An Examination of Wood Tie Deterioration

And the Protective Capabilities of an Asphalt Coating

Ft. Outdoor Weathering Experiment, Moisture Content Fluctuation Study

Railway Innovative Solutions, LLC

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Executive Summary

Railroad professionals are well aware that wood rail ties inevitably deteriorate and require costly replacements. While chemical preservatives are the go-to option to extend rail tie operational lifetime, maintenance-of-way professionals have noticed alarming rates of tie deterioration, notwithstanding the type of treatment these ties have undergone. Consequently, engineers have recently sought additional solutions to the issue of expensive wood tie turnover, but have yet to find a definitive answer to improve this situation.

To address this issue, Railway Innovative Solutions, LLC has formulated an asphalt-based coating under the commercial name Tietan™. Tietan eliminates the threat of UV and minimizes water damage from the top surface of the tie. It is applied hot and seeps into existing openings in the wood prior to cooling, forming a durable and flexible membrane that will bond with solvent-based treatments like creosote, copper naphthenate, and DCOI.* The hot asphalt is immediately covered with aggregate for slip resistance. Over time, the engineered asphalt flexes with the natural expansion and contraction of wood, ensuring a complementary protective layer to extend the service life of wood ties.

This coating has recently demonstrated major reductions in the impact of weathering on wood, whether applied to untreated or preservative-treated nondurable hardwoods such as red oak, sweetgum, and southern yellow pine, to name a few. Outdoor weathering shows that untreated ties can deteriorate rapidly. Water and UV radiation are a threat to wood's mechanical integrity, where their combined effect with temperature fluctuations accelerates both dimensional changes and accumulation of internal stresses. Tietan can reduce levels of water uptake by 34% on average, offering the tie a more stable environment where moisture content, stress and strain on the wood fibers can be minimized, thus reducing the development of cracks, splits, and checks.

* DCOI: 4,5-Dichloro-2-n-octyl-4-isothiazolin-3-one is an oil-borne preservative that's been standardized by the American Wood Protection Association (AWPA), used in various applications, including utility poles, crossarms, and decking and fencing to name a few.

Introduction

The use of wood for railway ties is a time-tested choice, backed by decades of proven performance and sustainability. [1] In the US, wood ties comprise 90+% of all installed ties—ca. 450 million units spanning 140,000 miles of railroad—supporting both freight and passenger transportation. [2] [3]

This preference for wood remains strong; cost models estimate that it consistently offers a lower cost per mile per million gross tons (MGT)† compared to alternative tie materials. Unlike European rail systems, North American freight operations prioritize long, slow, and heavy trains, making the flexibility and shock absorption of wood ties particularly valuable for handling these load demands.

Railway Innovation Solutions has been developing a series of products that address relevant gaps in the use of traditional preservation methods. These products offer additional resilience to environmental factors that are well-known to contribute to wood tie deterioration. This whitepaper aims to introduce a formulated asphalt coating as a supplementary tie-protecting solution that markedly improves weathering resistance and ultimately elongates tie service time.

Mechanisms For Wood Deterioration and Fundamentals of Wood Treatment

Wood deterioration can be caused by a variety of biological and environmental factors. Parasitic organisms, including fungi, insects, and bacteria, are equipped to degrade wood carbohydrates—mainly cellulose—either by feeding or nesting. Moisture, UV radiation, temperature fluctuations, and freeze-thaw cycles are the main environmental causes that damage wood's mechanical integrity. Wood preservation treatments contain chemicals that improve wood's resiliency to the proliferation of parasitic organisms, while conferring additional resistance to the effects of water content fluctuations and UV radiation exposure. While it is clear why parasites are detrimental to wood's structural integrity, understanding how moisture and UV radiation affect wood's attributes is key to getting a grip on what makes current preservation treatments for wood ties subpar to service life expectations.

