IV-C ACCELERATED WEATHERING OF FIRE-RETARDANT-TREATED WOOD FOR FIRE TESTING

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ABSTRACT

Fire-retardant-treated products for exterior applications must be subjected to actual or accelerated weathering prior to fire testing. For fire-retardant-treated wood, the two accelerated weathering methods have been Method A and B of ASTM D 2898. The rain test is Method A of ASTM D 2898. Method B includes exposures to ultraviolet (UV) sunlamps in addition to water sprays. D 2898 was recently revised to include Methods C and D. Method C is the "amended rain test" described in the acceptance criteria for classified wood roof systems (AC107) of the ICC Evaluation Service, Inc. Method D is the alternative rain test described in ASTM E 108 for roof coverings. Issues with the current methods are the limited availability of the UV sunlamps specified in the standard and the large amount of water used that may require special disposal.

INTRODUCTION

With increased efforts to improve survivability of structures in the wildland–urban interface, interest in fire performance of building products for exterior applications has increased. Weathering of wood results in color change, slow erosion of the wood surface, and surface checking (Williams 2005). Erosion of the wood surface resulting from photo-oxidation of the wood and leaching of fire-retardant (FR) chemicals from the wood can reduce the flame retardancy characteristics of fire-retardant-treated (FRT) wood. Thus, products for exterior applications should be subjected to actual or accelerated laboratory weathering prior to fire testing. For many years, the standard practice for accelerated weathering of FRT wood for fire testing has been ASTM D 2898. Issues with the current methods are limited availability and suitability of ultraviolet (UV) sunlamps specified in the standard and environmental aspects of using large amounts of water.

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ASTM D 2898

ASTM International Standard D 2898 contains the recognized methods for artificial or laboratory-accelerated weathering of wood specimens treated with fire retardants. It was developed for and is intended for wood products treated with FR chemicals by pressure impregnation rather than surface coatings. Standard D 2898 was originally approved with a Method A and Method B (Table 1) in 1970, which was around the time of major activities in the successful development of exterior leach-resistant pressure-impregnated FR treatments for wood shingles (Shunk 1972, Juneja 1972). Before the development of such treatments, exterior applications for FRT wood were largely addressed by the use of fire-retardant paints or the use of paints or other sealers on the FRT wood (Gardner 1965). Two existing accelerated weathering tests were incorporated into the D 2898-08e1 version of the standard as Methods C and D. The original two methods of D 2898 are also the basis for the Nordtest Method NT Fire 053 on accelerated weathering of FRT wood for fire testing, which was incorporated in a January 2009 draft of prEN 15912 "Durability of reaction to fire performance—Classes of fire retardant treated wood-based product in interior and exterior end use applications."

Method A is the rain test in the Underwriters Laboratories (UL 790) and ASTM (E 108) standards for testing roof coverings, such as FRT wood shingles and shakes, and the one generally specified for FRT wood for exterior applications. The exposure in Method A is limited to water spray and heat for a total duration of 12 weeks. Method A and Method B produced similar fire test results for a leach-resistant treatment and a non-leach-resistant treatment (Holmes 1973).

Method B is associated with a weathering chamber developed at the U.S. Forest Service Forest Products Laboratory (FPL) and includes exposure to ultraviolet light (UV) in addition to water sprays (Holmes 1971, 1973). The UV exposure is provided by reflector-type sunlamps. Total duration of Method B is 6 weeks (half the time of Method A). Method B exposure was an adaptation of a method specified by City of Los Angeles in 1964 for a weathering test of FRT shingles and shakes (Holmes 1971). Water sprays in Method B have flow rates 40 times greater than those in Method A, but total duration of water spray is 29% of Method A. In addition to the earlier work of Holmes (1971), Sweet and others (1996) used Method B in the evaluation of a combined preservative–FR wood treatment.

Method C is the "amended rain test" in the ICC Evaluation Service, Inc., acceptance criteria for classified wood roof systems (AC107). To address concerns about the test that had been used (Method A), the ICBO Evaluation Service issued in 1995 an AC107 that included requirements for 3 years actual outdoor weathering and fire testing before approval. Method C was added to AC107 as an alternative to the outdoor weathering for initial qualification of the roof covering. Method C was created by merging features of Methods A and B. Like Method B, Method C has UV exposure. Method C has the larger flow rate of Method B and the longer duration of water

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application of Method A. Total water flow over the specimens in Method C is much greater than for other methods. Like Method A, the total duration of Method C is 12 weeks.

