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# Cost effective extension of service life of bridge tie (sleepers)- Effectively applying borate during Boulton conditioning and treatment with copper naphthenate

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# Cost effective extension of service life of bridge tie (sleepers)-Effectively applying borate during Boulton conditioning and treatment with copper naphthenate

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## ABSTRACT

Current longevity of creosote treated wooden bridge ties in the South Eastern US is about 15 to 25 years, which is well below of the average service life of 33-50 years of railroad ties. Such short service life increases costs associated with maintenance of railroads including bridge down time for tie replacement as well as the cost for the new ties themselves. Because of this, many railroads are seeking non-wood alternative ties, even at vastly elevated initial cost. The objective of the study was to see if it is possible to apply borate as part of a dual treatment with copper naphthenate, in order to increase the service life of wooden bridge timbers at minimal additional cost.

Green hardwood ties were ported, borate treated, and then Boulton treated with copper naphthenate at a commercial tie treatment plant in Pennsylvania. Diffusion of borate within the wood appeared to be significantly enhanced by the elevated temperature and steam generated during the Boulton cycle and subsequent pressure treatment with copper naphthenate. The achieved retention and penetration of borate and copper naphthenate met AWPA standard retentions and AREMA guidelines. The longevity of ties should be significantly increased by protecting the heartwood with disodium octaborate tetrahydrate (DOT) and the sapwood with copper naphthenate. The results suggested that hardwood ties can be successfully treated with borate during a Boulton cycle and should allow the continued effective use of sustainable wooden bridge timbers.

**Keywords:** bridge timbers, dual treatment, DOT, copper naphthenate

## 1. INTRODUCTION

Wooden railroad bridge ties have been used more than 100 years and many of them are still in service. Low initial cost, ease and expedient construction and ease of maintenance are advantages of bridge timbers (Uppal and Rizkalla, 1992). However, wood ties are subject to a variety of biological and physical degradation during service. Therefore, they are pressure treated with preservatives such as creosote and copper naphthenate to prevent biological deterioration. Typically, green wood ties are air-dried in stacks to below certain moisture content before preservative treatment. 4-8 months of drying time is required depending on wood species and climate of the location of the drying yard. Typically specified moisture contents are 50% for oaks (white oak, hickory and red oak) and 40% for mixed hardwoods (largely gum but most other hardwood species). After drying, ties are pressure treated with creosote or copper naphthenate. Green or partially dried ties can be Boulton conditioned to prepare them for impregnation without air seasoning. Although this requires very long treatment cycles, it is currently the industry standard for bridge ties.

Dual treatment of railroad ties using borate and creosote was first tried by the Malaysian railway in the 1960s (Arthur, 1967). Amburgey *et al.* (2003) demonstrated that dual treated ties last much longer than ties treated with creosote alone. Dual-treatment is especially effective on ties made with large heartwood and hard to treat wood species such as white oak and hickory. Borates in dual treated ties have been shown to penetrate and protect the otherwise untreated interior against wood-destroying organisms and protect wood around spikes from corrosion induced decay (Amburgey *et al*. 2003). In addition, borate treatment on green or partially seasoned ties (treated as a part of dual treatment, especially with two-step process) protects wood from incipient decay during storage and seasoning (Schoeman *et al.* 1997).

Dual treatments are typically performed in either a 'one-', 'one-and-a-half-', or 'two-step' process using traditional croeoste or copper naphthenate in oil. In 'one-step' process, a borate ester is dissolve in an oil-borne preservative and then the mixed borate and oil preservative system is used for pressure treatment. In the 'one-and-a-half' step process, the air-dried ties are empty cell treated with water soluble disodium octaborate tetrahydrate (DOT, typically with amine oxide) and then over-treated with creosote, or pressure treated green and subsequently boultonized, or steam conditioned and then over-treated (Taylor *et al*. 2013). In the two-step process, green ties are dip diffusion treated in high concentrations of DOT at elevated temperature, momentarily dipped in a high-concentration colloid (a micro-micelle emulsion) of borate in water at ambient temperature, or pressure treated with DOT solution. These borate pre-treated ties are then stacked, air dried and then pressure treated with coreosote or copper naphthenate. The retention of borate in this dual treatment has been standardized by the AWPA at 2.68 kg/m$^3$ of $B_2O_3$ (4.0 kg/m$^3$ of DOT) retention in a 3" assay zone (or by gauge).