Understanding How Moisture Affects Wood Ties

Harvested wood typically holds 25-30% moisture for most types of trees. It is the ebb and flow of moisture that causes the natural contraction and expansion of wood. [4] Wooden railroad ties undergo constant wet and dry cycling due to exposure to humidity, precipitation, and temperature fluctuations in the environment. The expansion and contraction of the wood generate strain within the structure. With sufficient strain formation during the drying cycle—when railroad ties lose moisture—shrinkage occurs, followed by the formation of cracks (fracture or fissure), checks (a crack on one surface of the wood along the grain), and splits (a separation extending from one surface to an adjacent). These voids allow for water ingress where, over time, repetitive wet/dry cycles can cause the wood fibers to weaken, further propagating the cracks and compromising the structural integrity of the wooden structure. Furthermore, with excess water from rainfall

† Million Gross Tons (MGT) is a measure of the total weight of trains passing over a section of track annually. It helps determine wear and durability requirements for railway infrastructure, including type of ties used. Tracks with higher MGT values require stronger materials.

and snow melt, moisture can open up a vulnerability to parasitic attacks. For example, research shows that fungal spores do not easily germinate in wood when the moisture content is below 20% where wood can be considered immune to fungus. [5]

Impact of UV Radiation on the Degradation of Wood Surfaces

UV radiation, particularly in the UV-B (280-315 nm) and UV-A (315-400 nm) ranges, initiates the photodegradation of wood. [6] This process involves breaking down lignin at the surface, oxidizing wood components, and forming free radicals. Polysaccharides (e.g., cellulose, hemicellulose, pectin) are structurally saturated compounds, rendering them poor absorbers of UV-B/A and visible light, and thus more resistant to photodegradation compared to lignin. Lignin degradation is significantly accelerated when UV exposure is combined with water leaching, compared to UV exposure alone. [7] Photodegradation products‡ are highly leachable; depending on the wood species, 3 to 10 days of water exposure can result in their complete removal. The loss of lignin and its colored degradation products leads to a characteristic white-grey discoloration in most wood species. Elevated temperatures further accelerate photodegradation. [8]

As lignin depletes, it leaves behind a rough, fibrous surface that diminishes the structural integrity of wood, making dead cells more prone to mechanical failure, while susceptible to parasitic attack and increased water retention. Surface cracking, often resulting from the destruction of the middle lamella—rich in lignin and responsible for bonding adjacent cells—is a major contributor to the mechanical deterioration observed during wood weathering. [9] Concurrently, the relative concentration of polysaccharides increases, providing sustenance to pathogens. Finally, the removal of lignin increases structural porosity which favors water retention, helping further soften the wood structure. These factors, working in conjunction with repetitive wet/dry cycles, further increase the chances for crack induction and propagation, favoring mechanical failure of the wooden structure.

Current Wood Treatment Methods and The Need for Supplementary Protection

Treatment of rail ties with chemical preservatives has long been an industry-accepted approach to extending rail lifetime, with industry publications on the cost-benefit analyses justifying the expense of chemical treatment dating back over a century. [10] Current rail tie preservative treatment methods include creosote (CR), copper naphthenate (CuN), and borate (SBX).§

<u>Creosote (CR)</u> – Creosote is an oil-soluble liquid produced from coal tar residue. It has effective antimicrobial, antifungal, and insecticidal properties which are inherent of its large content of polyaromatic hydrocarbons (PAHs). PAHs are known to be carcinogenic to humans, which is why creosote has become more tightly regulated by governments and the industry to limit worker exposure, environmental release, and potential associated liabilities. [11] In essence, the properties responsible for its utility as an effective preservative agent are also the reason to be cognizant of the dangers of its use. For treatment purposes, creosote is diluted in fuel oil and subsequently used to pressure treat wood ties prior to installation in track. Pressure treatment with oil-diluted creosote yields a deep penetration of the organic material into the wood, providing it with a measure of waterproofing in addition to the preservative properties of the creosote.

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‡ Particularly unconjugated carbonyl compounds.

§ AWPA U1 standard presents abbreviations for these preservatives as CR, CuN, and SBX. See ref. [23] for further details.

Copper Naphthenate (CuN) – Copper naphthenate is a chemical reaction product of copper ore with naphthenic acid, a byproduct of crude oil refining. It is oil-soluble and typically diluted in fuel oil for application. When pressure-treated into wood ties—in a similar fashion as creosote—it imparts antifungal, antimicrobial, and water-resistant properties. A key advantage of copper naphthenate is its lower human and environmental toxicity compared to creosote, while still offering effective biocidal preservation.

