

# Development, testing, and application of recycled plastic composite sleepers

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## INTRODUCTION

### BACKGROUND

From early in the construction of railways, wood has been the traditional sleeper material. However, several factors related to the environmental hazard, sustainment, and material wear of wood sleepers have led the railway industry to search for suitable alternative materials. An increase in axle loading in the US from 39 tons (35,400 kg) per axle, compared to 36 tons (32,650 kg) over a decade ago, accelerated the wear of wood sleepers. Additionally, railways closely monitor current environmental regulations and restrictions on the use of creosote, a necessary preservative treatment that provides reasonable service life to wood, especially in certain aggressive exposures which threaten railway construction and maintenance.

## ORIGINS OF PLASTIC COMPOSITE RAILWAY SLEEPERS

Early in the 1990s, new industries were being developed in the US for engineering recycled plastic waste. Early manufacturers attempted to produce and market plastic railway sleepers with the benefits of locking plastic waste in a sustainable long term form. It was quickly realised that the production of a block of plastic would not provide proper track performance. An early grant from the State of Illinois led to production of recycled high-density polyethylene (HDPE) sleepers. A short line installation of these sleepers was not successful due to mechanical property limitations of unreinforced HDPE. Researchers at Rutgers University believed the deficiency in mechanical properties could be overcome through the use of appropriate reinforcement

elements into the recycled-plastic matrix. Apart from mechanical property limitations, HDPE offers performance and environmental advantages that wood lacks. Warm, moist soil can be especially problematic to wood as rot can set in and biological organisms can attack wood sleepers, shortening useful service life. To counter these issues, wood sleepers must be chemically treated. HDPE, however, requires no such treatment due to its inherent resistance to rotting and insects. Moreover, given the large volume of sleepers replaced every year (20 million in the US alone) and that a considerable quantity of plastic is needed to make each sleeper, there is sufficient availability of waste plastic to be diverted from landfills to fill the market need.

By the mid-1990s, Rutgers University developed an engineered plastic composite railway sleeper using recycled HDPE mixed with other materials for property enhancements (Ref 1).

## MINIMUM PERFORMANCE REQUIREMENTS

In 1994, a research program, using a joint team of personnel from Rutgers University, Norfolk Southern, the former Conrail, the U.S. Army Construction Engineering Research Laboratory and a major plastic lumber manufacturer established a set of performance target goals for both physical and mechanical properties of plastic railway sleepers to serve as a guide for developing plastic sleepers for Class 1 rail service in the US. These goals were as follows:



Image 1: Plastic sleeper with ideal "dimple" surface pattern for increased lateral stability



## DIMENSIONS / APPEARANCE

Cross-section: 17.8 x 22.9 cm (7 x 9 in.) +/- 0.318 cm (0.125 in.)

## MECHANICAL PROPERTIES

Under the following conditions the track will maintain gauge within + 0.318 cm (0.125 in.)

- Lateral load: 106.8 kN (24,000 lbf)
- Static vertical load: 173.5 kN (39,000 lbf); Dynamic vertical load: 622.7 kN (140,000 lbf)
- Modulus of elasticity: Greater than 1,172 MPa (170,000 psi)

## GENERAL PERFORMANCE REQUIREMENTS

- Less than 5% water absorption
- Exposure to diesel fuel and grease will not affect properties over 10%

- Electrically non-conductive
- Surface degradation due to ultraviolet light will not exceed 0.0076 cm. (0.003 in) per year
- Installation of the sleepers can be accomplished using standard equipment
- The sleepers must be compatible with standard rail fastening hardware

The research program, which included extensive performance analysis of a number of polymer composite technologies, both in laboratory and in test track over several years, was deemed a great success by the AAR and led to the publication of the draft US AREMA standard for composite railroad ties (sleepers) in 2003, Chapter 30, Part 5. This draft standard was, however, only ratified by AREMA in 2012, following the monitoring of more than 10 years of successful commercial application of composite railroad sleepers supplied in accordance with the AREMA Standard across the US in passenger and freight lines.