TABLE 1

COMPARISON OF THE FOUR METHODS OF ASTM D 2898

		Method A	Method B	Method C	Method D
Cycle	Number	12	42	252	7
	Cycle duration, h	168	24	8	336
	Total duration, h	2,016	1,000	2,016	2,328
Water exposure	Duration, h/cycle	96	4+4	4	168
	Flow rate, L/min-m^2	0.30	12.2	12.2	0.30
	Recirculation	No	Yes	Yes	No
	Temperature, °C	2–16	<32	2–32	2–16
	Total duration, h	1,152	336	1,008	1,152
	Total flow rate, L/m^2	20,700	246,000	738,000	20,700
Drying	Duration, h	72	4 + 4	4	120
	Temperature, °C	57–60	60–66	63–68	57–60
	UV exposure	No	Yes	Yes	No
	Air flow, m/s	>0.127	>0.127	>0.127	>0.127
	Total duration, h	864	336	1,008	840
Rest	Duration, h/cycle	None	8	None	48
	Total duration, h	—	328	—	336

Method D is an alternative rain test described in ASTM E 108 and UL 790. It is similar to Method A in terms of total flow rate of the wet cycles and total duration of the dry cycles but includes 48-h rest periods within each 14-day cycle. It is more compatible to a normal workweek. The duration of Method D is about 14 weeks, slightly longer than the 12 weeks of Method A.

A study of treated wood shingles suggests Method B exposure is equivalent to 2–3 years of outdoor exposure in Madison, Wisconsin (Holmes and Knispel 1981, LeVan and Holmes 1986). More recently, comparative tests of FRT and coated products were performed in a cone calorimeter after exposure to Method A and after 1, 2, 3, and 5 years of outdoor exposure. Method A tests appeared to be equivalent to at least 2–3 years of outdoor exposure (Östman and Tsantaridis 2004, 2007).

WATER SPRAY AND WATER USAGE

In accelerated weathering of FRT wood, the objective is to obtain leaching of the FR chemicals consistent with field applications. In the leaching of the FR chemicals from the wood, liquid water moves within the board to the surface, carrying the FR

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chemicals with it, and then drips from the surface (Gardner 1965). As discussed by DeGroot and Nesenson (1995) for preservative-treated shingles, water must penetrate the wood product to dissolve the chemical and form continuous pathways for leaching of the diffusible chemical to occur.

D 2898 WATER APPLICATION

Unlike weathering protocols for nonmetallic materials that emphasize UV exposure, the D 2898 methods are primarily rain tests. The quantity of water needs to be given more consideration. With water increasingly a precious commodity, the use and disposal of excessive amounts of water is not environmentally sound. The water may become contaminated with the treatment chemicals and other materials from the test specimens. Such water may be subject to disposal regulations.

The water flow rates are 17.8 mm/h (0.7 in/h) for Methods A and D and 731 mm/h (29 in/h) for Methods B and C. As stated in ASTM E 108, Method A was intended to simulate 2.0 m (80 in.) of rainfall per year for a period of 10 years. The approximately 250 m (10,000 in.) of water sprayed during the 1,000-h exposure of Method B was calculated as equivalent to 1 m (40 in.) of rainfall per year in a 35-year period over the eave end of an average 5.5-m (18-ft) roof slope (Holmes 1971).

Recent laboratory tests on leaching of chemicals from preservative-treated wood have shown that the amount of chemicals leached for a given amount of water depends on the rate of application (Lebow and others 2004b). Higher flow rates reduce the amount of chemicals leached for a given amount of water used. In tests using deionized water at flow rates of 2.5, 8.0, and 25.4 mm/h (Lebow and others 2004b), the amounts of copper and arsenic leached per total amount of water applied decreased as flow rates increased. Durations of water application were varied to obtain a total of 762 mm of water at the end of 3 weeks. In case of arsenic, the total amounts of chemical leached were 3.5 mg for 25.4 mm/h water flow rate, 4.9 mg for 8.0 mm/h, and 10.2 mg for 2.5 mm/h. In development of Method B, it was recognized that the large flow rates being specified for water spray application would not be as effective as light spray application. For polymeric materials, duration of the rain or dew period is considered more important than total amount of water because longer durations allow deeper penetration of water into the material (Atlas Material Testing Solutions 2001).

