Evaluation of Acetylated Wood for International Code Council-Evaluation Services Listing

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ABSTRACT

The acetylation of wood has been a known technology for years, but the practice has only recently been shown to be commercially viable. Acetylation provides a dimensionally stable product that imparts resistance to termites and to rot and decay fungi. As a potentially new commercial product in the United States, listing by the International Code Council-Evaluation Services, which standardizes building materials, is necessary. Recently Eastman Chemical Company has initiated an ICC listing for acetylated solid wood products. The process requires submittal and approval of acceptance criteria, then submission of supporting data to demonstrate compliance with performance features of the product. These performance features include strength, rot and decay resistance, termite resistance, as well as treatment permanence, and fastener corrosion. In addition, it is necessary to submit a quality assurance program for the manufacturing process, with documented protocols and mandatory inspections by an outside audit agency. The journey to ICC listing including test methods employed and testing results will be presented.

INTRODUCTION

Chemical modification of wood is known to alter, and in many cases, improve the properties of wood. Roger Rowell documented various modification techniques in 1983. At that time, Rowell noted that acetylation was the most studied of the chemical modification treatments, but that no commercial application had been proven, presumably due to the process not being cost effective. More recently a demonstration facility in the Netherlands has come on-line, and Eastman Chemical Company (Eastman). has begun evaluating commercialization of the process. Eastman's core competency in acetyl chemistry and cellulosics is a key factor in this undertaking. In order to ensure that the material is suitable for its intended applications, the International Code Council requires that new building and construction materials be evaluated, and the supporting data be provided as evidence of suitability. In a hearing on February 2, 2005, the Proposed Acceptance Criteria for Acetylated Wood Preservative Systems were presented to the International Code Council – Evaluation Service (ICC-ES) Committee and approved. The Acceptance Criteria (AC297) became effective March 1, 2005, and the document provided all interested parties with guidelines for demonstrating compliance with performance features of the codes for acetylated wood in above ground, in-ground, and freshwater contact applications. The key features for demonstrating the appropriateness of the product for use in the building and construction industry, especially in outdoor applications, include the following: strength, rot and decay resistance, termite resistance, treatment permanence, and fastener system suitability. Testing protocols for each of these key features were defined in terms of established or best practice methodology. In addition, it was necessary to provide evidence that the product would be manufactured under an approved quality control program. This included the preparation of a Quality Control manual compliant with ICC-ES AC10, and a plan for third party inspections of the manufacturing facility. Eastman contracted with Dr. Craig McIntyre of McIntyre Associates for assistance with the regulatory and agency relations common to the pressure treated timber industry. Dr. McIntyre has long been active in the wood industry, and recently received the Award of Merit of the American Wood Protection Association (AWPA). The AWPA is the treated wood organization in the United States. McIntyre Associates has greatly facilitated the preparation of the required documentation, such as the proposed acceptance criteria and the ICC compliant Quality Control Manual. These Acceptance Criteria will likely serve as the model for future alternative chemistries outside the realm of the pressure treated industry. Eastman defined the scope of the acceptance criteria to include acetylated wood in the form of sawn lumber, timbers, plywood, and oriented strand board (OSB), used in the ground, in freshwater, and in above ground locations. These materials would be acceptable for use in locations requiring preservative-treated wood for fungal decay and/or termite resistance. The preservative treatment was defined as wood which had undergone a reaction with acetic anhydride to achieve significant weight gains, done in such a fashion that retention of the acetyl groups is ensured. Figure 1 depicts the modification chemistry.

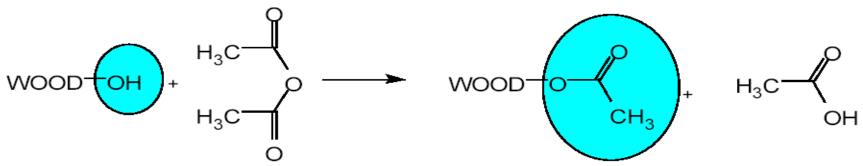

Figure 1. Acetylation of Wood

The modification of wood results in permanent swelling of the wood by substitution of many of the hydroxyl groups with acetyl groups. This results in a more hydrophobic substrate with significantly less affinity for water. Dimensional changes resulting from variation in humidity are therefore reduced in wood modified in this manner. Further, wood modified by acetylation is more resistant to rot and decay and termite damage than unmodified wood. The presence of the byproduct acetic acid, however, can result in a product that is somewhat corrosive to conventional fasteners.

