Louisiana Transportation Research Center

Final Report 14-1TIRE

Improvements to Highway Guardrail Assemblies

by

Todd Shupe

LSU

4101 Gourrier Avenue | Baton Rouge, Louisiana 70808
(225) 767-9131 | (225) 767-9108 fax | www.ltrc.lsu.edu

TECHNICAL REPORT STANDARD PAGE

1. Report No. **FHWA/LA.15/14-1TIRE**	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle **Improvements to Highway Guardrail Assemblies**	**5. Report Date** May 2016 **6. Performing Organization Code**	
7. Author(s) Todd Shupe, Professor	**8. Performing Organization Report No.**	
9. Performing Organization Name and Address Department of Civil and Environmental Engineering Louisiana State University Baton Rouge, LA 70803	**10. Work Unit No.** **11. Contract or Grant No.** LTRC Project No. 14-1TIRE DOTDLT1000031	
12. Sponsoring Agency Name and Address Louisiana Department of Transportation and Development P.O. Box 94245 Baton Rouge, LA 70804-9245	**13. Type of Report and Period Covered** **Final Report** **September 2014 – August 2015** **14. Sponsoring Agency Code**	
15. Supplementary Notes **Conducted in Cooperation with the U.S. Department of Transportation, Federal Highway Administration**		

16. Abstract

Highway guardrail assemblies play an important role in enhancing the safety of motorists. Guardrail assemblies contain three main components: (1) galvanized steel guardrail, (2) posts, and (3) blockouts. The purpose of the blockout is to increase the spacing between the rail and the post and thereby reduce the interaction of the vehicle with the post. It is essential that the blockouts are durable so that that the guardrail assembly can function properly. The goal of this study was to explore the feasibility of using recycled chromated copper arsenate (CCA)-treated wood to produce a composite blockout. This study had three tasks: (1) determine the properties of the raw materials, (2) production and testing of molded guardrail blockouts, and (3) conduct finite element analyses and design optimization. Decommissioned blocks were chemically analyzed and found to contain residual CCA that is consistent with over 10 years of service. The used bocks were shredded to particles, combined with polypropylene plastic, and used to make composite blockouts with varying amounts of wood, plastic, block density, and resin. Group 1 yielded superior results: internal bond strength, IB, (108 psi), modulus of rupture, MOR, (2,536 psi), modulus of elasticity, MOE, (440,250 psi), linear expansion, LE, (0.632 in.), and thickness swelling, TS, (12.6%). A finite element analysis conducted on this group revealed that a guardrail assembly comprised with wood/plastic blockouts should perform similar to one with solid wood blockouts. The development of the composite blockout will provide the motoring public and taxpayers a low-cost, high-performance blockout and enhance environmental stewardship. The success of the overall project will lead to the development of a durable, green composite blockout.

17. Key Words		**18. Distribution Statement** **Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.**	
19. Security Classif. (of this report) N/A	**20. Security Classif. (of this page)** N/A	21. No. of Pages 44	22. Price

Project Review Committee

Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

LTRC Manager
Walid R. Alaywan, Ph.D., P.E.
Senior Structures Research Engineer

Directorate Implementation Sponsor
Janice P. Williams, P.E.
DOTD Chief Engineer

Improvements to Highway Guardrail Assemblies

by

Todd Shupe
Principal Investigator

School of Renewable Natural Resources
Louisiana State University Agricultural Center
Baton Rouge, LA 70803

LTRC Project No. 14-1TIRE
DOTDLT1000031

conducted for

Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

May 2016

ABSTRACT

Highway guardrail assemblies play an important role in enhancing the safety of motorists. Guardrail assemblies contain three main components: (1) galvanized steel guardrail, (2) posts, and (3) blockouts. The purpose of the blockout is to increase the spacing between the rail and the post and thereby reduce the interaction of the vehicle with the post. It is essential that the blockouts are durable, so that the guardrail assembly can function properly. The goal of this study was to explore the feasibility of using recycled chromated copper arsenate- (CCA-) treated wood to produce a composite blockout. This study had three tasks: (1) determine the properties of the raw materials, (2) produce and test molded guardrail blockouts, and (3) perform finite element analyses and design optimization.

Decommissioned blocks were chemically analyzed and found to contain residual CCA that is consistent with over 10 years of service. The used bocks were shredded to particles, combined with polypropylene plastic, and used to make composite blockouts with varying amounts of wood, plastic, block density, and resin. Group 1 yielded superior results: internal bond strength, IB, (108 psi), modulus of rupture, MOR, (2,536 psi), modulus of elasticity, MOE, (440,250 psi), linear expansion, LE, (0.632 in.), and thickness swelling, TS, (12.6%). A finite element analysis conducted on this group revealed that a guardrail assembly comprised with wood/plastic blockouts should perform similar to one with solid wood blockouts. The development of the composite blockout will provide the motoring public and taxpayers a low-cost, high-performance blockout and enhance environmental stewardship. The success of the overall project will lead to the development of a durable, green composite blockout.

ACKNOWLEDGMENTS

The PI would like to acknowledge the technical assistance of Drs. Walid Alaywan, Project Manager, and V.J. Gopu, Associate Director, Louisiana Transportation Research Center. In addition, the PI would like to acknowledge Doug Arnold, President of Arnold Forest Products, Shreveport, LA for providing decommissioned CCA-treated wood blockouts.

IMPLEMENTATION STATEMENT

TIRE projects are exploratory in nature and are intended to aid young faulty in furthering their novel ideas. As such, the TIRE projects are not expected to result in implementable work.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Guardrail assemblies are an important means to increase the safety of highway travel. A typical installation includes a series of metal guardrail attached to wooden posts that are driven into the ground (Fig 1). The blockouts connect the wooden posts to the metal guardrail. Blockouts usually have a dimension of 6 x 8 x 14 in. and help absorb kinetic energy during a vehicular crash. Since steel blocks were proven ineffective based on NCHRP 350, the primary material for new blockouts is wood, which is frequently preservative treated with chromated copper arsenate (CCA) (Figure 1) *[1]*.

