Relationship between Moisture Content and Mechanical Properties of Gypsum Sheathing – Phase 2 Research

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ABSTRACT

A lack of information exists regarding acceptable levels of moisture content for gypsum-based sheathing products and on the consequences of exposure to moisture in terms of mechanical properties and the integrity of the wall assemblies. A complementary need is the assessment of a method to measure moisture content of these products using hand-held electric resistance meters.

Previous work examined the relationship between moisture content and mechanical properties of gypsum sheathing (i.e., gypsum wallboard intended for use as exterior sheathing on buildings). Gypsum wallboard is typically specified to conform to ASTM C1177 or C1396 performance criteria, and it was the particular interest of this study to determine whether moisture content affects this performance (and if so, to determine the moisture content at which the product no longer meets the ASTM criteria). Specific properties examined included:

- adhesion or delamination of facer material (either glass-fibre mats, treated paper or untreated paper)
- ability of the sheathing to resist fastener pull-out
- flexural strength of the sheathing, for seismic considerations and as a common index of overall mechanical integrity
- water absorption

The study also determined whether hand-held electric resistance meters are suitable for measuring moisture content are reasonably accurate, or if some new apparatus or protocol is required.

This paper discusses Phase II of this project, which examined the possibility of rehabilitating gypsum sheathing that had been wetted and subsequently dried out. The above mechanical properties were assessed for three subsets of the specimen group:

- one subset was tested before wetting to predetermined moisture-content levels;
- after wetting to predetermined moisture-content levels, half the remaining samples were tested; and
- the remaining samples were oven-dried, and then tested to determine the same mechanical properties

The focus of this paper is on whether the re-dried samples regain the original level of mechanical properties that were exhibited by the first set of samples.

INTRODUCTION

The objective of this project was to assess the mechanical properties of various gypsum-based sheathing products at varying levels of moisture content. Specific properties to be examined include the ability of the sheathing to resist fastener pull-out; and flexural strength of the sheathing, for seismic considerations and as an index of overall mechanical integrity.

There are several reasons why it is important to understand the mechanical properties of gypsum sheathing, and how these properties vary with moisture content:

1. Although gypsum sheathing by itself is not part of the structure that holds up the building, the Building Code gives some credit for gypsum sheathing in providing shear strength. Most cladding systems are attached to the framing components of the building, and do not rely on the strength of the gypsum sheathing to support the cladding. Nevertheless, some exterior insulation finish systems (EIFS) are adhered to the sheathing, and in this way the sheathing can play a role in keeping the cladding on the building for EIFS-clad designs.

2. Many designs rely on the sheathing to support an air-barrier membrane, whether this is a self-adhered membrane (e.g., in coastal climates with high exposure to wind-driven rain) or a spun-bonded polyolefin. If the gypsum sheathing loses its structural integrity, the air barrier may not perform as expected, which could lead to significant consequential damage and deterioration of building-envelope performance.

3. In some cases, cladding has fallen off of a building onto the street below, or onto a ground-floor patio (which, fortunately, was unoccupied). Some of these failures appear to have been related to wet gypsum sheathing: the sheathing held water in place for an extended period of time, which accelerated the corrosion of the cladding fasteners. The wet sheathing was not strong enough to resist being crushed, so the fasteners were subjected to shear and rotational forces that caused them to fail. A better understanding of the mechanical properties of gypsum sheathing – and how these properties vary with moisture content – would help avoid catastrophic failures.

4. Gypsum can hold a substantial amount of moisture: Phase One of this study found that gypsum sheathing can hold up to 200% of its weight in water. This can damage water-sensitive components next to the sheathing (e.g., wood or metal framing).

5. Building scientists who conduct diagnostic investigations of buildings require accurate performance criteria against which to evaluate the condition of existing assemblies. Some practitioners cannot obtain professional liability insurance in cases where mould is involved. In that case, it could be useful to have performance criteria for building materials that are not related to the formation of mould.

In new construction, designers need to be able to effectively specify the expected performance of gypsum sheathing. ASTM C1396 provides a method for determining performance levels, but designers need to know when the material has become so wet that it no longer meets the criteria.