Calculated estimates of total water usage are 20,700 L/m^2 (500 gal/ft^2) of specimen surface for Methods A and D. To conserve water, some recirculation of the water is permitted in Methods B and C. Generally cited negative aspects of recirculation are (1) potential deposit of leached FR chemicals onto samples during subsequent cycles and (2) higher concentrations of the leached chemicals in the water at time of disposal. Recirculation may necessitate (1) filtering of the water of debris that will clog the nozzles and (2) nozzles and plumbing suitable for contaminated water.

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In the case of chambers such as the FPL chamber, the small distance from the spray nozzle to the specimen may necessitate the use of special nozzles with very low flow rate to achieve the flow rate per unit surface area of Methods A and D. Greater distances, such that used for the exposure of full-size ASTM E 108 roof test specimens, allow nozzles with larger openings to be used. Larger openings reduce the potential for debris to clog the nozzles.

For the first three cycles (24 h of water spray) of Method B, water is not re-circulated and 17,600 L/m^2 (430 gal/ft^2) of water is used per specimen surface area. At least 19 L (5 gal) of fresh water must be introduced through each spray nozzle for each of the 39 subsequent cycles. Specimen surface area per nozzle is not defined in the standard. In the FPL weathering chamber, there is one nozzle per 0.74 m^2 (8 ft^2) of specimen surface area (Holmes 1973). Thus, the additional water needed for the rest of the exposure is 1,000 L/m^2 (24 gal/ft^2). In the FPL chamber, the 19-L (5-gal) fresh water requirement means that all the water in the 82-L (21.6-gal) reservoir tank is replaced for each 4 + 4 h cycle. In the late 1960s FPL tests (Holmes 1971), water was replaced at the start of each 4-h spray period.

Although total water flow in Method C (737,856 L/m^2 (18,100 gal/ft^2)) is much greater than that for any of the other methods, a significant degree of recirculation of water is permitted. Water in the system must be replaced at the end of the first three cycles and at the start of the last three cycles. During the other cycles, a minimum of 19 L (5 gal) of fresh water is required per nozzle, per cycle. Specimen surface area per spray nozzle is not defined. Assuming the water spray is applied by a spray nozzle per 2.25 m^2 (24 ft^2) specimen surface area, the estimated fresh water needed is 2,100 L/m^2 (51 gal/ft^2) of specimen surface area for the middle 246 cycles. Assuming a nozzle per 0.74 m^2 (8 ft^2) surface area, the estimate is 6,300 L/m^2 (155 gal/ft^2). Additional water for the initial three cycles and final three cycles would depend on the system used to recycle the water within a single cycle. In the FPL chamber, an additional 166 L/m^2 (4 gal/ft^2) is required for the six cycles. For larger chambers capable of exposing multiple E 108 specimens, the additional required water may be on the order of 700 L/m^2 (17 gal/ft^2). The initial AC107 issued in 1995 did not allow any re-circulation of the water.

D 2898 includes a note warning that water quality, such as pH and hardness, can impact the accelerated weathering of specimens. Literature on the effects of water characteristics on leaching of preservatives from treated wood was reviewed by Lebow (1996) and Lebow and others (2004a). Tests have shown that lower pH and higher water temperatures can increase leaching of chemicals from wood treated with chromated copper arsenate (CCA). The ASTM standards for accelerated weathering of nonmetallic materials (G 151 and related standards) require the use of high-quality water such as that obtained by distillation or deionization/reverse osmosis.