Figure 1
Highway guardrail assembly

This assembly shows wooden posts and blocks with the exception of one steel post in the forefront of the picture.

Non-wood blockouts have gained market share in recent years. However, a recent study found that CCA-treated wood guardrail posts offer notably lower environmental impacts for fossil fuel use (almost half), net greenhouse gas emissions (one-sixth), acidification (approximately half), and ecotoxicity (approximately half) relative to galvanized steel posts *[2]*.

Eventually, the posts and blockouts are decommissioned and are typically landfilled. The life span of guardrail assemblies is typically 5-6 years due to infrastructure improvements and mechanical damage through the states and municipalities are continually increasing regulations for landfilling treated wood. Therefore, this material continues to be landfilled because of the lack of a viable recycling system.

There are vast quantities of CCA-treated wood available for recycling purposes in Louisiana and throughout the U.S. Although the exact number of guardrail blockouts replaced on an annual basis is unknown, it is thought to be a substantial number.

Disposal of spent preservative-treated wood has increasingly become a major concern because of its residual preservative content. Popular waste disposal options for spent preserved wood, such as incineration and landfilling, are becoming expensive or even impractical because of increasingly strict regulatory requirements. Average landfill tipping fees in the U.S. increased from $8.20 per ton in 1985 to $32.20 per ton by 1995, according to surveys conducted by the National Solid Waste Management Association. In 2013, the U.S. average tipping fee was $49 per ton with a maximum of $91 per ton in Maine *[3]*.

The public has long been concerned about environmental issues related to the wood products industry. It is important for producers and purchasers of treated wood posts and blockouts that a recycling method be developed for CCA-treated wood that (1) provides low cost and high performance products and (2) is environmentally friendly. Thus, recycling of decommissioned blockouts and posts will keep toxic preservatives from entering the waste stream and is of great importance for environmental stewardship.

One of the direct recycling options for preserved wood is for composite manufacturing. Research results of Munson and Kamdem showed that particleboard made from 50% of furnish obtained from CCA-treated utility poles and 50% untreated wood displayed comparable durability properties with those made from entirely from untreated wood *[4]*. A preliminary study on composite guardrail blockouts was conducted by the PI. The materials used to fabricate blockouts were fresh untreated wood particles and urea-formaldehyde and isocyanate adhesives. The composite blockouts were molded in a steel mold at 350^{o} F for 60 min. The durability and strength test results showed that molded composite guardrail blockouts had the potential to be an alternative to solid wood blockouts. This study was a key advancement in the development of this product because traditional hot pressing techniques cannot be used to produce such a thick product. Additional research is necessary to use decommissioned CCA-treated wood, which is more difficult to bond that untreated wood, and to refine the process variables.

Reuse of decommissioned treated-wood provides the opportunity to extend its useful service life and represents the best environmental option. Utilization of treated wood to make guardrail blockouts converts the decommissioned treated wood to new composite treated wood products and extends the service life of the wood. It is expected that this technique would be welcomed by the guardrail post and blockout manufacturers and purchasers because it will reduce production costs in terms of wood material and lessen disposal costs.

OBJECTIVE

The goal of this study was to explore the feasibility of using recycled CCA-treated wood to produce a composite blockout for highway guardrails.

SCOPE

The scope of this work is new highway guardrail assemblies. This work does not pertain to existing highway guard assemblies.

METHODOLOGY

This study comprised three tasks: (1) determination of the properties of the raw materials, (2) production and testing of molded guardrail blockouts, and (3) performing finite element analyses and optimization design. Each task was conducted sequentially.

Task 1

Twenty decommissioned CCA-treated highway posts were recovered from two sites in Louisiana: (1) DeSoto Parish and (2) Ascension Parish (See Appendix, Fig. 15-16). Incremental cores were taken from each sample and the data obtained from the analysis of the cores is reported in Tables 1-2. The data indicates that the posts were properly treated in accordance with AWPA standards and were likely in service for over 10 years *[5]*. The posts were considered typical and representative of posts and blockouts that are decommissioned for infrastructure improvements.

Task 2

The spent posts were crushed by a roller machine at Arnold Forest Products Co. (Shreveport, LA) and then harmer-milled to fine particles. Recycled polypropylene pellets with a melting point of 250° F were commercially obtained. Blocks measuring 14 x 7.5 x 3 in. were produced in the laboratory using compression molding. Three groups were produced: (1) wood 75%, Polypropylene (PP) 25%, Urea Formaldehyde (UF) 8%, Isocyanate (ISO) 1%, 53 pcf; (2) wood 75%, plastic 25%, UF 8%, ISO 1%, 43 PCF; and (3) wood 87.5, plastic 12.5%, UF 8%, ISO 1%, 43 PCF. Blocks were pressed at 400° F, close to 150 tons, 15 min. press time. Six replications were made of each group. Samples were cut and tested in accordance with ASTM standards for internal bond (IB), modulus of rupture (MOR), bending modulus of elasticity (MOE), linear expansion (LE), and thickness swelling (TS).

Task 3

A single car vehicle collision was simulated as presented in Figure 2. In this case, a vehicle has crashed into the guardrail at a 30° angle in the horizontal plane. Group one from Task 2 was chosen as the blockout for the rail assembly. For simplicity, the car was simulated as a rigid ball; the diameter of the ball equaled to the bumper height. In the simulation process, only the translational degree of the ball was considered and the self-rotational degree was ignored. The dimensions of a typical highway guardrail assembly are presented in Figure 3. The key guardrail components include post, block, bolt, and double corrugated guardrail. The post was assumed to be typical southern pine solid wood and the block was assumed to be Group 1 (see Task 2). The bolts and double corrugated guardrail were assumed galvanized steel. The deformation of the parapets and columns as well as the energy conversion was calculated.