METHODOLOGY

The experimental procedure was as follows:

1. Samples of gypsum sheathing were obtained from local suppliers, representing typical materials available to builders. Specimen types included
   - 12.7mm (1/2") and (5/8") exterior-grade gypsum sheathing (XGG);
   - 12.7mm (1/2") and 15.9mm (5/8") fibre-faced gypsum sheathing (FFG)

   In Phase One of the study, standard interior gypsum wallboard was included as a control. Wallboard was not included in Phase Two, which focused on the potential for gypsum sheathing to be rehabilitated once it is wetted. Samples were obtained from the same manufacturers in both phases of the study, in an attempt to obtain comparable results.

2. Specimens were prepared in accordance with ASTM C473. Specimens were initially oven-dried to obtain a baseline dry weight (moisture content is expressed as % of dry weight), and to provide baseline test specimens for comparison with subsequent Phase Two results. The samples were dried at 30°C to avoid dehydrating the gypsum, as it is a hydrated molecule ($CaSO4 \cdot 2H2O$). There was some concern that excessive heat could drive off the bonded water molecule, changing the material properties, so low-temperature oven-drying was used. Each sample was removed from the oven and weighed every three hours: when the weight changed by less than 0.02%, the specimen was considered to have reached steady-state, and the value recorded at that point was taken as the dry weight.

   Water was added to the specimens to obtain specimens with predetermined moisture-content levels, nominally 1%, 2%, 4%, 8% and 16%. The actual moisture content was measured for each specimen before and after testing. Specimens were conditioned to promote uniform distribution of moisture, which involved sealing the specimens in plastic wrap to minimize evaporative loss and turning the specimens over every 24 hours to promote uniform moisture distribution. Specimens were typically conditioned for two weeks, to ensure moisture equilibrium within each specimen (there is no "Standard" protocol for this procedure). Final weighing was then used to determine the actual moisture content.

3. Flexural and fastener pull-through testing was conducted for the oven-dried specimens and the 1% specimens, and on half of the 4%, 8% and 16% specimens. Figures 1A and 1B show test specimens being tested for mechanical properties.

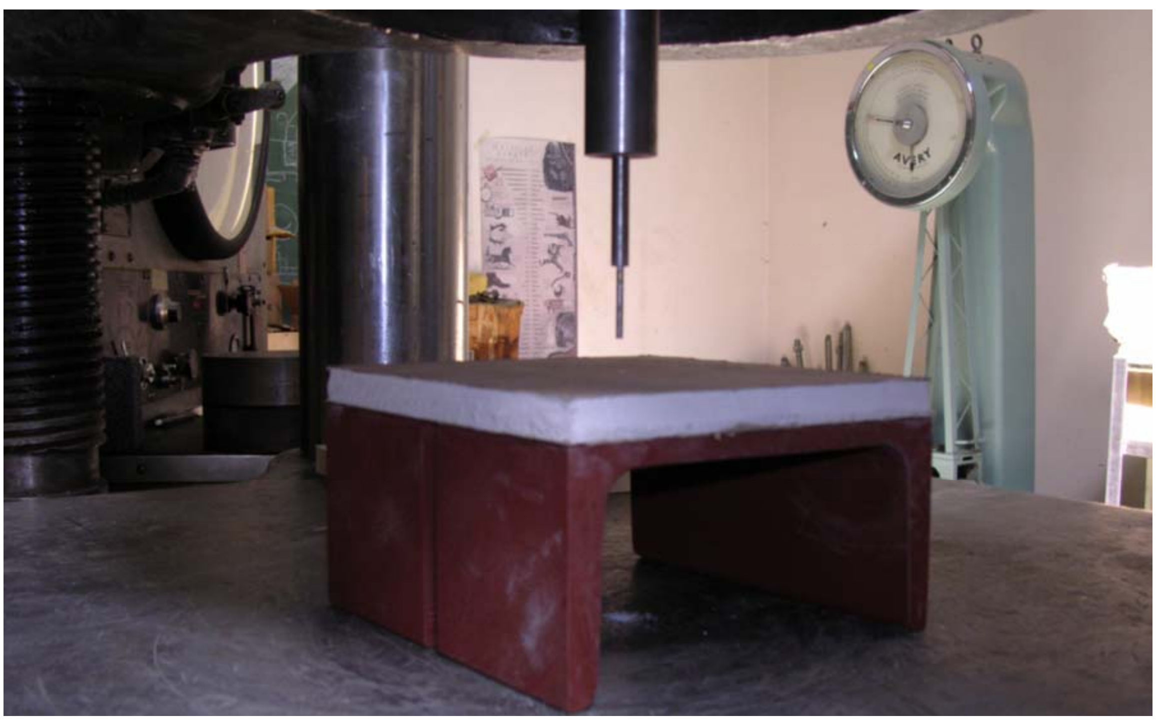


FIGURE 1A. TESTING APPARATUS FOR FASTENER PULL-THROUGH

FIGURE 1B. TESTING APPARATUS FOR FLEXURAL STRENGTH

4. In Phase Two of the study, some 4%, 8% and 16% specimens were oven-dried. The wetted-and-redried specimens were tested for flexural strength and fastener pull-through. This was done to examine the hypothesis that gypsum sheathing that had been wetted (by weather, construction moisture, plumbing leaks, etc.) might be rehabilitated by drying it out again.