## TYPES OF PLASTIC COMPOSITE SLEEPERS

In the two decades since the first plastic sleepers were installed in the Chicago-area short line railway, several manufacturers have entered the market with a variety of plastic composite sleeper designs. The longest track tested technologies are the Rutgers University composite sleepers with two formulations, which exceed the minimum performance requirements previously stated:

- Glass-fiber reinforced HDPE matrix
- Immiscible Polymer Blend (IMPB) PS-HDPE matrix

## SLEEPER PERFORMANCE

### LABORATORY TESTING

#### BENDING

Flexural tests have been performed on full-sized plastic composite sleepers using a modified four-point flexural test apparatus routinely used in the railroad industry (Reference 2). The support span is 152.4 cm. (60 in) and the load span is 15.2 cm (6 in.). The Rutgers developed sleepers tested in this manner demonstrate ultimate strengths exceeding 31.0 MPa (4,500 psi) and elastic moduli (stiffness) higher than 2,069 MPa (300,000 psi).

#### FASTENER HOLDING POWER

Laboratory testing demonstrated screw spike holding power in plastic composite sleepers as better to that in wooden sleepers. Cut spikes will need to be tested to determine the pull out force in the sleeper to ensure sufficient properties. In wood, cut spikes are known to loosen considerably over time (reference 3). The rate of decrease in pullout force of cut spikes in plastic sleepers is slower than in wooden sleepers. Field installations using cut spikes in the Rutgers plastic sleepers have yielded satisfactory results.

## FIELD TESTING AND DEMONSTRATIONS

### FACILITY FOR ACCELERATED SERVICE TESTING

In April 1996, two plastic sleepers were installed in a 5-degree curve in the Facility for Accelerated Service Testing (FAST) at the Association of American Railroads (AAR) Transportation Technology Center, Inc. (TTCI) in Pueblo, CO. One of the sleepers was removed for laboratory testing after 130 million gross tons (MGT) (117.9 billion gross kg) of traffic at 40 mph (64.4 km/hr). This sleeper was subjected to a rail seat abrasion test to determine the sensitivity of the sleeper material to sleeper plate cutting. After 900,000 cycles with no evidence of sleeper plate cutting, the testing machine broke down.



Image 2: London Underground plain line and S&C installation

The satisfactory performance of the originally installed sleepers led to the installation of an additional 24 plastic composite sleepers in March 1997.

Lateral track stability is another major performance criterion for sleepers. To maintain track stability both vertically and horizontally requires an important mechanical interaction between the sleeper and the ballast. This issue applies equally to hardwood sleepers of similar dimensions and weight. Hardwood sleepers are, however, sufficiently soft to allow the ballast to indent into the sleeper sides and base after a number of train passes, which provides additional friction and stability.

TTCI performed lateral sleeper push-out testing on some of the newly installed plastic composite sleepers. The maximum force for push out of the composite sleeper was approximately 4.45 kN (1,000 lbf), in the range of an equivalent sized wood sleeper. A wooden sleeper will begin to "lock" into the ballast and the lateral push-out forces increase to around 11.1 – 13.3 kN (2,500 – 3,000 lbf) after 15 – 20 MGT (13.6 – 18.1 billion gross kg) of traffic. TTCI push-out testing determined that the composite sleepers retained a value similar to when first installed after approximately 15 MGT (13.6 billion gross kg) of traffic. The smooth plastic composite sleeper was determined to be too frictionless to achieve appreciable mechanical locking into the ballast. After some work, it was shown that shape and depth of any surface pattern is critical to sleeper performance in ballasted track and that stress raisers must be prevented as a byproduct of the surface pattern.