The cyclic nature of the different methods induces gradients of moisture and temperature within the wood that in turn result in internal stresses that cause varying degrees of physical changes. In tests of leach-resistant treated and non-leach-

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resistant treated Douglas-fir plywoods, increases in moisture content of the specimens were similar for Method A and Method B (Holmes 1973). Specimen weights at the end of the wet cycles were approximately 20% greater than their initial weights. The two exposure cycles also include periods of drying in a heated environment. In the plywood tests, the severity of the 72-h drying cycle in Method A was such that moisture content decreased to below the initial moisture content. However, that was not the case in the 4-h drying cycle of Method B in that some of the moisture pick-up from the wet cycle was retained at the end of the dry cycle (Holmes 1973). In development of the standard, consideration was given to extending the drying time in Method B to 8 h to reduce moisture content at the end of the drying cycle. This was not found to be sufficient to consistently reduce moisture content to the initial level. There was also no definitive evidence that lower moisture content at the end of the drying cycle was a more severe exposure. In tests of untreated western redcedar shakes exposed to Method C, Grisack (1995) obtained moisture contents of 35% to 39% after the wet cycle and 7% to 9% after the dry cycle.

The drying cycle also results in hot surfaces for the start of the water spray cycle. The cold water spray striking the wood surface at 66°C (150°F) was considered to give a hot-and-cold bath effect that would force the water deeper into the wood to dissolve or further dilute water-sensitive chemicals and thus accelerate the leaching action (Holmes 1971). The inclusion of rest periods in the cycles may impact results while also facilitating the rotation of the specimens within the chamber to improve the uniformity of the water spray and UV exposures.

OTHER METHODS OF WATER APPLICATION

Simple soaking of the specimens in a beaker of water is often used to evaluate the leachability of treatments (Bescher and others 1948, Juneja 1972, Sweet and others 1996). An American Wood Protection Association standard for preservative-treated wood, E11, specifies immersion of 19-mm cubes for a total of 2 weeks, with periodic water changes. In addition to fire testing the samples, chemical analysis of the leachate can be conducted. Harada and others (2009) used scanning electron microscopy and x-ray microanalysis to examine leachability of polyphosphatic carbamate from Sugi sapwood impregnated with the chemical. The utilized weathering method consisted of 2,000 h of continuous exposure to xenon-arc UV radiation, with 18 min of deionized water spray every 2 h. For uncoated specimens, mean dry chemical retention decreased from 220 kg/m^3 to 76 kg/m^3 after 500 h and to 11 kg/m^3 after 2,000 h. Leaching was observed to a depth of 150 μm from the surface after 500 h and found to extend throughout the 8-mm-thick specimen after 1,000 h of accelerated weathering.

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UV EXPOSURE

UV exposure may significantly increase the loss of fire retardancy of treated wood. This loss of FR chemicals could be due to (1) surface erosion of wood as the result of photodegradation or (2) increased leaching of FR chemicals as a result of surface checking and other physical degradation mechanisms that increase surface area. Average erosion rates recorded for various wood species and grain angles for 8 to 16 years of outdoor exposures in Madison, WI, were 45 to 95 μm per year (4.5 to 9.5 mm in 100 years) (Williams 2005). Harada and others (2009) also observed surface erosion after 500 h of xenon-arc UV radiation exposure. UV exposure is often cited as one reason for the inferior performance of test specimens exposed to natural weathering compared to specimens exposed to comparable or greater amounts of water in the accelerated weathering methods of D 2898. In exposure cycles listed in the ASTM weathering standards for nonmetallic materials (G 151 and related standards), water exposure periods of the cycles include simultaneous UV exposure. Research on other materials has shown that the impact of UV exposure is different with and without water exposure. In addition to washing away the water-soluble reaction products, water might be facilitating movement of reaction products into the wood (Williams 2005). UV degradation of wood results in loss of lignin, which makes the surface more hydrophilic (Williams 2005). Lignin is also mainly responsible for the char layer when wood is subjected to fire exposure.

Lebow and others (2003) found that exposure of uncoated CCA-treated wood to UV radiation and water spray increased leaching of chemicals by a factor of three as compared with exposure to water only. The UV xenon-arc irradiance was about 65 W/m^2 for the 300 to 400-Nm range. They concluded that UV exposure is necessary to assess the ability of wood coatings to reduce leaching. Although fire performance was not evaluated, Stark (2006) found that water and UV light had synergistic effects on the degradation of wood–plastic composites.