EFFICACY AND PROPERTIES

Strength

The strength properties of Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of acetylated wood were assessed using ASTM D143. For this testing, 24 sets of 16 ft long (4.9 m) Southern Pine (Pinus spp.) decking lumber were used and one eight foot (2.4 m) half was acetylated. Then 24 matched pairs were cut and tested. The average MOR for acetylated wood was slightly greater than the untreated wood and statistical analysis showed 95% confidence of this difference. The mean MOE was slightly less for acetylated wood than untreated wood, but these values were not statistically different. Table 1 provides the mean MOR and MOE for the samples with the acetylated wood expressed as a percentage of the unmodified wood.

Table 1: Relative MOR and MOE for 24 Paired Sets of Acetylated/Untreated Wood

Sample	Relative MOR	Statistical Grouping[a]	Relative MOE	Statistical Grouping[a]
Acetylated	110	A	94	A
Untreated	100	B	100	A

[a] *Levels not connected by the same letter are statistically different*

Fungal Decay Resistance

Most wood is susceptible to rot and decay by various fungi, providing that the conditions of moisture, temperature, and oxygen are met. Moderate moisture levels (30-80%) favor white and brown rot fungi, while higher moisture content is required for soft rot fungi to thrive. The testing to demonstrate the efficacy of the acetylation process on mitigation of rot and decay were demonstrated using several AWPA testing methods. These included Simulated Field Tests (AWPA E23), Field Stake Tests (AWPA E7), Ground Proximity Tests (AWPA E18), and Soil Block Tests (AWPA E10). For this work, Eastman contracted with the Forest and Wildlife Research Center, Forest Products Department, at Mississippi State University to conduct the testing.

<u>Soft-Rot Decay/Fungus Cellar</u>

AWPA Method E23, "Standard Method of Evaluating Wood Preservatives in Soil Contact", exposes samples of treated and untreated wood to wood destroying organisms in bins of unsterile (typically native) soil which are maintained at conditions designed to accelerate the decay effect. The samples are either inspected periodically or strength tested periodically and compared to the performance of samples treated with preservatives known to be effective under the same conditions. Soft rot is favored at conditions of high moisture (100-120% wood moisture content), while Basidiomycetes (includes all the brown rot and many of the white rot fungi) are favored by dryer conditions (30-80% wood moisture content). Wood stakes of specific dimension (quartersawn 3mm x 14mm x 150mm) were used. The acetylated samples were obtained from several pieces of decking boards which had been acetylated and then cut to the desired dimension. Control stakes of untreated southern pine served as the negative control, and ACQ treated stakes at two levels of retention (0.25 and 0.4 pcf (4 and 6.4 kg/m^3)) as positive controls were also included. Ten specimens of each substrate were exposed. Testing was conducted by Mississippi State University using a soil bed containing 50/50 mixture of soils from Central and Southern Mississippi. The soils were taken from sites with well-known decay potential. The samples were evaluated every six months for 36 months.

For the high moisture soft rot conditions, the data for the stiffness loss in Figure 2 show that the control samples (untreated) are completely compromised at 1.5 years. The ACQ treated specimens averaged 66-83% stiffness loss after three years, while the acetylated specimens have only 22% loss. At conditions which favor Basidiomycetes fungi, the acetylated and ACQ-treated wood performed similarly with only 10-14% MOE loss after 3 years. Again the untreated specimens are completely compromised at 1.5 years. These data demonstrate that acetylation is effective at mitigating decay by soft rot, brown rot, and white rot fungi. The resistance of the acetylated wood may be in part due to this treated wood having much lower equilibrium moisture content than normal wood. Alternatively, the modification of the wood polymers by acetylation may also make the material a poor substrate for the degradative enzymes of the fungi.

