



SUMMARY AND RECOMMENDATIONS OF RECYCLED MATERIALS IN ROADSIDE SAFETY DEVICES

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16. Abstract In response to the increased interest in the use of recycled materials such as plastics, rubber, paper, and glass, etc., the Texas Department of Transportation (TxDOT) sponsored project 0-1458, entitled "Recycled Materials in Roadside Safety Devices." The purpose of this project was to investigate and explore the use of recycled materials in roadside safety applications with the goal of product implementation. This report summarizes a three-phase research program intended to evaluate the use of recycled materials in roadside safety devices. In the first phase, information regarding recycled material manufacturers and their products was acquired through an extensive literature review and survey of research organizations, state and federal transportation agencies, professional and trade societies, and manufacturers. In the second phase of this project, products were further evaluated through a series of static and dynamic laboratory tests. The testing focused on the applications of Type III barricades, guardrail posts, guardrail offset blocks, and sign supports which were identified as areas with high potential that lacked suitable recycled alternatives. The products showed a wide range in behavior due to different material compositions. Phase III consisted of full-scale crash testing of selected products to validate laboratory results, verify their crashworthiness, and assist with the development of performance specifications. Three products were evaluated for use as temporary sign supports. Another product was evaluated for use as guardrail posts and offset blocks in strong post W-beam guardrail. Performance specifications were prepared for these applications and are included as appendices in the summary report.			
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IMPLEMENTATION RECOMMENDATIONS

Based on the results of this research project, the authors propose the following recommendations for TxDOT:

1. In Phase I of this project, a number of products were identified for implementation. Applications in which products were identified as suitable include: barricades, traffic cones, channelizing drums, delineator posts, guardrail offset blocks, guardrail posts, and sign blanks. The recommendations were based on information provided by manufacturers and state agencies. The evaluation was based primarily on their recycled content, ability to meet nationally recognized safety standards, and field experience reported by other agencies.

A list of commercially available roadside safety products manufactured in part or in whole from recycled materials and considered suitable for experimental implementation is presented in Table 1. The products are categorized by application area and are listed by manufacturer and product name as well as material type. For some of these products, information regarding long-term performance and durability is lacking. It is therefore recommended that these products initially be implemented and monitored on an experimental basis. If in-service performance is judged to be satisfactory, the devices could then be upgraded to full operational status.

Factors such as cost, availability, and ease of handling should be considered in the final selection of products for applications in which more than one product is recommended. These factors were not considered in the initial evaluation due to lack of information in these areas. The project panel was provided with detailed information (e.g., description, function, cost, contact source, product literature, etc.) for the implementable products identified under Phase I. The information was requested to assist with implementation and for inclusion on a CD-ROM on available recycled products being developed by the General Services Division for use by the districts. Since the completion of Phase I, additional products have continued to enter the market. Later project phases updated the list of recycled products presented in Table 1 to include these new products. It should be noted that this list may not be all-inclusive in some application areas.

2. Hollow profile lumber manufactured with recycled plastic was evaluated for use as vertical supports and horizontal rail members in work zone barricades. Generic Type III barricade designs incorporating these products were developed under this project and successfully crash tested under another research project (5). Since full-scale crash testing demonstrated that standard wooden Type III barricades were unacceptable, these alternate designs manufactured from readily available, cost-effective recycled materials filled a critical need for TxDOT. The same recycled products and design concepts were subsequently extended to generic Type I barricades and short-duration temporary sign supports (7). All of these designs have been implemented by the department through revised “BC Standards” and the “Compliant Work Zone Traffic Control Device List.”
3. Three recycled sign support candidates were successfully crash tested and are considered suitable for implementation in temporary work zone applications from a crashworthiness perspective. However, Phase II testing indicated that these and other recycled plastic products have a relatively low stiffness. Therefore, the allowable sign area for each support should be appropriately limited to comply with both strength and serviceability requirements. The serviceability criteria should be based on sign legibility and reflectivity for the design wind (service) load. A performance specification for recycled content sign supports is presented in Appendix B for consideration and possible implementation after an appropriate field review period.
4. Testing performed under Phase II of this project indicates that most solid recycled plastic products will have sufficient compressive strength to perform acceptably as guardrail offset blocks. A solid offset block manufactured from 100 percent recycled HDPE was successfully crash tested under this project. Other offset blocks manufactured from a variety of recycled materials have been successfully tested by the private sector. A list of approved offset blocks is provided in Table 1. These recycled offset block alternatives can be implemented at the discretion of TxDOT. It should be noted that the approval of these products is based on safety performance. Information regarding long-term durability is not available. A performance specification for guardrail offset blocks is presented in Appendix A.

5. This project conducted a full-scale test on a guardrail system constructed with recycled plastic posts and block outs. The guardrail post product was selected based on its strength, price, and availability. It was comprised of recycled HDPE and chopped fibers. During the test, the guardrail ruptured as a result of vehicle pocketing. Subsequent analysis indicated that the flexural strength of the posts was 30 percent lower than expected due to the presence of voids and impurities. The results emphasize the need for monitoring and quality control of structural products manufactured from recycled materials. Because the guardrail post did not conform to specifications, the validity of the proposed performance specification presented in Appendix C could not be evaluated. Therefore, full-scale crash testing is still recommended for evaluating the performance of recycled content guardrail posts. The performance specification for recycled content guardrail posts can be used in part or as a guide to assist in the development of recycled posts prior to full-scale crash testing. As further experience is gained, the validity of the specification can be evaluated.