   The question that Phase Two of the study was designed to answer was: do the mechanical properties regain their original levels (i.e., as measured on the original oven-dry specimens) once they are redried to a nominal oven-dry moisture content?

DATA ANALYSIS

Figure 2 is taken from the Phase One study, and shows the accuracy of handheld moisture meters in assessing moisture content in gypsum sheathing. The meters are reasonably accurate for paper-faced gypsum sheathing up to (approximately) 6%, but above that the moisture meter reads lower than the actual value. The results also show that the moisture meters read 3 - 3.4% higher than the gravimetric values for fibre-faced sheathing, over the range investigated. Samples labelled "GWB" are for interior gypsum wallboard, which was used in Phase One as a control specimen.

In the calibration procedure for these meters, the electric resistivity of a standard gypsum sample is measured at 0% and 6.4% moisture content, and a linear correlation is assumed between those points. Thus, the measured electrical resistivity of a sample is compared to the endpoints using linear interpolation, to determine the assumed moisture content that is displayed on the meter (whether by a needle on a scale or by a digital readout).

Figure 2 (each point is an average of 3 readings taken on 6 different specimens) indicates that the linear assumption is reasonable between 0% and 6% for all cases. Even the FFG samples, which tend to read 3 - 3.4% lower than the gravimetric moisture content, still appear to exhibit a liner relationship. Above 6%, however, the linear assumption does not appear to be appropriate.

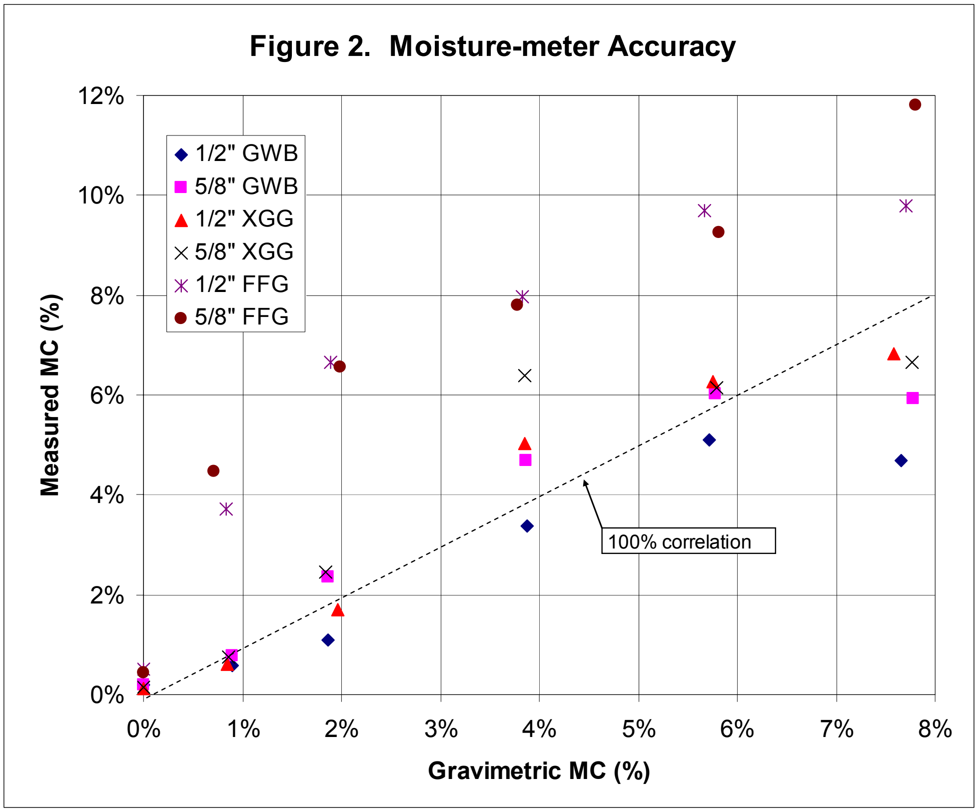
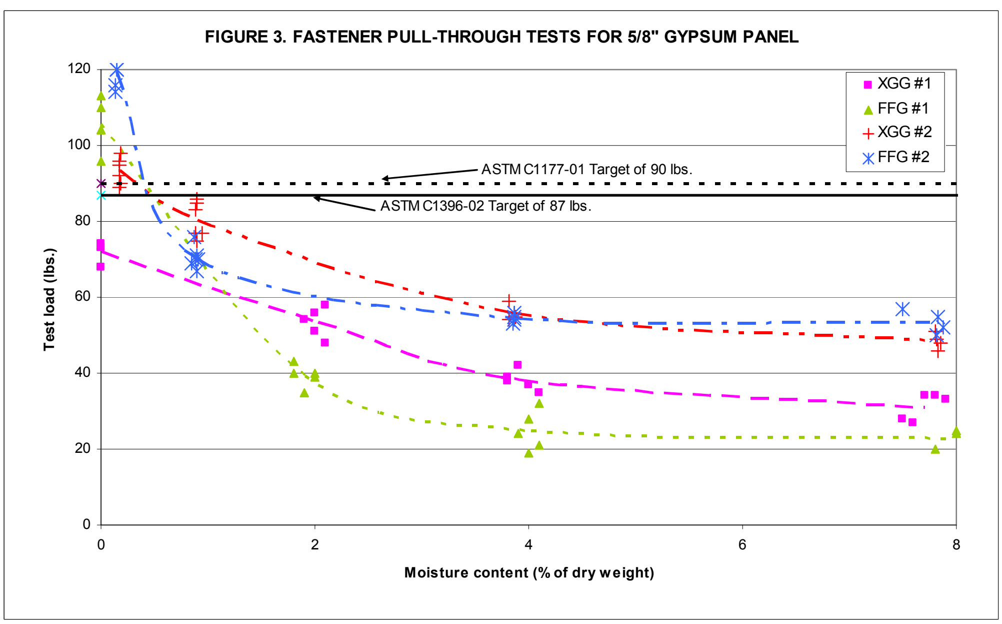