Borate (SBX) – Treatment of wood using boron-based preservatives is also a common method to prevent wood-boring insect infestation. It is typically applied as a spray-on aqueous solution of disodium octaborate, which imparts parasitic resistance by rendering the insects incapable of digesting wood. Borate is applied after tie manufacture as a spray, after which the ties are allowed to dry prior to being put into service. Pressure treatment of ties by aqueous borate is possible, but due to the high water solubility of the borate and risk of leaching into the environment, is not allowed for ground-contacting wood ties to prevent the leaching of borate into soil.

Current CR-PS and CuN treatments offer strong UV light absorption and bio-repellency. [12] They can be dissolved or diluted with various petroleum-based oils and then introduced deep into the wood fibers under pressure. These treatments help mitigate the exchange of moisture between the wood structure surrounding atmosphere. However, there are limitations, thus driving the demand for additional protective measures.

Introducing Tietan™: a Formulated Asphalt Coating as Supplementary Tie Protecting Solution

Bituminous materials—commonly referred to as asphalt in the United States—are ancient construction substances valued for their versatility and performance. While most widely used in roofing and paving, asphalt is prized for its durability, flexibility, and resistance to environmental stressors. Its ability to accommodate thermal expansion and contraction helps prevent cracking, thereby preserving structural integrity under dynamic operating conditions. Additionally, its impermeability, UV resistance, and toughness make asphalt an excellent protective coating for wood railroad ties, much like its use in asphalt-based roofing products.

Tietan is a polymer-modified asphalt designed to enhance wood's durability against weather conditions. By capitalizing on the aforementioned asphalt attributes, Tietan is intended to serve as a life-extending barrier that limits exposure to harmful UV light and intrusion of water, by shielding wood ties for long periods of time, and conforming to its underlying shape as it ages and warps.

Performance Attributes of Tietan

The asphalt used in its application has been optimized to meet specific performance criteria, as detailed below:

1. Strongly adheres to wood: 3/16" Tietan coatings were applied to creosote-treated wood specimens. The force required to detach the asphalt layer from the wood substrate was measured using a Universal Testing System and a modified pull adhesion method based on ASTM D4541, as illustrated in Figure 1. All failures were adhesive fractures at the asphalt-wood interface in which the asphalt layers displayed resilience to ruptures even >1" in vertical displacement.

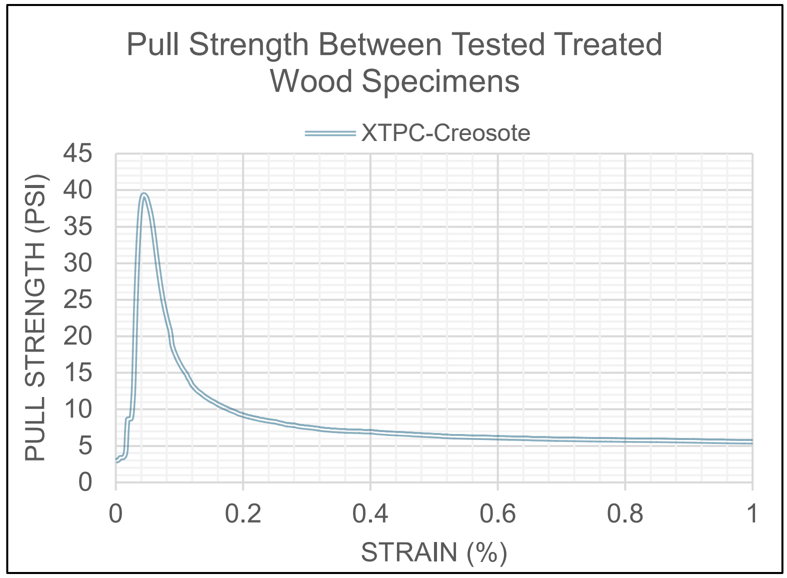

Figure 1. *Left* - Sample clamped into place prior to pull-adhesion testing. Aluminum dolly was adhered to the Tietan surface using a strong epoxy adhesive. *Right* - Representative Pull-Off Adhesion Data collected from Tietan Bonded to treated wood tie specimen. Pull rate was set at 5 mm/min.

2. <u>Conforms to Wood Surface / Flexible</u>: Tietan™ is a shear-thinning material. Its viscosity increases upon settling, allowing it to resist sagging upon cooling while maintaining its ability to conform to the shape of the surface of the wood as it ages and warps. Tietan is also able to continually fill cracks without external stimulus, as depicted in Figure 2. This phenomenon was observed in an outdoor aging study over the course of two years, as depicted by a set of sweetgum samples treated with Tietan in which a crack develops and grows while the treatment continually fills the crack (Figure 9, see below).

