basis for standards.

Based on the results of this study, the following recommendations are made:

1) Additional information regarding the performance of the insulation should be developed through field observations and laboratory research. Data are needed on the long-term performance and durability of the low-density magnesium oxychloride foam insulation. Data are also needed on cell structure and composition, shrinkage, effect of environmental conditions (e.g., temperature and humidity, water penetration), effect of the foam on other wall components including corrosiveness, and resistance of the foam to vibration and other movements.

If foams of this type are to be used commonly for insulating walls of buildings, the industry including users may consider that a voluntary consensus standard specification should be developed. A standard could set minimum acceptable requirements for both performance and safety. The research conducted to provide the needed data on the properties of the foam would help develop the technical basis for the preparation of a performance or other type of standard.

2) Caution should be exercised when applying magnesium oxy-chloride foam insulation in wall cavities that contain metal objects. The results of the present study have indicated that the available evidence describing the corrosiveness of the foam is not definitive. As a matter of caution, the foam insulation should not be installed in wall cavities which have iron, steel, or aluminum objects such as studs, wall ties, or pipes without evaluation of the potential corrosiveness of the foam on such metallic components. This recommendation is based on citations in the literature that magnesium oxychloride cements are corrosive to iron and steel, and may stimulate corrosion of aluminum. Studies regarding the corrosiveness of the magnesium oxychloride foam insulations in the presence of iron, steel, and aluminum, as well as other metals, were not found in the literature.

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Table 1. Reported[1] Properties of Magnesium Oxychloride Cement-Based Foam Insulation

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	REFERENCE
Ash Content	98%; shape of specimen retained	Muffle furnace	24h at 700°F (371°C)	Average of three tests; data subject to question.	[18]
Behavior on Heating	no color change, no formaldehyde or other organic vapors detected	*[2]	2h at 150°F (66°C)	-	[18]
Density	2.1 lbm/ft^3 (33.2 kg/m^3)	*	Sample thickness 1.6 in. (41 mm)	Sample used for thermal conductivity test	[19]
Flammability					
flame spread smoke density fuel contributed	0 0 0	ASTM E 84-81a	-	-	[20]
					[21]
Formaldehyde	None detected	*	-	-	
Content	Negative for formaldehyde	Chromotropic Acid	-	-	[22]
	No contribution from the insulation material	Dessicator method using chromotropic acid procedure	2h at 75°F (24°C) in dessicator	-	[23]

1 This table lists results of tests conducted by independent laboratories and made available from the foam manufacturer. Data were not developed based on NBS research.

2 The asterisk indicates that a test method was not reported.

Table 1. Reported[1] Properties of Magnesium Oxychloride Cement-Based Foam Insulation (Continued)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	REFERENCE
Metallic Constituents			-	-	[18]
Magnesium	22.1%	Unspecified atomic absorption procedure			
Aluminum	1.03%				
Calcium	0.33%				
Iron	0.006%				
Manganese	0.006%				
Zinc	0.001%				
Copper	0.0003%				
Arsenic	<0.002 mg/L	EPA "Methods for Chemical Analysis of Water and Wastes"	Extraction procedure was as given in the Federal Register May 19, 1980	-	[24]
Barium	<1. mg/L				
Cadmium	<0.01 mg/L				
Chromium	<0.01 mg/L				
Lead	<0.1 mg/L				
Mercury	<0.002 mg/L				
Selenium	<0.02 mg/L				
Silver	<0.01 mg/L				

[1] This table lists results of tests conducted by independent laboratories and made available from the foam manufacturer. Data were not developed based on NBS research.

Table 1. Reported[1] Properties of Magnesium Oxychloride Cement-Based Foam Insulation (Continued)

PROPERTY	VALUE	TEST METHOD	TEST PARAMETERS	COMMENT	REFERENCE
Smoke Characteristics Hydrogen Chloride Hydrogen Cyanide Hydrogen Fluoride Nitrous Fumes Carbon Monoxide Carbon Dioxide Other Gases	 1.5 ppm 0 0 0 10 0.1 0.25	Smoke density chamber -- drager tube method[2]	Smoldering combustion	Values represent the average of two determinations.	[25]
Hydrogen Chloride Hydrogen Cyanide Hydrogen Fluoride Nitrous Fumes Carbon Monoxide Carbon Dioxide Other Gases	4.5 ppm 0 0 3.5 95 1.1 0.65	Smoke[2] density chamber -- drager tube method*	Flaming combustion	Values represent the average of two determinations; carbon monoxide values were adjusted for background levels in the chamber.	[25]
Thermal conductivity	0.257 Btu in/h·ft^2·°F (0.0371 W/m·K)	ASTM C518	Density of 2.1 lb/ft^3 (33.2 kg/m^3); thickness of 1.6 in. (41.2 mm)	-	[19]

[1] This table lists results of tests conduct by independent laboratories and made available from the foam manufacturer. Data were not developed based on NBS research.

[2] Specimens exposed as in E 662 test procedure, but no optical density measurements were reported.

Table 2. Preliminary List of Performance Characteristics for In-Situ Foam Insulations: A Comparison With the Availability of Information Regarding the Properties and Performance of Magnesium Oxychloride Foam Insulation[1,2]

Performance Characteristic	Availability of Information
Cavity-Filling	No
Cell Structure/Composition	No
Density	Limited Availability
Durability	No
- freeze-thaw resistance	No
- temperature and humidity effects	No
- temperature effects	Limited Availability
Effect on Other Building Materials	
- gypsum plaster and wall board	No
- metals (corrosiveness)	No
- paints, coatings	No
- wood	No
Electrical Resistivity (fresh wet foam)	No
Flammability/Combustibility	Limited Availability
Friability	No
Fungus Resistance	No
Offgassing/Release of Particulates	Limited Availability
Shrinkage	No
Specific Heat	No
Strength	No
Thermal Conductivity	Limited Availability
Water Absorption	No
Water Penetration	No
Water Transmission	No

1. This table refers to information available from test reports from independent laboratories.
2. The comments on the availability of information given here for the listed performance characteristics are based on the information in Table 1 of the present report.

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This report reviews available information concerning the properties, performance, and use of magnesium oxychloride foam insulation. Laboratory testing was not included in the scope of the study, and data summarized were not developed based on NBS testing. These insulations are produced at the job site from formulations based on the reaction of magnesium oxide and magnesium chloride to form magnesium oxychloride cement. The low-density foams have been available in the U.S. for insulating walls of buildings for about three years.

This review indicates that data are not complete regarding the characterization of this thermal insulation. One density and one thermal resistance value have been reported, in addition to some properties that concern the safe use of the insulation. Additional properties such as composition and structure, durability, effect on other building materials including corrosiveness, heat of combustion, shrinkage, strength properties, and water absorption and moisture transfer, that affect its performance as thermal insulation in buildings, have not been reported in the archival literature. It is recommended that more data be developed through laboratory research and field observations to provide for the characterization of the insulation.

It is also recommended that caution be exercised when applying magnesium oxychloride foam insulation in wall cavities that contain metal objects. The available evidence describing the corrosiveness of magnesium oxychloride products is not definitive. As a matter of caution, the foam insulation should not be installed in wall cavities which have iron, steel, or aluminum objects such as studs, wall ties, or pipes without evaluation of the potential corrosiveness of the foam on such metallic components.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

cement; foam; energy conservation; magnesium oxychloride; performance; properties; thermal insulation; walls

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