As discussed, sleepers must interact with the ballast to provide resistance to lateral rail movement and prevent a system failure. It is well understood that the surface roughness of hard composite sleepers must be enhanced to deliver necessary sleeper-ballast interaction. This can be done via carefully designed surface patterns. For example, Sicut's patented dimple pattern (image 1), when moulded into the sleeper surface increases lateral resistance from 4.5kN to over 11kN, surpassing that of newly installed wood sleepers, without the need for a "break-in" period. Embossed patterns applied after moulding have also been tried. While these have shown similar initial resistance to a moulded design of the same shape, over time the "protruding" material, with its sharp, thin edges, tends to break away leaving a less deep pattern, reducing resistance to well below that expected, suggesting that a suitably designed moulded pattern is necessary for long term performance.

To date, plastic composite sleepers installed at FAST have accumulated over 2000 MGT of traffic. A 100-sleeper section of plastic composite sleepers was installed two decades ago in a 6-degree curve using all cut spike fasteners. TTCI reported no track alignment or vertical profile problems, and comparable

static and dynamic vertical track modulus to wood-sleeper track.

## FIELD INSTALLATIONS

Plastic composite sleepers made using the Rutgers technologies have been accumulating traffic not only at the FAST, but also in revenue and mass transit applications. The Union Pacific (UP) Railroad has the largest number of plastic composite sleepers installed of any U.S. railroad, using mostly cut spikes. In one UP installation carrying 119,000 kg coal cars, composite sleepers accumulated 850 MGT between July 1998 and 2004 with no indication of degradation, gauge widening, plate cutting or spike pull-out. UP has more recently installed a further 150,000 sleepers using Rutgers technologies.

Over the years, the dripping of creosote onto people and property from elevated track has been a problem for the Chicago Transit Authority (CTA). After a successful trial of a small group of plastic sleepers in one of its elevated stations, the CTA decided to install plastic composite sleepers not only in their elevated (open) track but in ballasted track as well, installing tens of thousands of sleepers for use. Other users in the US include Long Island Railroad, Miami Dade, San Francisco MTA, New Jersey State Transit and many more. A three year review into composite sleeper technologies by London Underground concluded that the Rutgers technology, exclusively licensed to UK company Sicut Enterprises Ltd, is the most suitable after technical evaluation and trialing (image 2) and the most likely composite sleeper to deliver the value and whole life cost savings sought by LU.

In addition to the US & UK installations, plastic composite sleepers manufactured using the Rutgers technologies have been successfully installed on a variety of tracks (plain line, S&C, over tunnel bridges, metros, light rail, narrow gauge & freight) in 16 countries worldwide including France, Belgium, Germany, Sweden, Australia, and Canada. Polymer composite sleepers using the Rutgers technologies have been installed in passenger lines at up to 201 km/hr, freight tracks with axle loads exceeding 39 tons, in tunnels, on bridges, both open and closed deck and as bearers in S&C. The material technology has also been used for the construction of road and rail bridges.

## DESIGN

### BACKGROUND

As established by their successful performance in track to date, Rutgers composite railway sleepers have demonstrated that they can be used as a replacement for wood sleepers in many applications. In particular, 25 years of in track performance positively indicate the reliability and performance of the product. In the autumn of 1998, the U.S. Army Engineer Research and Development Center started working with the Federal Railroad

Administration to help address design and safety issues that may arise with the use of plastic composite railway sleepers.

## DESIGNED FOR SUCCESS

The collaborative research program, between the Association of American Railroads (AAR), the U.S. Army Corps of Engineers, Norfolk Southern Railway and the AMIPP Advanced Polymer Centre at Rutgers University determined the failure modes in **all types of plastic based sleepers** that can occur, on the basis of criticality and operational safety, are as follows:

1. Failure to meet recommended minimum performance requirements
2. Fracture (failure to possess adequate strength to prevent fracture under static and dynamic loading or stiffness to prevent unacceptable elastic sleeper deformation)
3. Low sleeper-ballast interaction
4. Fire
5. Creep (increase of gauge due to axial sleeper loading)
6. Thermal expansion
7. Stress-relaxation, resulting in spike loosening
8. Deterioration of properties due to exposure to the elements

Some of the failure modes listed would be catastrophic, with essentially no early warning, while others would be more gradual in nature. A breakdown of the failure modes in these categories is listed below.