In contrast, comparative tests of specimens exposed to D 2898 Method A (no UV exposure) and Method B (UV exposure) did not result in any significant differences in the fire test results (Holmes 1973). In ASTM E 84 tests, the leach-resistant FRT Douglas-fir plywood specimens had flame spread indices (FSIs) of 18 to 30 without any exposure, 23 to 25 after Method A exposure, and 25–28 after Method B exposure. The non-leach-resistant FRT samples had FSIs of 25 and 28 without any exposure, 59 and 59 after Method A exposure, and 54 and 69 after Method B exposure. Östman and Tsantaridis (2004) reported a Nordic study using the cone calorimeter that also found Methods A and B to be equivalent. This agreement between results from Method A and Method B could be due to the UV exposure of Method B compensating for the shorter duration (70% less) of water spray application in Method B. The much greater flow rate of Method B likely also helps compensate for the shorter duration of water spray application. Inclusion of UV exposure is likely to be more important in the testing of untreated and treated wood products with coatings.

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UV EXPOSURE IN D 2898

D 2898 Methods B and C specify "sunlamps" for the UV exposure. The original footnote for Method B stated General Electric (GE) Type H275 RUV (275 W) bulbs were acceptable. These Type RS reflector, 110 to 125-V sunlamps are no longer manufactured. Irradiance data for GE RS sunlamps were cited by Dryja and others (1980) and Crosby and Moilanen (1974). Later, the footnote was revised to include Osram Ultra-Vitaloz® (300W) bulbs as a suitable sunlamp. In company literature, these 220 to 230-V Osram lamps were described as a quartz discharge tube and a tungsten filament. D 2898 was revised to include 5.0 $W/m^2/nm$ irradiance for a wavelength of 315 to 400 nm at 1 m as a technical specification for the sunlamp. Spectral data for the sunlamp published in Osram company literature distributed at the time the sunlamp was added to D 2898 were 2.0 W/m^2 for 280 to 315 nm, 5.0 W/m^2 for 315 to 400 nm, and 11.8 W/m^2 for 380 to 780 nm, all for a distance of 1 m. The "/nm" in the D 2898-08 provision appears to be in error. Current company literature for the Ultra-Vitaloz® lamp (catalog.myosram.com, 3/19/2009) includes a light emission profile (Deka and others 2008). The UVB radiated power (280 to 315 nm) and the UVA radiated power (315 to 400 nm) are given as 3.0 W and 13.6 W, respectively. Global solar spectral irradiance numbers from CIE Pub. 85, Tab 4, include 2.19 W/m^2 for 280 to 315 nm wavelength and 72.37 W/m^2 for 315 to 400 nm wavelength (Atlas Material Testing Solutions 2001), which indicates the sunlamps only duplicate natural sunlight at the lower 280 to 315 nm wavelengths.

Thorson (1993) measured irradiance from a used GE lamp and a new Osram bulb at 0.5 m. For both of these dual-element lamps, there were sharp emission line peaks throughout the spectrum power distribution from 280 nm to 600 nm wavelength. Except for these sharp peaks in the data, values on the irradiance curves were less than 0.008 $W/m^2/nm$ with the GE bulb and less than 0.050 $W/m^2/nm$ for the Osram lamps between 300 and 400 nm. The smooth portions of the curves gradually increased in near infrared region (600 to 800 nm wavelength) to 0.04 $W/m^2/nm$ for the GE sunlamp and 0.05 $W/m^2/nm$ for the Osram sunlamp at 800 nm wavelength. When the two curves were normalized at 560 nm, there was near perfect match in the comparison of the spectrum of an old GE bulb and a new Osram bulb over the 300 to 600 nm wavelength range. For comparison, the spectral power distribution curve for average Miami sunlight (26° S Direct) increases from zero irradiance at 300 nm wavelength to a peak of about 1.0 $W/m^2/nm$ irradiance at approximately 460 nm and then decreases to about 0.5 $W/m^2/nm$ at 800 nm (Atlas Material Testing Solutions 2001).