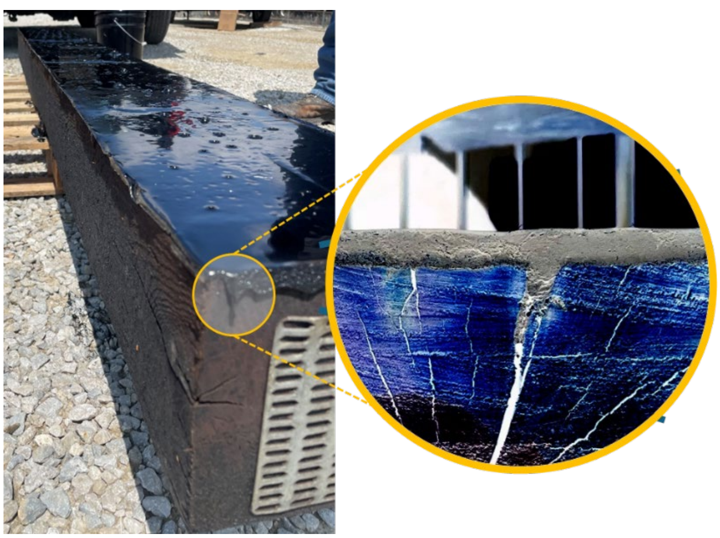

Figure 2. Tietan coated creosote-treated rail tie. Inset. Negative amplification of top surface. Notice the difference in contrast between Tietan and voids.

In a test of Tietan's ability to stretch and maintain its coating in an extreme case, sheets roughly 2" x 4" in surface and 1/16"-1/8" in thickness were applied to specialized testing blocks designed to simulate crack development and growth. As the gap expands, Tietan's resistance to tearing could be observed. One set of samples was tested directly, while another set underwent accelerated aging in a Q-sun Xenon Arc Chamber Model XE-3 at a light intensity of 0.35 W/m^2 for 216 hours. During testing, blocks were spread to a maximum width of 1" (Figure 3) and any surface breaches were confirmed by applying a watercolor solution to the surface of the elongated sample and checking for the presence of color in a paper towel placed directly beneath the resulting span.

A summary of observations for the tested samples is presented in Table 1. Both unweathered samples displayed zero hole formation up to 1" spread, corroborating the film resilience to rupture exhibited in the pull adhesion test (see above). For weathered samples, only the 1/16" thick layer of asphalt developed a small hole at a spread width of 11/16". While it is unexpected, the product will be subjected to such extremes