### POTENTIAL CATASTROPHIC FAILURES

- Failure to meet recommended minimum performance requirements
- Fracture
- Low sleeper-ballast interaction
- Fire

### GRADUAL FAILURES

- Creep
- Thermal Expansion
- Stress-relaxation
- Deterioration of properties via environmental exposures

## MINIMUM PERFORMANCE REQUIREMENTS

The previously listed minimum performance requirements were based on Class 1 freight applications in the US, considered the most demanding. These requirements provided valuable direction for the research targets as the goal of the development team was to create a plastic composite sleeper that could withstand the most demanding situation a sleeper can expect to endure.

The inability of some recycled-plastic composite sleepers to meet the minimum



performance requirements as described above is considered the most likely reason for sudden catastrophic failure of the track system (resulting from excessive deflections) that may lead to a derailment. Conversely, if the minimum performance requirements are met, and installation is successful, the sleeper will succeed.

To that end, the Rutgers based sleepers, exceed the minimum standards set through thorough quality control mechanisms that ensure the proper sourcing of raw materials, sourcing and testing to sleeper forming, and final sleeper property testing. A twelve-point inspection of raw materials ensures that the materials are in specification, and are properly

formulated prior to sleeper formation. The sleeper manufacturing process involves an automated manufacturing system to ensure that produced sleepers provide consistently formed surfaces and product composition. After production and cooling, sleepers are tested to assure mechanical property specifications.

Recent Rutgers improvements in the manufacturing process of the Rutgers sleeper technology, via global licensee Sicut Enterprises Ltd has led to a dramatic increase in the toughness of sleepers, improving the resistance to fracture during spike installation (**image 3**) and severe operational conditions. Sicut's UK manufacturing plant is the most

technologically advanced composite sleeper production plant that Rutgers has been involved with and builds on the lessons and improvements learnt from previous manufacturing set ups. Broadly, these innovations have led to improved toughness, surface flatness and increased strength and stiffness of the sleepers.

## LOW SLEEPER-BALLAST INTERACTION

As mentioned earlier, sleepers are expected to interact with the ballast and provide resistance to lateral rail movement. Unnoticed this factor can lead to a system failure. Sleeper-ballast interaction can be enhanced, as needed, by varying the surface roughness of the bottom and sides of the plastic composite sleepers. This characteristic is easily addressed by fabricating sleepers with Sicut's patented engineered surface patterns to increase the ballast interaction from 4.5kN to over 12kN surpassing that of wood sleepers and all without the need for a "break-in" period that inhibits train speeds on newly ballasted wooden sleepers. Furthermore, the Sicut conical shaped dimple pattern (**image 1**) is built into the body of the sleeper with a 12kN ballast interaction, whereas embossed designs applied after tie moulding protrude from the main body of the sleeper, with thin plastic, at sharp angles, limiting the ballast interaction below the Sicut dimple pattern.

## FIRE

The combustion energy associated with pure HDPE is approximately 45,600 kJ/kg (19,500 BTU/lb) with composite made of HDPE being less dense in burn energy. The wood ignition temperature ranges from 536 to 932 oF (280 to 500 oC), according to the Wood Handbook (4), with creosote treated sleepers igniting more easily than untreated wood sleepers. Even in their most susceptible powder form; HDPE, polypropylene, and polystyrene materials have ignition temperatures of 770, 788, and 932 oF (410, 420, and 500 oC), respectively, according to Mark's Standard Handbook for Mechanical Engineers (reference 5). Experiments conducted by Underwriters Laboratories in support of standards development for plastic lumber decking made from HDPE does not represent a greater fire hazard than wooden decks.