Although the sunlamp captures irradiance at the very short UV wavelength (280 to 315 nm) that causes the most damage, irradiance levels from a single sunlamp are much lower than those obtained from natural sunlight as the wavelength increases. Radiant energy is inversely proportional to the wavelength of the radiation. The higher the energy of the radiation, the more damage there is from the radiation. Thus, UV radiation (280 to 400 nm) is widely considered to be the portion of the spectrum

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that needs to be duplicated in any accelerated weathering experiments. However, the depth of penetration of the radiation into the wood is proportional to the wavelength in the 246 to 496 nm range (Kataoka and others 2007). As a result, degradation due to UV radiation is largely at or near the wood surface. In the case of FRT wood, degradation at depths beyond the surface may also be important. Thus, violet light (403 nm) may also be an important factor in the degradation of pressure-impregnated FRT wood at depths beyond that of the surface of the wood. The irradiance levels can be increased by using more than one sunlamp per unit area. Per ASTM D 2898, one lamp is mounted 660 mm (26 in.) above the specimen, and one lamp is used for each 8 ft^2 (0.74 m^2) of specimen surface.

OTHER METHODS OF UV EXPOSURE

Other types of UV technologies would likely improve the effectiveness of UV exposures for better simulating sunlight and thus producing the desired impact. Mercury vapor and tungsten lamps are no longer widely used for accelerated weathering tests. Other light sources include enclosed carbon arc (ASTM G 153), open flame carbon arc (ASTM G 152), xenon arc (ASTM G 155), fluorescent UV lamps (ASTM G 154), and metal halide. Harada and others (2009) used xenon-arc UV radiation to examine the leachability of polyphosphatic carbamate from Sugi sapwood impregnated with the chemical. Exposure was continuous for 2,000 h, with 18 min of deionized water spray every 2 h. Unfortunately, commercial accelerated weathering chambers that use alternative technologies have relatively small specimen holders only suitable for testing 100- by 100-mm cone calorimeter specimens or smaller specimens.

SMALL SPECIMENS

The methods of D 2898 reflect the large specimens used in fire tests for FRT wood (i.e., ASTM E 108 and E 84). Since early development of the weathering tests in the 1960s, there have been interests in alternative small-scale fire tests. More recently, the standard has been used to weather specimens for the cone calorimeter (ASTM E 1354). The difficulties of scale are two-fold: the weathering test and the fire test. As discussed by Lebow and others (2004a), physical dimensions of specimens can impact the leaching of the treating chemicals out of the wood. In particular, exposed end grain will increase the amount of leaching. The Nordtest Method NT Fire 053 standard addresses the use of smaller size specimens by requiring coating of the edges perpendicular to grain, specifying minimum dimensions in the grain direction (500 mm), and requiring the final cutting of the small specimens to be done away from the sealed edges (≥100 mm). The issue of scale is also an issue with the fire tests themselves in that small-scale fire tests often do not fully duplicate the behavior exhibited in the larger fire tests.

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CONCLUDING REMARKS

Available information suggests improvements could be made to optimize leaching in terms of consumed water, test duration, degree of recirculation, and other parameters. Proper design of accelerated weathering experiments requires a better understanding of the mechanisms of the degradation modes that are important for the performance properties being investigated. The research needs identified by Östman and others (2001) continue as needs.

Rain, temperature, and sunlight conditions in actual exterior applications will obviously be different than those used in the accelerated weathering tests and even those conditions of actual testing of products in outdoor exposures. In addition to the wide variety of cyclic rain, temperature, and solar exposures, the durability of the FRT wood in actual outdoor exposures will depend on many other factors such as atmospheric pollutants, relative humidity, physical abrasion, biological attacks, freeze/thaw cycles, aging, and construction details. Synergistic effects of the parameters only compound the difficulties in making judgments on expected performance in the field. Any weathering under controlled laboratory testing conditions, be they interior or exterior, only provides relative measures of what may be seen in practice. Other recommended practices for accelerated weathering include the use of control specimens for comparative purposes. It is desirable to conduct fire tests after different durations of exposure to better understand the leach resistance of the treatment. Differences in fire test results may be apparent only when treatments with low retentions are evaluated because results tend to plateau at higher retention levels.

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