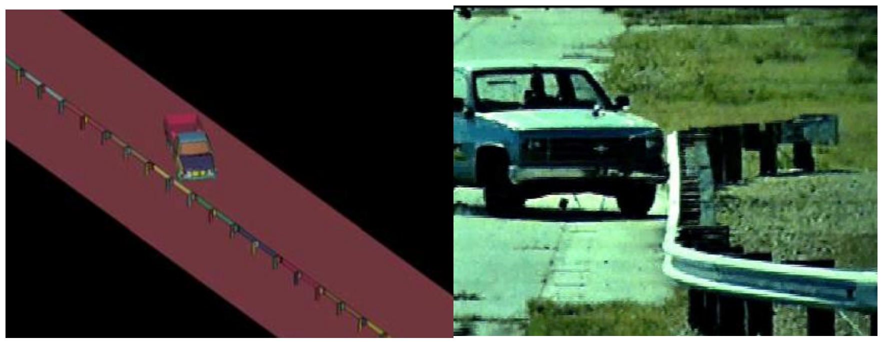

Figure 2
Vehicle collision presentation

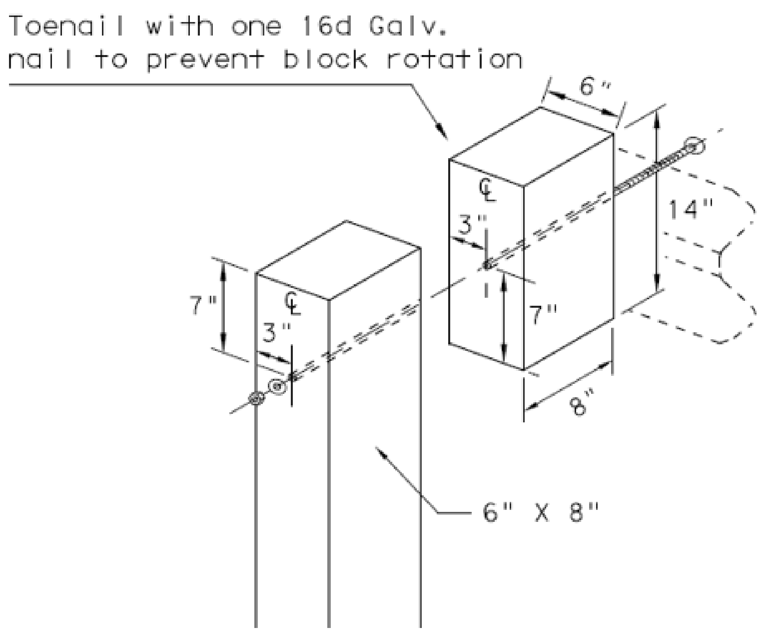

Figure 3
Dimensions of posts, blocks, bolts, and guardrails used in the simulation process

The finite element mesh and modeling were conducted with the ABAQUS software. The post and block model and finite element mesh are shown in Figures 4-6. Figure 7 shows the whole mesh and model of the highway guardrail being impacted by the ball. The C3D8R unit was selected for this model.