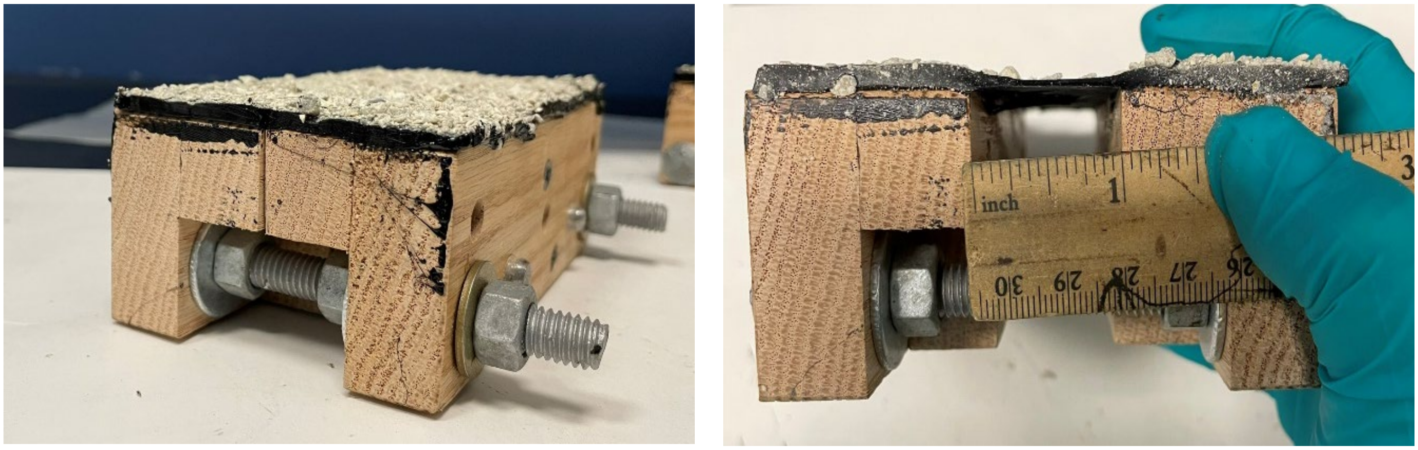

Figure 3. 1/8" Tietan layer as applied (left), and after spreading block to 1" separation (right).

during rail operations, this test clearly illustrates the resilience of Tietan to rupturing under shear and tensile loads even for thin layers.

Table 1. Qualitative Resistance to Hole Formation

Sample Thickness	Unweathered	Weathered
1/16"	No hole formation up to 1" spread	Small hole observed at 11/16" spread
1/8"	No hole formation up to 1" spread	No hole formation up to 1" spread

Figure 4. Before and after pictures of Tietan with aggregate applied hot to several bridge ties.

3. Applicability of Tietan to Railroad Ties: Tietan can be applied to wood surfaces either as a hot-applied liquid or as a pre-formed pad. In the case of hot-applied Tietan, the hot asphalt develops a strong bond with the wood as it cools, and remains in place through the lifetime of the coating, as illustrated in Figure 4. Ideally, hot-applied Tietan can be completed at the point of tie manufacture prior to shipping for installation into a rail track. As a pre-formed pad, Tietan, can be secured in place with mechanical fasteners (i.e., staples) and an absorbable adhesive until strong bonding between the asphalt and the wood surface is formed. Pre-formed Tietan pads can be applied at any point in the tie supply chain, but are better suited for application to in-place ties, especially above or near protected waterways (i.e., bridge ties).

Wet Dry Cycling & Changes in Wood Weight

Figure 5. Top down picture of 3″x3″x9″ pieces of used railroad ties cut from the same piece of used railroad tie. One is uncoated and the other is coated with an aggregate-free version of the Tietan product.

A recent study of ours highlighted the ability of Tietan™ coating to mitigate cracking and weight fluctuations during dry/wet (D/W) cycles at about 34% on average. In these studies, eight samples were cut from bookend sections of a salvaged railroad tie to minimize variability in wood properties, which can significantly impact weight fluctuations. Half of the specimens were left uncoated and the other half was top-coated with aggregate-free Tietan. The initial weight of the samples was recorded and the change in the wood weight was tracked as a relative percentage.

Figure 5 depicts example specimens with and w/o top-coat, where the latter displays a complete surface coverage with a protective Tietan application. X-bar charts from Figure 6 illustrate the average change in weight with each cycle, alongside reference lines for comparison purposes. These charts demonstrate that over the 10 D/W cycles, the uncoated samples exhibit a significantly higher percent increase in wet weight, along with a broader range of variability. In contrast, the aggregate-free Tietan coating limits water uptake and reduces variability, underscoring its effectiveness as a moisture barrier.