Whilst dual treatments with DOT and even other borates have been widely commercialized in the USA for cross ties (sleepers), the benefits shown for these treatments would arguably be even more important for the larger and more expensive hardwood bridge ties and timbers. Due to their size, they are more difficult to treat and have more untreatable heartwood content than cross ties and this probably explains their shorter service life. However this same characteristic combined with the fact that most need to be Boulton conditioned and treated from 'green' wood of very high moisture content, make the current methods of dual treatment impractical as it is difficult to achieve adequate preservative retentions and penetration of either preservative system (the borate or the oil-borne treatment).

In the current research, DOT is to be delivered through a series of holes (ports) in the ties. The holes are filled with 45 % DOT as an aqueous mixture (available commercially as CelluTreat 50 DOT Borate Preservaive from Nisus Corporation, Rockford TN USA) and 40 % DOT in glycol (available commercially as Jecta or Bora-Care from Nisus Corporation) and then Boulton treated with copper naphthenate. The heat and pressure applied during boulton process expected to enhance diffusion of borate and thus protect inside of ties from decay or insects.

## 2. MATERIALS AND METHODS

Three timber species were selected for the initial test. They were sweet gum (*Liquidambar styraciflua*) , white oak (*Quercus alba*) and hickory (*Carya spp*.). The size of each tie was 10"x10"x10' (25 x 25 x 300 cm) for gum and oak and 10"x12"x10' (25 x 30 x 300 cm) for hickory.

Drilling patterns are as follow:

Gum and White oak: Drilled two 2” dia x 6” deep (5.1cm dia x 15.2cm deep) holes about two feet apart and two feet from the end; on the other end, four 13/16” dia x 6” deep (2.1 cm dia x 15.2 cm deep) holes were drilled. Sleeves were inserted prior to applying DOT. The holes had 45% DOT solution (obtained commercially as Cellutreat from Nisus Corporation) applied to them.

Hickory: Drilled two 2” dia x 6” (5.1cm dia x 15.2cm deep) deep holes about two feet apart and two feet from the end; on the other end, four 13/16” dia x 6” deep (2.1 cm dia x 15.2 cm deep) holes were drilled. Plastic sleeves were inserted prior to applying borates. One 2” (5.1 cm) dia hole was applied with 45% DOT solution while the other (inner one) was applied with 40% DOT in glycol (obtained commercially as Jecta® from Nisus Corporation). Three smaller holes were treated with 45% DOT solution while one hole was treated with 40% DOT in glycol. All sleeves were capped and the 2” (2.5cm) prototype caps were secured with a metal strap. One cap was left unsecured as an additional test. Figure 1 shows insertion of 7/8” (2.2cm) sleeves in the 13/16” (2.0cm) holes and figure 2 shows capped two inch holes.

Figure 1. Insertion of 7/8” (2.2cm) sleeves in the 13/16” (2.1cm) holes

Figure 2. Capped 2” (2.5cm) holes

The bridge ties with holes filled with 45% DOT solution and 40% glycol borate were Boulton conditioned then pressure treated at 190°F (88°C) with copper naphthenate (obtained commercially as QNAP from Nisus Corporation) in #2 Diesel meeting AWPA P9. Total charge time was 18hrs. After treatment, ties and holes were inspected.