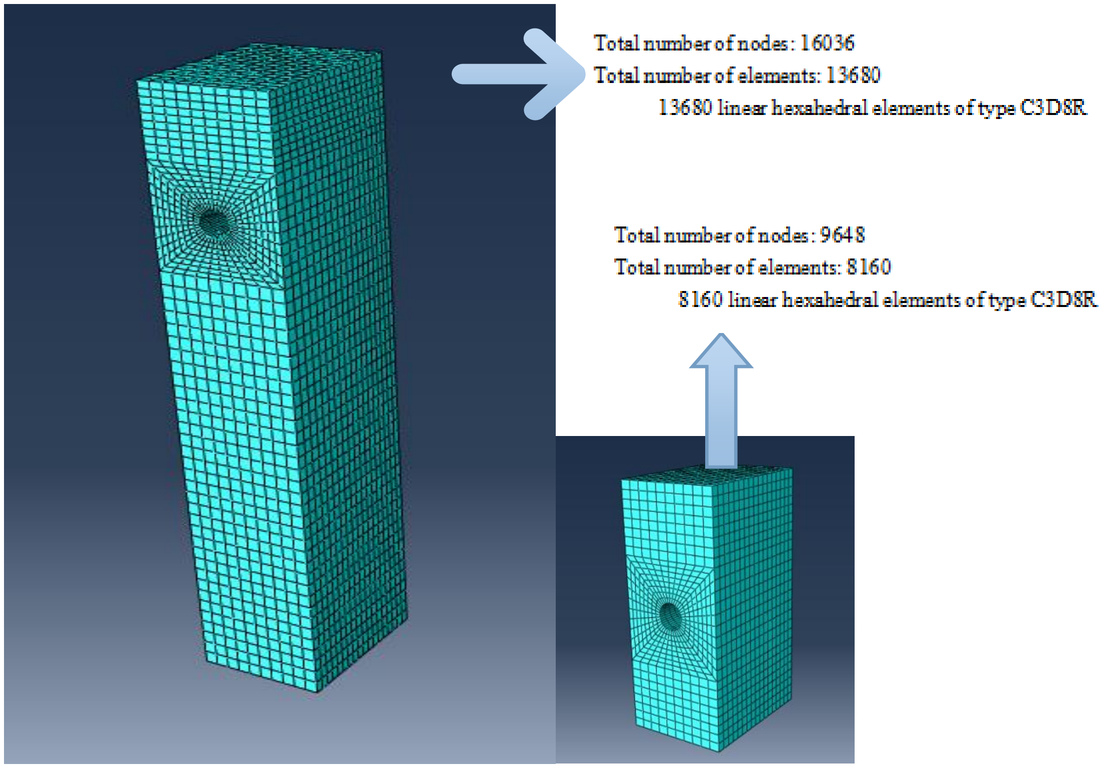

Figure 4
Finite element meshing and model of post and block

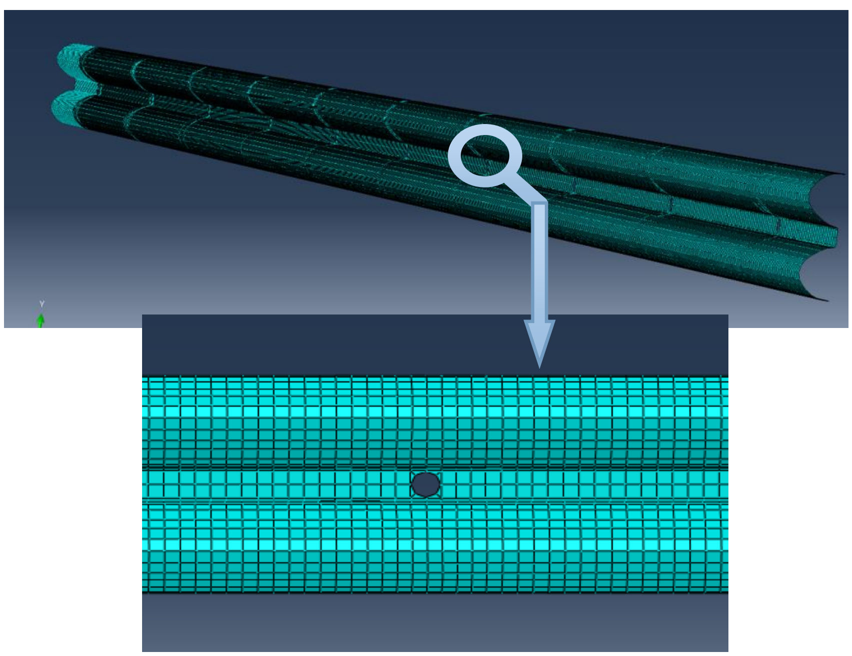

Figure 5
Mesh and model of guardrail

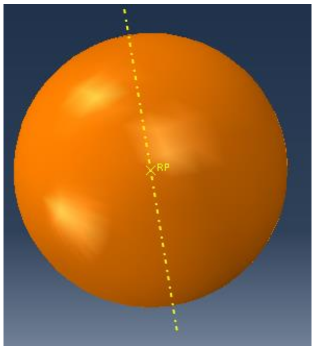

Figure 6
Rigid ball (weight 1.5 ton and speed of 20m/s)