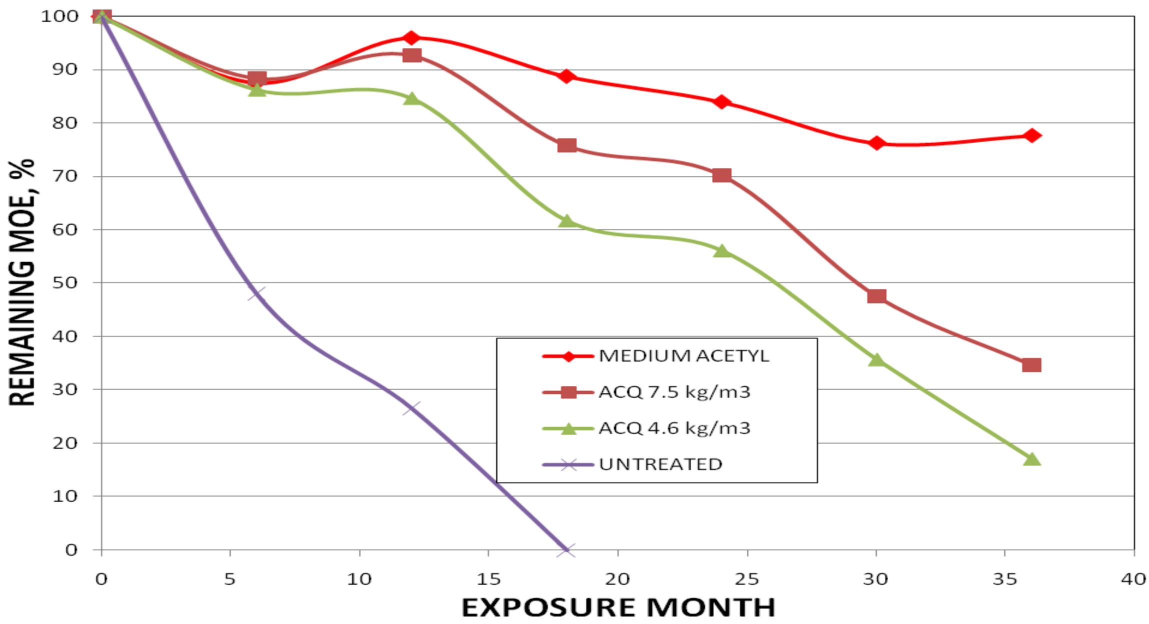

Figure 2: MOE Remaining for Conditions Favoring Soft Rot Fungi

Field Stakes

In AWPA Method E7-01, "Standard Method of Evaluating Wood Preservatives by Field Tests with Stakes" treated stakes are exposed in the ground to the action of wood-destroying fungi and termites in field plots. The test plots are natural, undisturbed fertile land of uniform soil properties. An annual visual inspection assigns ratings for both fungal and termite attack where 10 is sound and 0 is failed. For this testing, stakes of 1 x 1 x 18 in. (25x25x450 mm) were employed. Three levels of acetylation were evaluated and untreated southern pine and ACQ treated stakes at three levels of retention (0.15, 0.25, and 0.4 pcf) (2.4, 4.0 and 6.4 kg/m^3) control stakes were included. Stakes were installed at both the Central (Dorman) and Southern (Saucier) Mississippi sites in early 2005. After 3-years of exposure, the Mississippi acetylated field stakes have average decay ratings of 9.7 or above, and average termite ratings of equal to or greater than 9.9. The ACQ-treated wood also has fared well after three years of exposure, although slight rot is noted for the 0.15 pcf level, which is known to be an inadequate treatment level for in-ground usage. The Southern pine controls are compromised at both sites, with the harsher environment at the Saucier site resulting in greater termite and rot degradation. In addition to the Mississippi data, further evidence of the resistance of acetylated wood to the destructive processes of in-ground exposure is provided by a Scandinavian study initially reported by Larsson Brelid *et al*. (2000) Acetylated wood stakes were installed at Viikki, Finland and Simlångsdalen, Sweden. Stakes of three acetylation levels were exposed along with untreated Southern Pine and Southern Pine treated with two formulations of CCA, at two treatment levels. Similar performance was observed at both locations. The Simlångsdalen site provided the most aggressive decay and selected performance data for this site is shown in Figure 3 for 16 years of exposure. These data demonstrate efficacy of the two higher levels of acetylation commensurate with in-ground performance of CCA.