Twenty days after treatment, the diffusion of borate from the holes were checked by first cutting ties in half cross-wise and then in a longitudinal direction (through the hole) to reveal fresh surfaces. Curcumin/salicylic acid was applied to reveal penetration and diffusion of borate

(Smith and Williams 1969). The tie sections were further cut into smaller pieces (0.5, 2.5 and 6 inch, 1.3, 6.4 and 15.2cm thick) cross-wise to reveal fresh cross sectional surfaces using a Wood-Mizer band saw. Between each cut, the saw was cleaned by cutting fresh wood that contained no DOT. The cross-cut tie sections were also tested with curcumin/salicylic acid and chromazurol-s. The diagram of cross cutting is shown in Fig 3. For each section, one freshly cross cut surface was curcumin/salicylic acid sprayed to check borate diffusion and penetration and the other surface was sprayed with chromazuro-s for detection of copper. The 0.5” (1.3cm) sections were further knife-milled for DOT extraction and subsequent quantification using potentiometric titration with sodium hydroxide following AWPA A40-07.

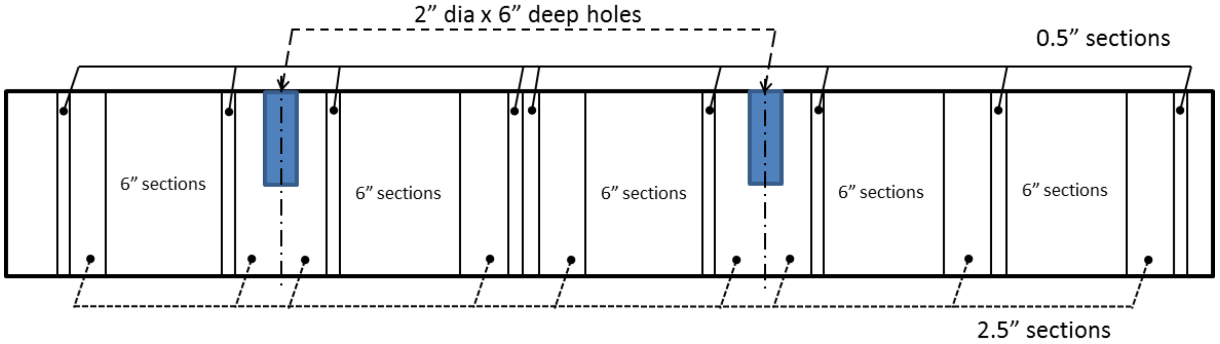


Figure 3. Diagram of tie showing cross-cut sections used for analysis.

## 3.RESULTS

After treatment, tie surfaces were clean and dry to the touch. Some slight signs of DOT residue were also observed around ports and in heart checks at tie ends (Fig. 4).

Figure 4. Bridge ties after Bouton treatment.

The unsecured cap on 2” (5.1cm) hole stayed in place (Fig 5). There were signs of a small amount of DOT on the surface around several holes. When the caps were removed, several holes were empty. One hole was full of CuNap and another hole was partially filled with CuNap.

There was no noticeable difference between the aqueous DOT and DOT in glycol regarding appearance of the ties.