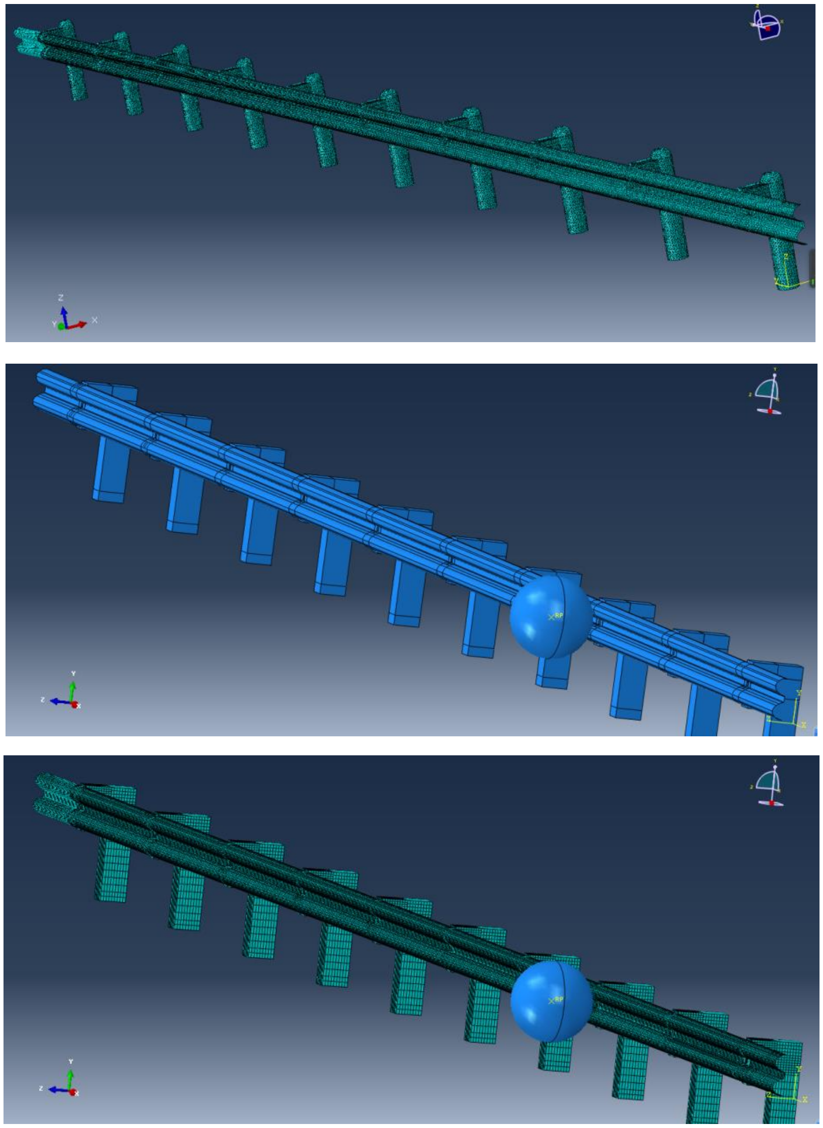

Figure 7
A whole mesh and model of the highway guardrail

DISCUSSION OF RESULTS

Task 1

Decommissioned CCA-treated posts were collected from two Louisiana sites and analyzed for residual preservative content and density (Table 1-2). The residual preservative content for the Ascension Parish site was 0.30 pcf of Chromium Trioxide (CrO_3), 0.11 pcf of Copper Oxide (CuO), and 0.20 pcf of Arsenic Pentoxide (AS_20_5). The residual preservative content for the DeSoto Parish site was 0.301 pcf of CrO_3, 0.11 pcf of CuO, and 0.19 pcf of AS_20_5. All samples from both sites, with the exception of one from DeSoto Parish, showed excellent heartwood penetration (82-100%). These data indicate that the wood (1) was properly treated, (2) demonstrated minimal leaching in service, and (3) is representative of typical decommissioned CCA-treated wood.

All posts for both sites were determined to be in excellent condition based on the visual inspection. There was no indication of decay. The visual inspection of all of the incremental cores from both sites indicated sound wood and no presence of decay.

The cores from the Ascension Parish site had excellent penetration because they were taken from round stock, which typically shows better preservative penetration due to a smaller and well-centered heartwood zone as compared to rectangular stock. The retention analysis for the Ascension Parish site showed CrO_3, CuO, and As_2O_5 to be 0.300, 0.113, and 0.195 pcf, respectively. The total pcf was found to be 0.608. All metals were in balance according to AWPA P5-09 (2).

The cores from the DeSoto Parish site (rectangular posts) had good penetration. Three samples showed no penetration due to the absence of sapwood in the cores. The retention analysis for the DeSoto Parish site showed CrO_3, CuO, and As_2O_5 to be 0.301, 0.109, and 0.192 pcf, respectively. The total pcf was found to be 0.602. All metals were in balance according to AWPA P5-09 (2).

AWPA T1-09 allows for a charge to be accepted if 80% of the material sampled satisfies the penetration requirement of 2.0 inches or 85% of sapwood *[5]*. The posts with no penetration still had adequate preservative retention to allow for excellent long-term durability. An incremental core in a different location likely would show some penetration and in fact, the increment taken for analysis had slight penetration but was judged to be zero for simplicity.

If it is assumed that the posts were treated to applicable AWPA standards at the time of installation (0.60 pcf), it is seen that there has been extremely little, if any, leaching. This finding is consistent with the previous research done on long-term leaching of CCA in ground contact. In short, there may be a small, insignificant amount of initial leaching (approximately 2 months) but virtually no leaching is also common *[6]*.

These minor deviations are largely attributable to differences in fixation that may be used in the studies as well as site variability (climate and soil) and also differences in individual samples. CCA works extremely well in real-world exposures.

The common CCA toxic threshold for most organisms is 012-0.18 pcf. The exception is white rot fungi attacking hardwood. The threshold for these organisms with hardwood is much higher due to more difficult fixation and micro-distribution in hardwoods *[7]*.

A comprehensive study on long-term CCA treated southern pine wood was published by Woodward et al. with the USDA Forest Products Lab *[8]*. They reported of the waterborne preservatives in tests that contain copper and arsenic (24 to 61 years in Mississippi), and concluded that the formulations of chromated copper arsenate (CCA) are better performers with only 30% failures using retention levels of 0.29 pcf (oxide basis) or 20% using 0.44 pcf or greater for CCA. It should be noted that larger sized members, such as posts and poles, almost always perform better than the smaller sized stakes used in this study. They reported on the average life of 0.26 pcf treated CCA Type 1 2 x 4 treated samples to be 28.7 years. All of these CCA formulations are salt formulation and not the oxide formulation used today. Lebow et al. showed excellent ratings and no failures for 1.5 x 3.5 in. CCA-C treated at both 0.2 and 0.4 pcf southern pine field stakes after 35 years of exposure in Saucier, MS *[9]*.

Task 2

Figures 8A-C illustrate some examples of the compression-molded blocks that were fabricated. Figures 9-11 show the MOR, MOE, and IB, respectively, of the test groups. Group 1 provided the highest values for all three mechanical properties. However, this finding is likely due to the higher density of Group 1. It is well established that most mechanical properties are well correlated with wood density. Therefore, from a logistics perspective Groups 2 and 3 merit consideration. These groups will be easier to handle and cheaper to transport in bulk. It is noted that AASHTO has no mechanical requirements for highway blockouts *[10]*. The blockout serves as an integral part of a guardrail assembly by securing the guardrail to the post. It is essential that the post yield the soil in the event of a vehicular accident.

Future testing on all groups should determine mechanical properties following the ASTM accelerated weathering protocol. This will provide an indication of the ability of the groups to maintain long-term structural stability in service.

Figure 8A
Guardrail block (side view)

Figure 8B
Guardrail block (side view)

Figure 8C
Guardrail block (side view)