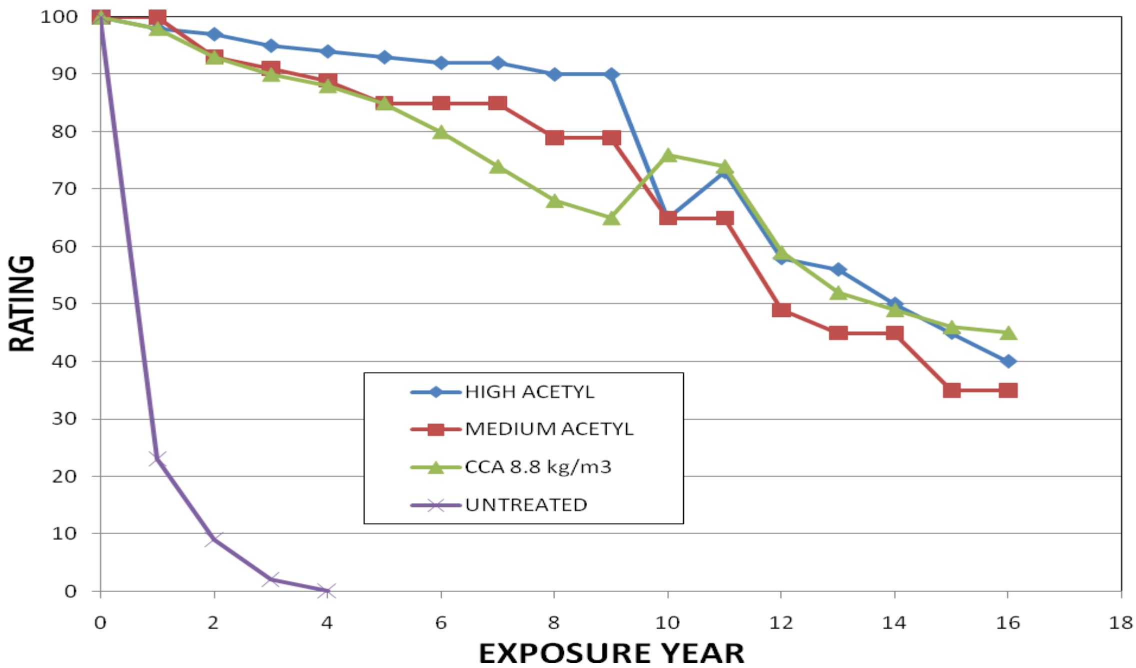

Figure 3: Simlångsdalen Field Stake Trial Results

Ground Proximity

The Ground Proximity test (AWPA E18) evaluates the performance of treated wood by exposing samples in close proximity to the ground, but out of direct soil contact by placing them on cinder blocks. Placement of the samples on the blocks allows wicking of moisture from the soil. The blocks are fully exposed in an outside environment, but protected from direct sunlight by a shade-cloth cover to allow rain penetration, and to slow drying between rain events. Decay is assessed annually by visual inspection using a 10 for sound and 0 for failure scale. The ground proximity samples were installed at Saucier, MS and at Hilo, HI. Both of these test sites are well known in the literature and Hilo is considered the most aggressive site for this type of test. However, after three years exposure, none of the treated specimens show any degradation at either site. Only minimal degradation is observed with the Southern Pine Controls (7.3 for Hilo and 8.4 for Saucier). Data collection will continue for two additional years, but little degradation is expected for the acetylated samples based on efficacy in the more aggressive accelerated laboratory evaluations (E23) and the in-ground field stake testing.

Soil Block

A laboratory decay test, AWPA E22, "Standard Accelerated Laboratory Method for Testing the Efficacy of Preservatives Against Wood Decay Fungi Using Compression Strength" was conducted using 8 boards of acetylated wood with four levels of acetylation. From each board, wafers 18 x 18 x 5 mm (r x t x l) were cut to provide 4 wafers for exposure and 4 wafers for the compressive strength unexposed control for each fungus. Wafers of untreated Southern Pine were also evaluated in an identical comparison. The wafers were exposed to pure cultures of six fungi (three brown rot *Gloeophyllum trabeum*, *Neolentinus lepideus*, *Postia placenta*, and three white rot *Trametes versicolor*, *Pleurotus ostreatus*, *Irpex lacteus*) for a minimum of four weeks. The test is continued until the untreated Southern Pine controls were compromised, as evidenced by a loss of >50% of the compressive strength. Generally, the acetylation levels that were effective in the Field Stake tests were also effective in this Soil Block test with monocultures. P. ostreatus gave anomalous results in that 16 weeks of exposure were required to achieve 50% weight loss in untreated pine with this white rot fungus and the report authors discount these results.