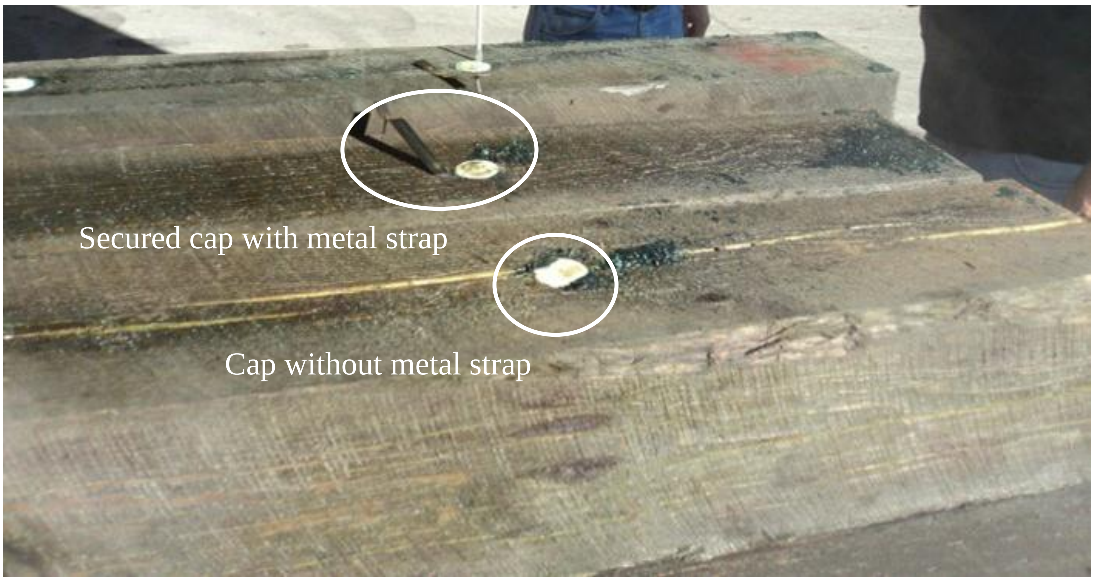


Figure 5. Cap on the third timber was not secured and the cap stayed in place after pressure treatment with QNAP.

The 2" (5.1cm) dia holes treated with aqueous DOT and DOT in glycol were also inspected. Several holes were empty but some were filled with CuNAp solution (Fig 6)

Figure 6. 2" (5.1cm) dia holes treated with aqueous DOT (left) or filled with CuNap solution (right)

Figure 7 shows the freshly cut (longitudinal) surfaces of three ties. Penetration and diffusion of DOT from the holes was significant as indicated by the red curcumin reagent.


Figure 7. Diffusion of DOT in freshly cut bridge tie. Significant longitudinal diffusion was observed.

Diffusion and penetration of DOT across the grain was also observed (Fig 8).