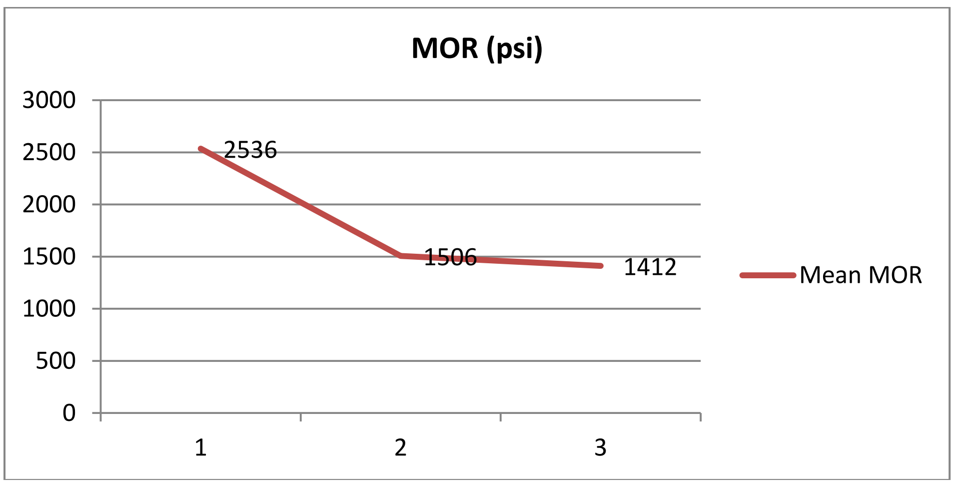

Figure 9
Flexural Modulus of Rupture, MOR, of the three experimental groups

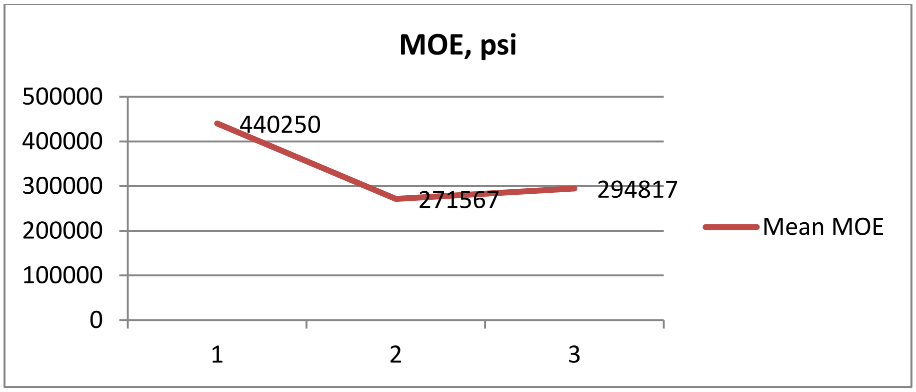

Figure 10
Flexural Modulus of Elasticity, MOE, of the three experimental groups

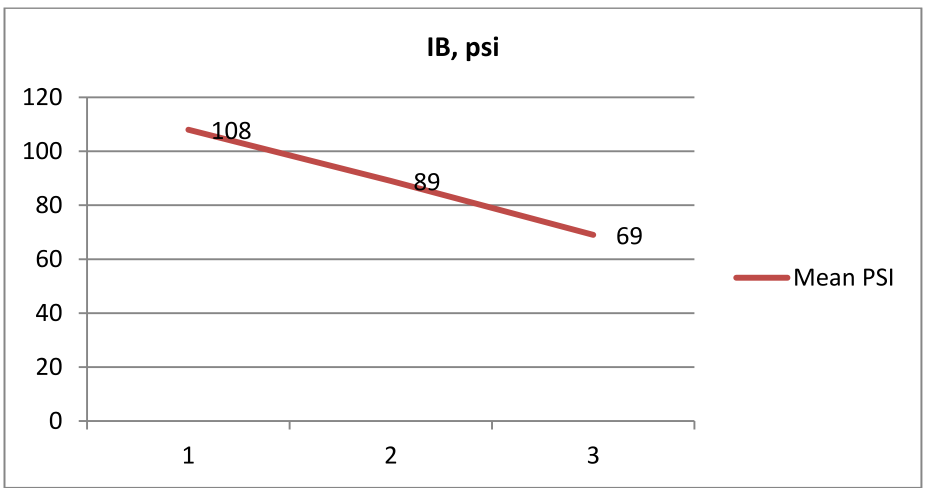

Figure 11
Internal bond strength, IB, of the three experimental groups

Task 3

The results of the finite element analysis are presented in Figures 12-14. Figure 12 shows the simulation of the impact stress. Figures 13-14 show the static stress distribution and static simulation displacement, respectively.

The initial impact energy ALLKE was calculated as following:

$$ALLKE = \tfrac{1}{2} mv^2 = 300\ kJ$$

where, ALLKE is the kinetic energy of the ball, ALLIE is the strain energy. The kinetic energy value of the rigid ball is a constant, i.e., 300 KJ.

Based on this simplified analysis, the impact energy was mainly absorbed by the guardrail and deformation of the post and block. A finite element model of the deformation and energy conversion was established. During the simulation, the rigid ball bounced back with a lower speed after collision into the guardrail. In the collision process, the deformation energy was less than the initial kinetic energy, while the final deformation energy and the final kinetic energy were equal to the initial kinetic energy.

In this analysis, the performance of a guardrail assembly featuring wood composite blockouts was no different than previous analyses by others of traditional assemblies with solid wood blockouts *[11]*.