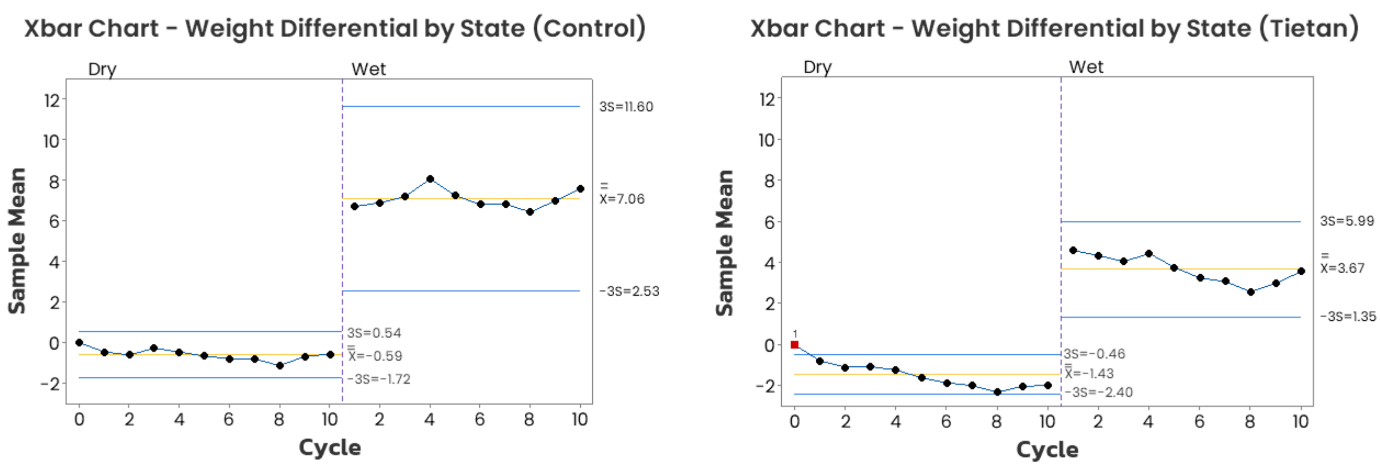

Figure 6. X-bar charts for uncoated (left) and aggregate-free Tietan coated (right) samples showing the average weight differences between cycled sample compared to initial (dry) state. The grand average is shown as $\bar{\bar{x}}$ as well as upper and lower boundary limits set at ±3σ.

A representative set of bookend samples—one uncoated and one coated—was used to evaluate the effect of the coating on preserving structural integrity via the appearance of cracks on the bookend cuts. Figure 7 shows the ends of the wood samples before and after ten cycles of environmental conditioning. Cracks tend to form perpendicular to the growth rings and often appear in mirrored locations across the paired samples. While the initial cracking patterns were similar, the uncoated sample showed wider and more extensive cracking after 10 D/W cycles. On the right, the color of the images was inverted to improve visual contrast.