Figure 3 is taken from Phase II, and shows fastener pull-through test results (Figure 1A). The specimens are labelled "exterior-grade gypsum" (XGG) – with moisture-resistant paper facers on a moisture-resistant treated gypsum core – or "fibre-faced gypsum" (FFG), with glass-fibre facers over a treated gypsum core. In Figure 3, the labels "XGG #1" and "XGG #2" refer to specimens that were tested in Phases I and II of the study (similarly for "FFG #1" and "FFG #2"). Each data point represents an average of five fastener pull-through tests on that specimen type.



The target levels shown in Figure 3 are defined in the ASTM Standard specifications for these materials: ASTM C1177 defines test-load criteria for exterior gypsum sheathing specimens, as ASTM C1396 does for fibre-faced gypsum sheathing.

Figure 4 shows the results of the testing on gypsum sheathing that was wetted and re-dried. The results for flexural testing parallel and perpendicular to the grain of the facer, and for fastener pull-through, are expressed as a percentage of the original oven-dried values (which are shown at 100% on the left side of Figure 4). Flexural testing on each type of product was done with specimens cut so that the longer dimension of a nominal 12” x 16” sample was parallel to the facer grain, with one sample tested face-up and another tested face-down. This procedure was repeated with specimens cut so that the longer dimension was perpendicular to the facer grain, as described in the ASTM C473 Standard. IN the case of the FFG products, there is no facer grain as such, but two sets of flexural tests were performed on each product type, just to maintain the same statistical sampling for all specimen categories.

The results show a tendency for the mechanical properties of most re-dried specimens to be lower than the initial values. Flexural load of the wetted 1/2" XGG specimens that were re-dried is 92% of the initial value in parallel loading, and only 66% of the initial value in perpendicular loading. The difference in strength is due to the difference the grain of the paper facer, relative to the longest dimension of the specimen. In the 1/2" specimen, almost all of the resistance to flexural loading is provided by the paper, and wetting reduces this resistance – slightly along the grain of the paper, but substantially across the grain of the facer. This effect is also seen with the 5/8” XGG specimens, but is less noticeable. The maximum flexural load of the wetted-and-redried 5/8” XGG specimens was 97% of the initial value when measured with the grain, and 91% when measured across the grain. Thus, the direction of the grain in the paper facer does make a difference, but perhaps the increased mass in the core of the 5/8” specimen (relative to the 1/2" sheathing) provides some additional strength.