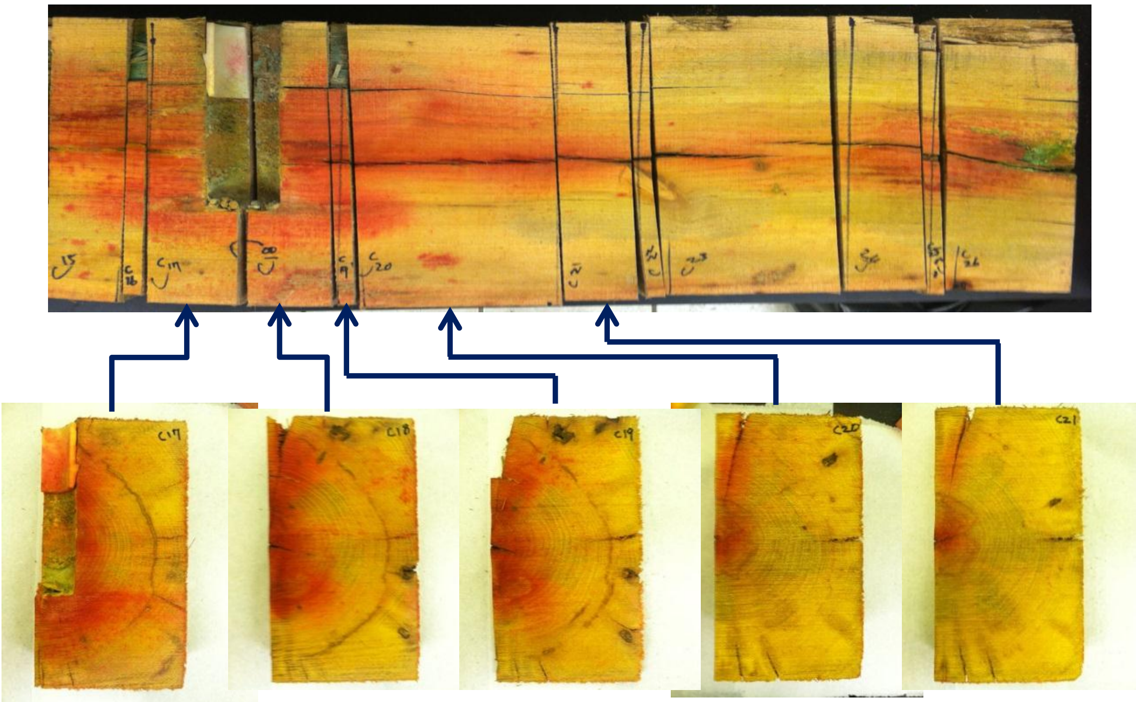

Figure 8. Part of a hickory bridge tie showing longitudinal surface (top) and corresponding sequential cross-sectional surfaces (bottom) tested with curcumin/salicylic acid.

DOT retentions are given in Table 1.

Table 1. Average retention of DOT from the whole tie section at three different locations from a 2” dia hole

| Species | Average % DOT | | |
|---|---|---|---|
| | 2.5” (6.4cm) from the center of hole | 11.5” (29.2cm) from the center of hole | 18” (45.7cm) from the center of hole |
| Gum | 0.50 | 0.15 | 0.10 |
| White oak | 0.48 | 0.23 | 0.08 |
| Hickory | 0.39 | 0.13 | 0.13 |
| Average of all species | 0.46 | 0.17 | 0.10 |

## 4. DISCUSSION AND CONCLUSIONS

From the results obtained it can be seen that good DOT retention and penetration can be achieved by treating via ports drilled in bridge ties and large timbers. Gauge retentions of DOT can simply be calculated using the amount of product applied to a number of certain sized ports. The subsequent Boulton treatment in copper naphthenate appeared to dramatically enhance DOT diffusion from these ports and the bridge ties had excellent distribution of DOT throughout much of the refractory heartwood. Diffusion of borate inside the tie appeared to be extensive in the longitudinal direction and also occurred in the radial and tangential directions. It is proposed that the penetration of DOT was driven by diffusion enhanced by the elevated temperature and steam generation during the Boulton cycle (steam is generated due to the combination of temperature and vacuum used in Boulton conditioning). DOT actually appeared to have travelled along heart checks within the bridge ties, serving as probable moisture evacuation routes. The achieved gauge retentions of copper naphthenate and borate met AWPA standards and AREMA guidelines (need to cite the standards and guidelines).

Cross-sectional chemical analysis of DOT within the wood at various distances from treatment ports also verified the curcumin qualitative results and demonstrated that gauge retentions of DOT would provide the same retentions by analysis throughout the bridge ties, assuming further diffusion and further distribution of DOT within the timber in service.

The authors would also like to propose that throughout the service life of the resulting dual treated bridge timber, DOT losses via slow leaching would be markedly reduced and so the performance over time increased further. Leaching is simply the reverse of diffusion and is also governed by concentration according to Fick’s Law. With this treatment, surface borate concentration is low to zero at the time that bridge ties would go into service and all of the concentration to drive diffusion (or leaching) is within the centre of the tie. Thus typical concentration curves across the cross section of wood are reversed when compared to wood treated in traditional pressure treatment or diffusion methods (e.g. compared to that shown by Smith and Williams, 1969).

The results demonstrate that hardwood ties can be successfully treated with dual treatment technology using DOT and copper naphthenate. It can be seen that the heartwood of these large dimensional timbers is now effectively treated with diffusible DOT preservative. Combining these results with those of tie life extension demonstrated by Amburgey and Saunders (2009) it can be concluded that the longevity of bridge ties in service will be dramatically enhanced, (possibly doubled), and it is hoped that this will allow the continued and effective use of sustainable hardwood bridge ties.

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