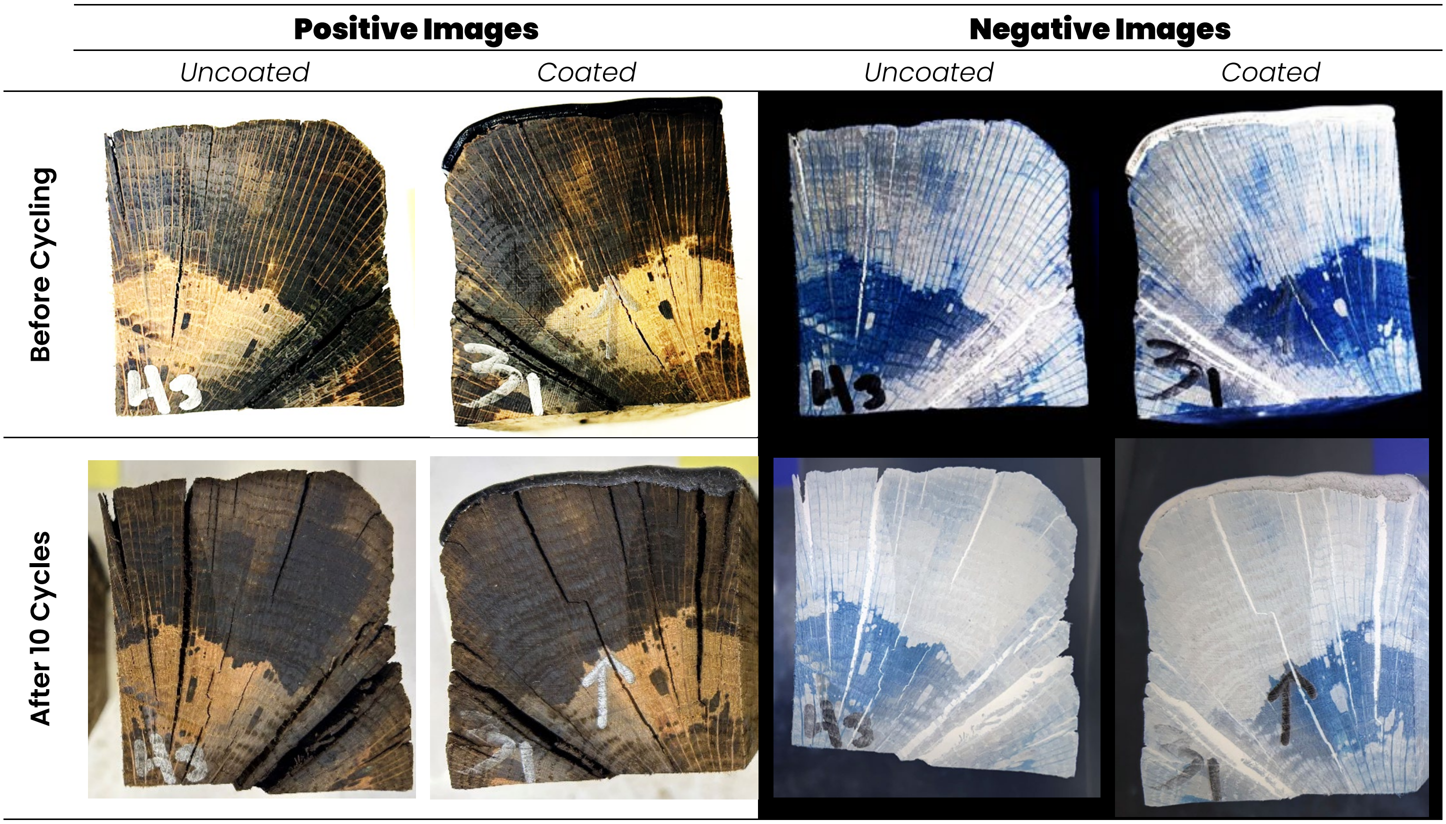

Figure 7. Pictures of two bookend pieces from a railroad tie, one uncoated and the other coated with aggregate-free Tietan before and after 10 D/W cycles. Negative images improve visual contrast of the void spaces.

Outdoor Weathering Studies

Wood specimens cut from southern yellow pine, red oak, and sweetgum samples were divided into three treatment groups: untreated, Tietan™ coated, and Tietan with aggregate. Untreated samples were left as is, treated samples were covered with a 3/16" layer of Tietan. Samples with aggregate were also treated with 4 lb/yd^2 manufactured sand. Samples were placed on a raised metal grate on the roof at the Heritage Research Group facility in Indianapolis, IN, pictured in Figure 8, and left to age outdoors. Samples were photographed monthly for the first year of testing, then every six months subsequently. Figure 9 provides a visual of the specimens weathered outdoors from day 0 (top) to ~2 years of conditioning. Most untreated samples (3rd row from the bottom) displayed the typical white-grey coloration attributed to loss of lignin. Samples have had the chance to undergo various cycles of rain and snow, as well as hot/humid and cold/dry conditions.

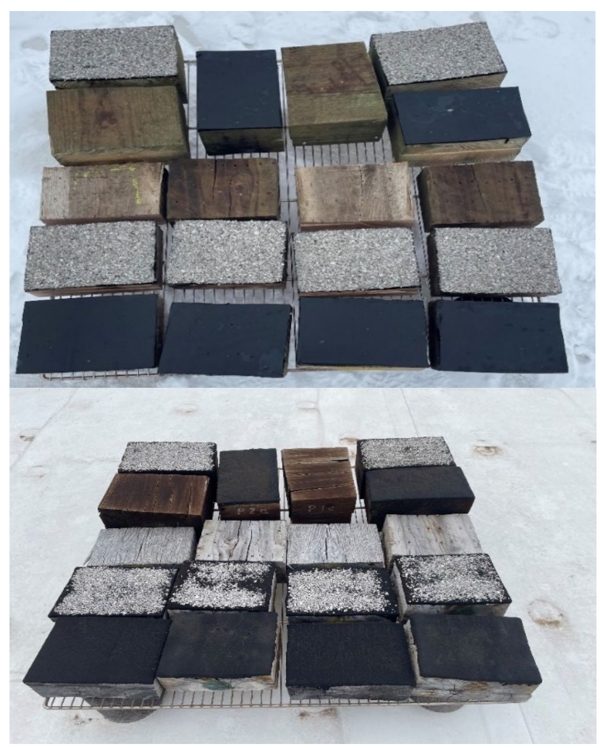

Figure 8. Rooftop aging of tie specimens. *Top* – day 0. *Bottom* – 24 months

Sweetgum and red oak samples developed some cracking within four months; however, in all cases, the Tietan coating remained adhered to the wood surface (data not shown). This was most clearly observed in several sweetgum samples as highlighted in Figure 9. Tietan filled existing cracks when applied and conformed to their shape as it expanded over time. This behavior suggests that Tietan maintains strong adhesion and structural integrity as the wood ages. In a direct comparison, all sweetgum samples exhibited some degree of cracking within two months, but those treated with Tietan appear to have developed fewer cracks than their untreated control counterparts.