## CREEP (INCREASE OF GAUGE DUE TO AXIAL SLEEPER LOADING)

It is well established that polymers are viscoelastic in terms of their mechanical properties. That is to say, there is an immediate response by the material when stress is applied to it, followed by a time-dependent or viscous response.

The long-term creep performance of any plastic composite railroad sleeper obviously plays a major role in whether the rails will stay



Image 3: Spikes being driven into Sicut's tougher and more durable plastic sleeper



Image 4: SNCF installation in plain line track





Image 5: Sicut railway sleepers and bearers manufactured in the UK from recycled materials

in gauge over the long term. The creep in this case would be deformation due to stresses acting to separate the rails, acting in some fashion over a long time and/or over a large number of loading cycles.

Creep is not expected to be a problem in vertical loading situations, due to the low stresses imparted by these loads. All of the plastic composite sleepers tested to date have equal or higher compressive strengths and modulus values than oak in the vertical load orientation.

Furthermore, Rutgers researchers have developed a long-term creep predictive theory that uses short-term tests using whole stress strain curves at different strain rates to predict long term (25 year) creep that correlate with the only real data available (Findley's results). The stresses in the Rutgers sleeper are below the long-term creep stresses for the material.

## THERMAL EXPANSION

Heat related expansion can place a tremendous amount of stress on the sleeper, ballasts and rail anchors that keep the tracks

fixed to the ground. In relation to plastic based sleepers, the low thermal conductivity requires the use of average daily temperature variations through the seasons and using installation temperature in determining the effect of thermal expansion on gauge. Use of seasonal variation is due to the low thermal conductivity of the bulk composite body, meaning that even if the temperature outside the sleeper changes considerably on an hourly basis, it takes a considerable time for the temperature, and thereby the expansion, to penetrate the depth of the sleeper.

## DETERIORATION OF PROPERTIES DUE TO EXPOSURE TO THE ELEMENTS

The properties of the Rutgers composite sleepers do not deteriorate in the field. The base material utilized in these products is HDPE, which is moisture-proof, but which does slowly degrade under the influence of ultraviolet (UV) light from the sun at rates up to 0.0076 cm (0.003 in.) per year. The Rutgers sleeper formulations contain at least 60% HDPE by weight, and have been shown

to not lose any mechanical properties when exposed to cyclic moisture, temperature and UV radiation at levels equivalent to 15 years of exposure for wooden sleepers.

## CONCLUSIONS

The technology of plastic composite railway sleepers has advanced significantly over the past decade. Successful performance of plastic sleepers in actual rail service demonstrates that the technology works in various applications with 1.5 million sleepers installed in track with 25 years of in track performance data. The most important performance issues affecting safety have been identified and dealt with. The Rutgers sleeper technologies have grown to a point where the commercial application of these technologies is proven and ready for growth.

## REFERENCES

- [1] Lampo, R., T. Pinnick, and T. Nosker, "Development, Testing, and Demonstration of Recycled-Plastic Composite RR Crosssleepers," proceedings of DoD-sponsored Transportation 2000 Conference, San Antonio, TX, February – March 2000.
- [2] Gillespie, B., M. Lutz, T. Nosker, and D. Plotkin, "Development of a Recycled Plastic/ Composite Crosstie," American Railway Engineering Bulletin, No. 760, May 1997, Volume 98.
- [3] Zarembski, A., "Aging of Wood Sleepers and Associated Loss of Strength," Railway Track & Structures, August 1993, p 10.
- [4] Williams, R., "Finishing of Wood," Wood Handbook - Wood as an Engineering Material, Forest Products Society, Chapter 15, p 15-3.
- [5] Avallone, E., and T. Baumeister III, Mark's Standard Handbook for Mechanical Engineers, Ninth Edition, McGraw-Hill, 1986, pp 7-31 to 7-33.



Image 6: Railway bridge manufactured entirely from the same material technology used to make railway sleepers