The 1/2" FFG specimens actually showed an increase in the maximum flexural load when the specimens were wetted and re-dried. The direction of the flexural loading makes almost no difference in the result for the FFG samples, as the facers are constructed of randomly woven glass fibres. The wetted-and-redried 5/8” FFG specimens produced slightly lower results than the 1/2" FFG samples.

Ultimately, the flexural strength of gypsum sheathing depends on the strength of the adhesive bond between the facers and the gypsum core. The specimens tested were not disturbed after they were wetted, and the oven-drying procedure was conducted to avoid damaging facer adhesion. Any damage to the facer that might occur in the field would likely remove any resistance to flexural loading. These results should therefore be viewed with caution when applying them directly to field conditions, especially if evidence of physical damage is observed along with water-staining of the gypsum sheathing. This may also explain why the resistance to perpendicular flexural loading is greatly reduced for the 1/2" XGG specimens, but not for the other flexural tests. If facer adhesion were lost, flexural strength might be retained in the direction of the facer grain, but there would be no lateral resistance (as seen in Figure 4, which shows reduction in strength for each specimen type, averaged over all moisture-content levels).

Also, note that the lack of handling reduced the likelihood of tell-tale signs of deterioration (e.g., powdering of the gypsum, abrasion of the facers) that might be observed under field conditions when handling wet gypsum sheathing.

The results of wetting and re-drying appear to have little effect on fastener pull-through tests. If anything, increased moisture content actually increased the resistance to fastener pull-through. This could be because an increase in moisture content swelled the gypsum core and provided some pre-stressing of the facer, but there may be many other reasons for these results.

CONCLUSIONS/RECOMMENDATIONS

Handheld moisture meters are reasonably accurate for paper-faced gypsum sheathing up to a reading of approximately 6%, but above that level the moisture meter reads lower than the actual value. The results also show that the moisture meters read approximately 3 - 3.4% higher than the gravimetric values for fibre-faced (FFG) sheathing, over the range of moisture contents investigated.