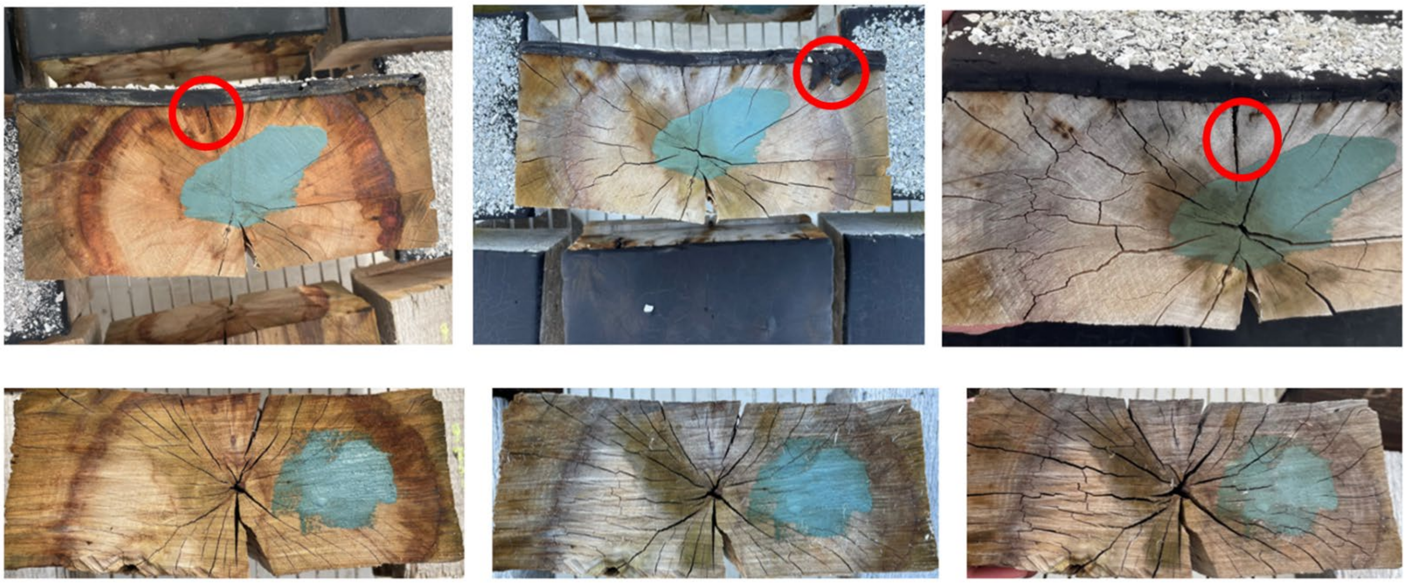

Figure 9. Coated (*top row*) and uncoated (*bottom row*) sweet gum samples at two months (*left column*), one year (*middle column*) and two years (*right column*)—*Red circles*: Tietan maintaining adherence to a new crack forming in wood surface.

Summary of Benefits and Conclusions

Tietan™ has been demonstrated to significantly reduce water uptake and release by over 30% on average. This reduction minimizes changes in moisture content, stress, and strain on wood fibers, thus decreasing the formation of, and threats from, defects such as cracks, splits, and checks throughout the wood tie. By conforming to the surface of the wood tie during application and exposure to ambient conditions, Tietan provides complementary protection that is easily applied and maintains its dimensional stability and mechanical strength.

In conclusion, the application of Tietan offers a promising solution to premature wood tie deterioration by enhancing water resistance, UV protection, and overall durability. This innovative coating, developed by Railway Innovative Solutions, LLC, in collaboration with the Heritage Research Group, stands out as a significant advancement in the maintenance and longevity of wooden railroad ties.

Want to learn more about this innovative solution to premature tie deterioration?
Visit Tietan.com or reach out to Buddy Clark at buclark@tietan.com

Tietan™ is developed in the labs of the Heritage Research Group, and owned and distributed exclusively through Railway Innovative Solutions, LLC, a company of The Heritage Group.

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