Termite Resistance

Termite resistance testing was done with the common subterranean termite, Reticulitermes flavipes, and the more voracious Formosan termite, Coptotermes formosanus using AWPA E1 and both "Choice" and "No Choice" procedures. In both cases, five replicate wafers of 1 x 1 x ¼ inch (25 x 25 x 6 mm) dimension are exposed to the appropriate mix of soldier and worker termites. In the choice test, a similar block of untreated wood was exposed with the acetylated block. In the no-choice test, only the acetylated block was provided. The weight loss after the 4-week exposure time was used as a measure of attack. Figure 4 shows the results for the common subterranean termite as a function of acetylation level. At the higher acetyl levels protection from termites in both the choice and no choice testing was observed. A similar graph is observed with the Formosan termite in the choice test. While some attack is observed in the no-choice test, this does not reflect the natural environment since untreated wood is always available.

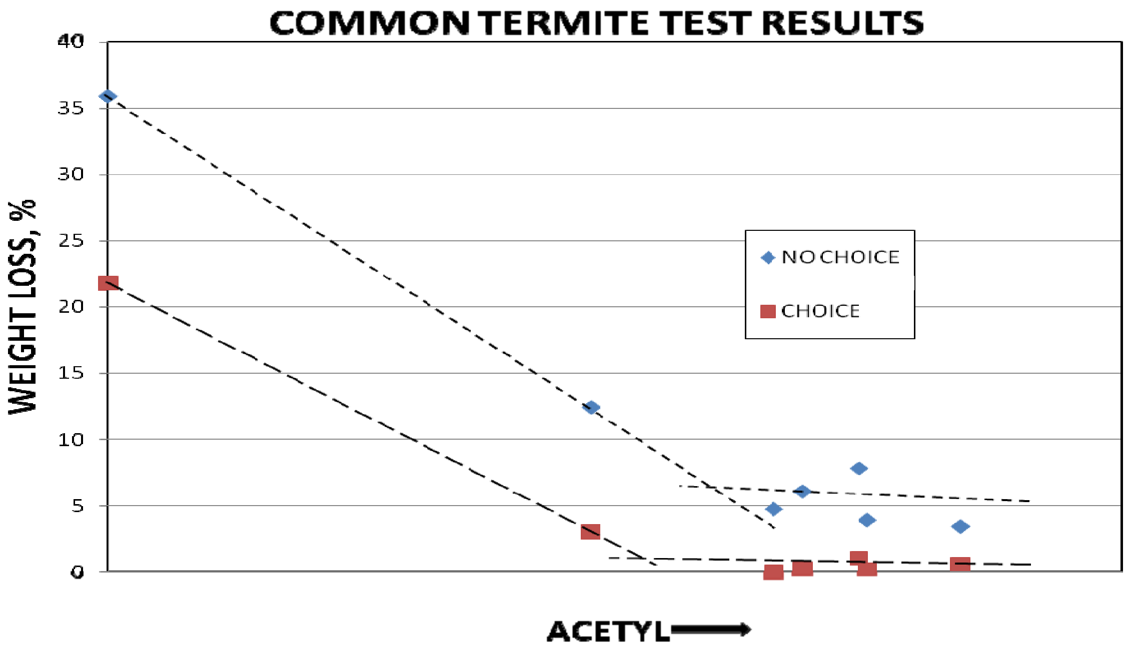

Figure 4: Weight Loss Observed as a function of % Bound Acetyl

Treatment Permanence

In order to determine the extent to which the protection could be affected by environmental conditions, samples of acetylated wood were evaluated with several decks which were constructed with boards of low, medium and high levels of acetylation. These decks were artificially weathered using an accelerated schedule of 48 hours of heat (50-60 ^{o}C and UV exposure), followed by 72 hours of rain (3 hours water spray, 3 hours rest), and followed by 48 hours of freeze for twelve weeks. Samples of each deck were taken after the rain cycle each week, and the level of acetylation determined (Figure 5). Over the course of the 12-week exposure, there was no loss of acetylation, regardless of the starting level.