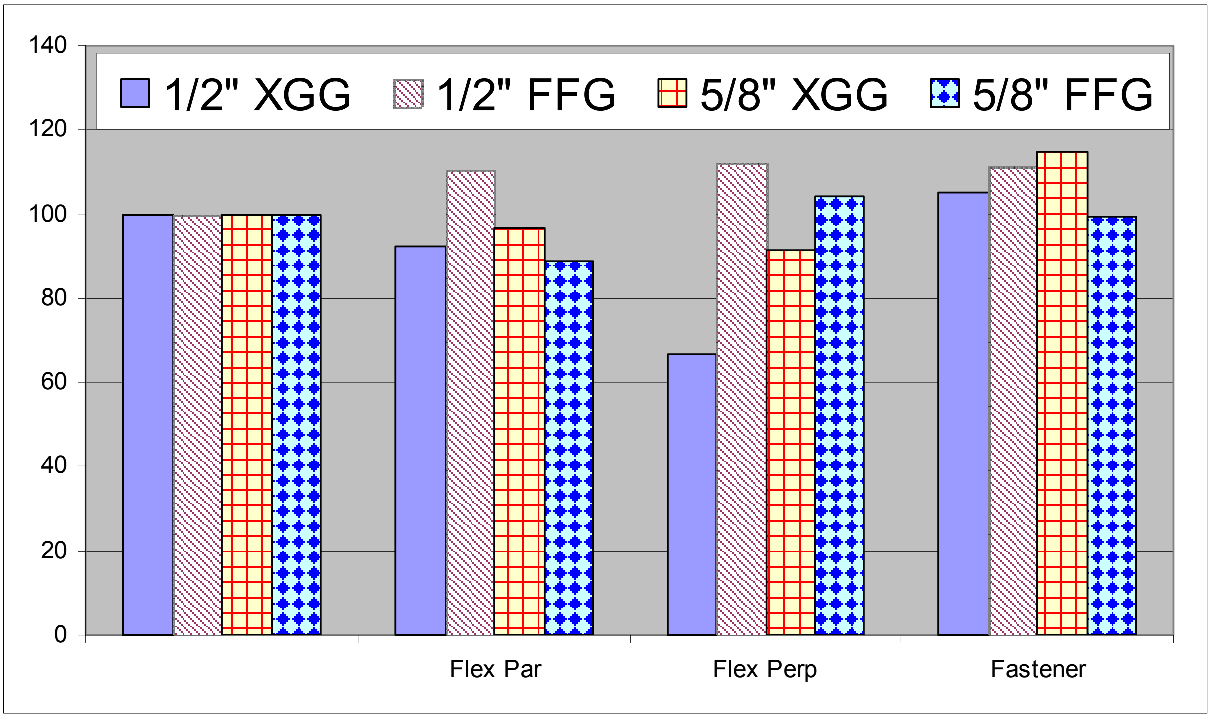


FIGURE 4. TEST RESULTS FOR RE-DRIED GYPSUM SHEATHING

This study confirms a strong correlation between moisture content and the mechanical properties of various types of gypsum sheathing, as was indicated in Phase One. ASTM tests for flexural strength and fastener pull-through produced the following results:

- 1/2" exterior-grade gypsum sheathing failed the fastener pull-through testing at all moisture-content levels, even oven-dry (nominal 0%);
- 1/2" fibre-faced gypsum sheathing failed the fastener pull-through testing at moisture-content levels above 1%;
- 5/8" exterior-grade and fibre-faced gypsum sheathing failed the fastener pull-through testing at moisture-content levels above 0.5%;
- 1/2" exterior-grade and fibre-faced gypsum sheathing failed the flexural testing (perpendicular) at moisture-content levels above 0.5%;
- 5/8" exterior-grade gypsum sheathing failed the flexural testing (perpendicular) at all moisture-content levels;

- 5/8" fibre-faced gypsum sheathing failed the fastener pull-through testing at moisture-content levels above 0.3%;
- 1/2" exterior-grade gypsum sheathing failed the flexural testing (parallel) at moisture-content levels above 1.1%;
- 1/2" fibre-faced gypsum sheathing passed the flexural testing (parallel) at all moisture-content levels, even over 8%;
- 5/8" exterior-grade gypsum sheathing passed the flexural testing (parallel) at all moisture-content levels, even over 8%;
- 5/8" fibre-faced gypsum sheathing passed the flexural testing (parallel) at all moisture-content levels, even over 8%;

Taken together, these test results suggest that the mechanical properties of gypsum sheathing would not meet the ASTM standards (C1177 for exterior-grade gypsum, C1396 for fibre-faced gypsum) at moisture-content levels above 1%. There is some question, however, as to whether the ASTM Standards are appropriate indicators of in-service performance (this is noted in the Standards), as some specimens tested did not meet the criteria even when oven-dry.

When these specimens are wetted and re-dried, the resistance to flexural loading of the fibre-faced gypsum sheathing essentially recovered to their original values. Exterior-grade gypsum sheathing recovered to approximately 94% of their original values, except where the facer-to-gypsum adhesion was lost (in that case, the resistance to flexural load was tested to be 66% of the original value). The resistance to fastener penetration of all sheathing tested did not appear to be affected by wetting, once the specimens were dried out.

The 5/8” exterior-grade sheathing never dried out, and only reached 1% moisture content even after several days of drying in the oven. In general, the fibre-faced specimens appeared to take less time to take on water to the nominal target values and less time to dry out. Mould developed on all of the paper-faced samples, and on none of the fibre-faced samples.

IMPLICATIONS FOR THE HOUSING INDUSTRY

The following recommendations can be derived from the above conclusions:

- Handheld moisture meters (i.e., those that have a separate scale for gypsum) are appropriate for measuring the moisture content of paper-faced gypsum sheathing, within the normal range of performance for these products. These meters tend to read high values for fibre-faced gypsum sheathing.
- In general, gypsum sheathing intended for exterior use should not be exposed to sources of moisture that will result in moisture-content levels above 1% (as a percentage of dry weight).
- Gypsum sheathing that experiences moisture levels in excess of 1% can be rehabilitated to some extent, if the gypsum is carefully dried in such a way that the bond between the facer and the gypsum core is not disturbed.
- The relevant ASTM Standards should be reviewed to verify that the criteria are at appropriate levels for in-service performance.
- Additional research would be useful to investigate the effect of prolonged high moisture-content levels on the strength of different types of fasteners and framing components. The gypsum itself may not be adversely affected, but retained moisture may cause deterioration in adjacent materials (e.g., corrosion in fasteners and steel studs, decay in wood framing).

REFERENCES

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