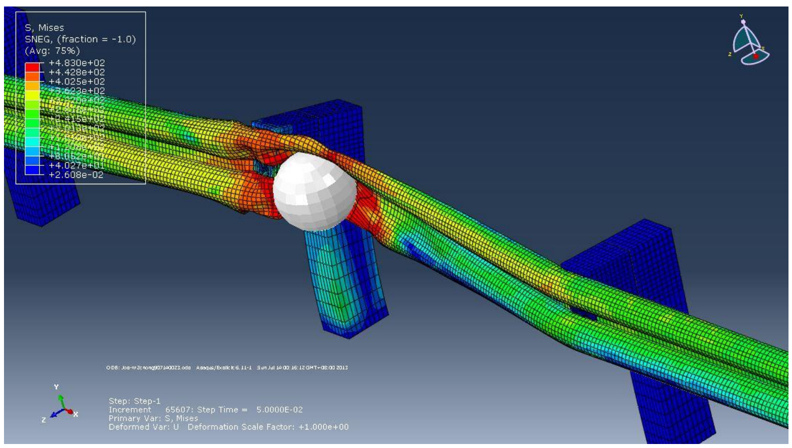

Figure 12
Simulation of impact stress

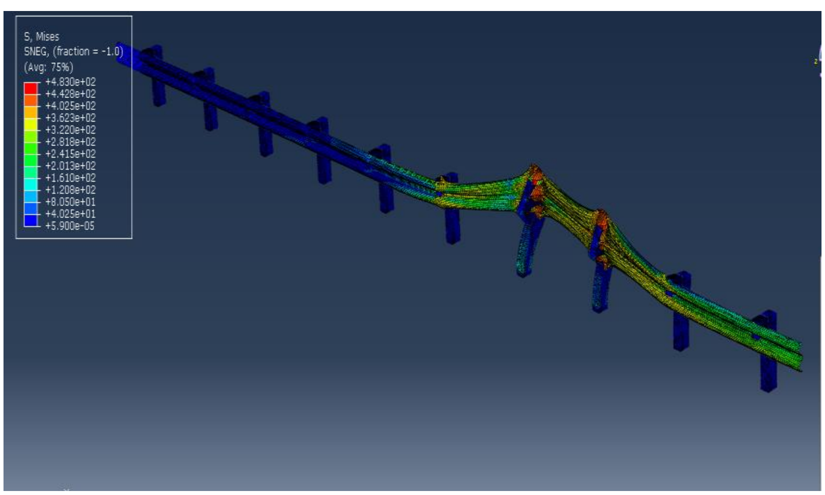

Figure 13
Static simulation results of von Mises stress distribution

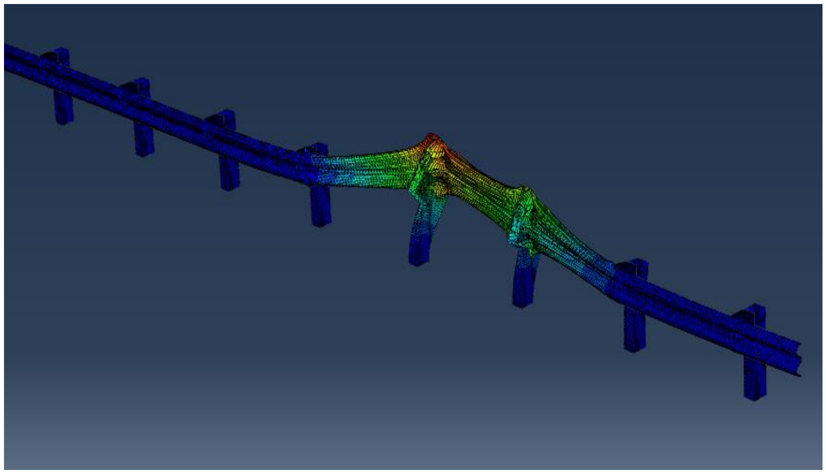

Figure 14
Static simulation displacement

CONCLUSIONS

This study has shown that highway guardrail blockouts can successfully be produced from recycled CCA-treated wood. The material used to produce the blockouts was well treated and can be considered typical of the available resource. Three unique groups of composite blockouts were manufactured. Group 1 provided the highest values for all three mechanical properties.   However, this finding is likely due to the higher density of Group 1. The findings of a simple finite element analysis of a guardrail assembly featuring wood composite blockouts was no different than previous analyses conducted by others of traditional assemblies with solid wood blockouts.

RECOMMENDATIONS

Future testing on all groups should determine mechanical properties following the ASTM accelerated weathering protocol. This will provide an indication of the ability of the groups to maintain long-term structural stability in service.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
AWPA	American Wood Protection Association
CCA	chromated copper arsenate
cm	centimeter(s)
DOTD	Louisiana Department of Transportation and Development
^{o}F	Fahrenheit
FHWA	Federal Highway Administration
Fig.	Figure
ft.	foot (feet)
IB	internal bond
in.	inch(es)
ISO	isocyanate
KJ	Kilojoule
LTRC	Louisiana Transportation Research Center
lb.	pound(s)
m	meter(s)
min.	minute(s)
MOE	modulus of elasticity
MOR	modulus of rupture
NCHRP	National Cooperative Highway Research Program
pcf	pounds per cubic foot
psi	pounds per square inch
PF	phenol formaldehyde
PP	polypropylene
psi	pounds per square inch
UF	urea formaldehyde
v	velocity

REFERENCES

1. National Cooperative Highway Research Program. NCHRP Report 350 “Recommended Procedures for the Safety Performance Evaluation of Highway Features.” Transportation Research Board, National Research Council, National Academy Press, 1993.

2. Bolin, C.A. and Smith, S.T. “Life Cycle Assessment of CCA-Treated Wood Highway Guard Rail Posts in the US with Comparisons to Galvanized Steel Guard Rail Posts.” *Journal of Transportation Technologies*. Vol. 3, pp. 58-67. 2013.

3. Repa, E.W. and Blakey, A. “Municipal Solid Waste Disposal Trends: 1996 Update.” Washington, DC. Environmental Industry Associations. 1996.

4. Munson, J.M. and. Kamdem, D.P. “Reconstituted Particleboards from CCA Treated Red Pine Utility Poles.” *Forest Products Journal*, Vol 48, No. 3, pp. 55-62, 1998.

5. American Wood Protection Association. AWPA *Book of Standards*. Birmingham, AL., 2009.

6. Lebow, ST., Lebow, P.K. and. Foster, D.O. “Environmental Impact of Preservative-Treated Wood in a Wetland Boardwalk.” FPL-RP-582, USDA For. Serv. Forest Products Lab, 2000.

7. Freeman, M. Personal Communication with T. Shupe on May 21, 2015.

8. Woodward, B.M., Hatfield, C.A. and Lebow, S.T. “Comparison of Wood Preservatives in Stake Tests 2011 Progress Report.” FPL-RN-02, USDA For. Serv. Forest Products Lab, 2010.