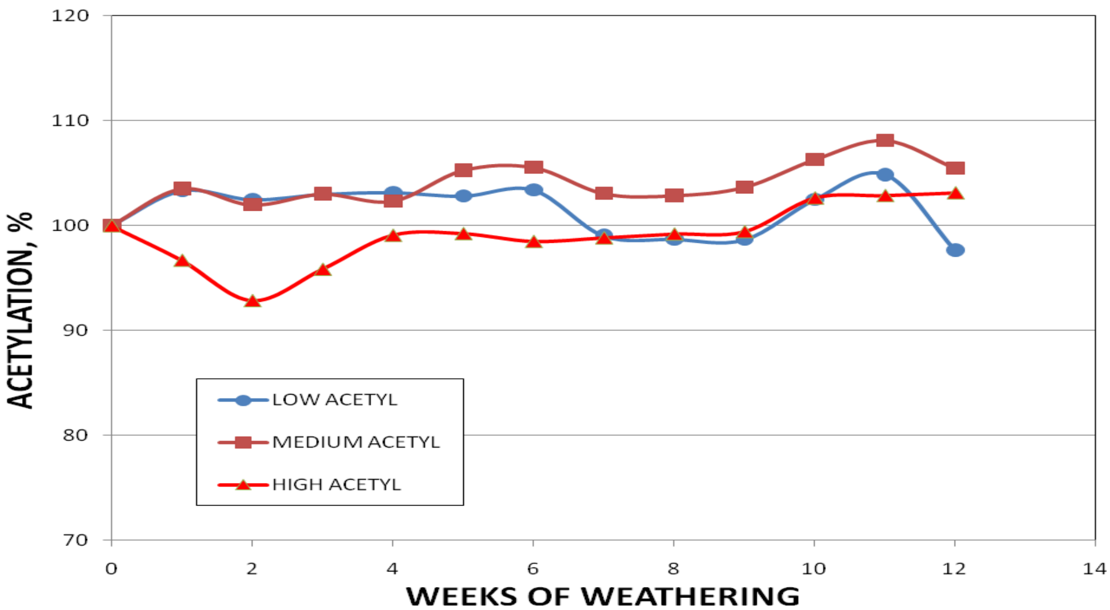

Figure 5: Remaining Bound Acetyl of Decking Weathered for 12 Weeks

A second evaluation utilized blocks leached per AWPA E11, "Standard Method of Determining the Leachability of Wood Preservatives". In this protocol, the level of acetylation was unchanged by the 2-week water leaching.

Fastener Corrosion

The compatibility of acetylated wood with the materials of construction typical of use in outdoor exposure was evaluated using both a coupon corrosion test, and a fastener corrosion test. For the coupon test, the average corrosion rates show that stainless steel, aluminum, and red brass are adequate materials of construction for use with acetylated wood with all having less than 2 mm of corrosion per year. The fastener corrosion test showed that the corrosion due to acetylated wood was less than that found for ACQ-treated wood. Although little corrosion was observed with the interior screw, the ACQ-designed fastener and the exterior steel fastener were not deemed acceptable for use with acetylated wood. Surprisingly, neither of these were acceptable with ACQ-treated wood in this test as well. Stainless steel is the recommended material of construction for either of these treatments.

QUALITY SYSTEMS AND SUBMISSION

Quality Documentation

Having demonstrated adequacy of the modified wood with respect to the performance parameters, it was also necessary to demonstrate to the code council that the product was manufactured with appropriate quality control systems in place. The elements here involve definition of adequate testing of the raw materials, and adequate assessment of the final product quality. Definition of a plan to quarantine out of specification product, and a plan for third party auditing were included. The quality control manual complying with the ICC-ES Acceptance Criteria for Quality Control Manuals (AC10) was prepared.

Data Submission

All efficacy data, which must be generated in ISO-17025 compliant and accredited laboratories, and the QC manual are then critically reviewed by professionals in the field. A critical review of the literature data of the proposed process is prepared as well as a literature compilation of suitable species for treatment in this case. A review of the efficacy data is used to define the acceptable treatment limit for the product for the various code uses is proposed. A professional engineer then reviews each of the testing protocols employed, and issues a summary noting any exceptions to the standard protocol. He also states whether the submitted efficacy reports are suitable for consideration in the body of evidence submitted to demonstrate the acceptability of the wood treatment system. The complete body of information is then submitted to the ICC-ES. Review of this material ensues, which if found acceptable, results in the ICC-ES issuing an Evaluation Services Report (ESR). The ESR signifies that acetylated wood is deemed to be an acceptable alternative to pressure treated wood for code specified uses.

CONCLUSION

The process of obtaining listing by the International Code Council is well documented by systems within that organization. Proposed acceptance criteria must first be approved by the ICC which outlines testing to demonstrate efficacy of the product in the proposed use categories. The protocols and data demonstrating compliance with the criteria must then be reviewed by professionals in the field. This documentation together with documentation of a quality system for the manufacture of the product comprises the submittal document. The Council then reviews the submission, and may then issue the Evaluation Services Report, designating the product acceptable for specific building and construction use categories.

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