9. Lebow, S., Hatfield, C., and Woodward, B. “Long-Term Durability of CCA and ACA: How is 0.4 doing?” Proceedings of American Wood Protection Association. Vol. 106, pp. 174-183. 2010.

10. AASHTO. *LRFD Bridge Design Specifications*, American Association of State Highway and Transportation Officials. Washington, D.C. 2015.

11. Bligh, R.P., Abu-Odeh, A.Y., Hamilton, M.E., Seckinger, N.R. “Evaluation of Roadside Safety Devices Using Finite Element Analysis.” Report No. FHWA/TX-04/0-1816-1, Texas Transportation Institute. Austin, TX. 2004.

APPENDIX

Table 1
Incremental core analysis from Ascension Parish site

Sample #	Sapwood in.	Heartwood in.	Penetration in.	Percent
1	0-2.50	2.50-4	2.50	100.0
2	0-3.25	3.25-4	3.25	100.0
3	0-3.00	3.00-4	3.00	100.0
4	0-1.75	1.75-4	1.75	100.0
5	0-2.00	2.00-4	2.00	100.0
6	0-3.50	3.50-4	3.50	92.9
7	0-3.25	3.25-4	3.25	92.3
8	0-3.00	3.00-4	3.00	100.0
9	0-2.25	2.25-4	2.25	100.0
10	0-3.25	3.25-4	3.25	100.0
11	0-2.50	2.50-4	2.50	90.0
12	0-2.00	2.00-4	2.00	100.0
13	0-2.75	2.75-4	2.75	100.0
14	0-3.25	3.25-4	3.25	92.3
15	0-3.00	3.00-4	3.00	100.0
16	0-2.25	2.25-4	2.25	100.0
17	0-2.50	2.50-4	2.50	100.0
18	0-2.50	2.50-4	2.50	100.0
19	0-3.25	3.25-4	3.25	100.0
20	0-2.75	2.75-4	2.75	100.0
Mean			2.73	98.4

Analysis By Oxford Lab - X

Compound	Retention	% Balance
CrO_3	0.300 pcf	49.3
CuO	0.113 pcf	18.6
AS_20_5	0.195 pcf	32.1
Totals	0.608 pcf	100.0

Table 2
Incremental core analysis from DeSoto Parish site

Sample #	Sapwood in.	Heartwood in.	Penetration in.	Percent
1	0-2.00	2.00-4	2.00	100.0
2	0-3.00	3.00-4	3.00	100.0
3	0-1.00	1.00-4	1.00	100.0
4	0-4.00		3.50	87.5
5	0-2.00	2.00-4	2.00	100.0
6	0-3.00	3.00-4	3.00	100.0
7	0-2.25	2.25-4	2.25	100.0
8	0-1.50	1.50-4	1.50	100.0
9	0-3.25	3.25-4	3.25	92.3
10	0-2.00	2.00-4	2.00	100.0
11	0-0.00	0.00-4	0.00	0.0
12	0-1.25	1.25-4	1.25	100.0
13	0-2.25	2.25-4	2.25	100.0
14	-	-	-	-
15	0-0.00	0.00-4	0.00	0.0
16	0-1.75	1.75-4	1.75	100.0
17	0-1.50	1.50-4	1.50	100.0
18	0-0.00	0.00-4	0.00	0.0
19	0-3.50	3.50-4	3.50	85.7
20	0-3.00	3.00-4	3.00	100.0
Mean			1.93	82.4

Analysis By Oxford Lab - X

Compound	Retention	% Balance
CrO_3	0.301 pcf	50.0
CuO	0.109 pcf	18.1
AS_20_5	0.192 pcf	31.9
Total	0.602 pcf	100.0

Figure 15
Test site in Ascension Parish, LA

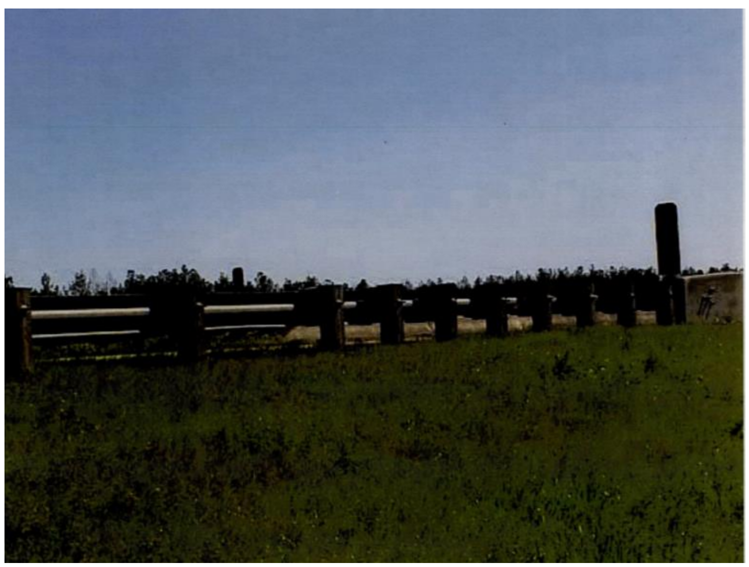

Figure 16A
Test site in DeSoto Parish, LA

Figure 16B
Test site in DeSoto Parish, LA

This public document is published at a total cost of $250
42 copies of this public document were published in this first printing at a cost of $250. The total cost of all printings of this document including reprints is $250. This document was published by Louisiana Transportation Research Center to report and publish research findings as required in R.S. 48:105. This material was duplicated in accordance with standards for printing by state agencies established pursuant to R.S. 43:31. Printing of this material was purchased in accordance with the provisions of Title 43 of the Louisiana Revised Statutes.