I. INTRODUCTION

STATEMENT OF PROBLEM

Rising costs have resulted in many products being recycled rather than buried in landfills. These recycling activities have resulted in large quantities of inexpensive materials that are ready for use in other applications. Products manufactured from recycled materials are becoming economically competitive with the original highway safety appurtenance counterparts in many instances.

Increased concerns for the environment have also influenced the use of recycled materials. The depletion of natural resources, space limitations of existing landfills, and health hazards associated with the material disposal are some of the primary reasons for the increased interest in the use of recyclable materials. Roughly 4.6 billion tons of non-hazardous solid waste materials are produced annually in the US (1). Domestic and industrial wastes constitute almost 600 million tons of this total. Wastes such as scrap tires, glass, and paper are receiving increased attention by state agencies, research organizations, and manufacturers. Although plastics constitute only 7 percent of the solid waste by weight, they comprise approximately 12 to 20 percent of the total volume (2).

Various roadside safety devices have become candidates for use of recycled materials. These devices include but are not limited to guardrail posts, rail-to-post offset blocks, sign supports, work zone traffic control devices, energy absorbing elements in crash cushions, and end treatments.

The number and cost of these devices installed and replaced annually is significant and the potential exists for effecting a measurable and positive impact on environmental problems in a cost-effective manner. However, further investigations are needed to determine basic properties of existing recycled materials and products, how they compare with the nationally recognized safety performances, and the practicality of the application in terms of safety, availability, cost, durability, etc.

OBJECTIVE OF PROJECT

In response to the increased interest in the use of recycled materials, TxDOT sponsored Project 0-1458, "Recycled Materials in Roadside Safety Devices." The purpose of this project is to investigate and explore the use of recycled materials in roadside safety applications. More specifically, the objectives of this project can be summarized as follows:

- identify existing or commercially available roadside safety products manufactured in part or whole from recycled materials and evaluate their suitability for implementation,
- determine fundamental properties of selected recycled materials and products considered candidates for use in roadside safety systems,
- evaluate the compliance of selected materials and products with nationally recognized safety performance standards, and
- develop recommended performance standards and specifications for selected applications.

It should be noted that although mechanical properties for various recycled plastics blends and commingled products are known, the wide variations in chemical compositions, processing techniques, and admixtures preclude the development of a set of material specifications for a given application. Therefore, it becomes necessary to develop performance specifications based on a series of standard test procedures.

SCOPE AND RESEARCH APPROACH

This report summarizes a three-phase research program intended to evaluate the use of recycled materials in roadside safety devices. In the first phase, information regarding recycled material manufacturers and their products was acquired through an extensive literature review and survey of research organizations, state and federal transportation agencies, professional and trade societies, and manufacturers.

In the second phase of this project, those products lacking the desired data to make a conclusive decision regarding their suitability for implementation were further evaluated through a series of static and dynamic laboratory tests. These tests were used to verify that a material met basic service requirements prior to running dynamic pendulum tests. For those products displaying inadequate performance compared to the baseline performance, necessary

improvements were made in collaboration with the manufacturer. As a result, several second- and third-generation products were submitted by the manufacturers for testing and evaluation. The Phase II test data were used to prioritize and select the most promising recycled materials and products for selected applications for further investigation of their impact performance under Phase III of this project.

Phase III consisted of full-scale crash testing of selected products to validate laboratory results, verify their crashworthiness, and assist with the development of performance specifications. The project evaluated three products for use as temporary sign supports. It looked at another product for use as guardrail posts and offset blocks in strong post W-beam guardrails. Researchers prepared performance specifications for these applications.

II. SUMMARY OF RESEARCH FINDINGS

PHASE I

Environmental concerns, declining disposal capacity, legislative mandates, economic considerations, and conservation efforts have begun to influence policies on the recycling of various waste materials and by-products. While the volume of waste continues to grow, approval of facilities for waste processing and disposal is becoming more difficult to obtain due to public concerns and increasingly restrictive environmental regulations. As a result, many manufacturers are now attempting to recycle and market plastics and other materials for a variety of widespread applications, including various roadside safety appurtenances and work-zone traffic control devices.

Researchers obtained information regarding existing products manufactured in part or in whole from recycled materials through an extensive computerized literature review and survey of research organizations, government/state agencies, professional and trade societies, and manufacturers. Roadside safety applications which were evaluated include: guardrail support posts, rail-to-post offset blocks, sign blanks and their supports, flexible delineator posts, and work zone traffic control devices such as channelizing drums, traffic cones, and barricades.

The information was summarized and categorized into two distinct areas:

(1) commercially available roadside safety products and traffic control devices having the potential for immediate implementation, and (2) other products and materials not specifically designed for use in roadside safety devices but having potential use in such applications.

A prioritization scheme was developed to assist in the evaluation of existing products. Fulfillment of specified safety requirements was considered to be of primary importance. Relevant field experience reported by state agencies and the availability of physical and mechanical properties from laboratory testing weighed heavily in the evaluation process. Factors such as cost, availability, and ease of handling were not directly considered due to lack of information in these areas. Based on this evaluation scheme, specific products considered suitable for implementation were identified and categorized by application type.

A list of commercially available roadside safety products manufactured in part or in whole from recycled materials identified as being suitable for implementation is presented in

Table 1. The recommended devices are listed by manufacturer and product name, and are categorized by application type. It should be noted that under Phase I, Texas Transportation Institute (TTI) researchers performed no independent testing or field evaluation of the selected products. Therefore, the recommendations contained herein are based on information found in the literature and provided to the researchers by manufacturers and state agencies.

The evaluation was based primarily on the ability of the product to meet nationally recognized safety standards, on field experience reported by other agencies, and on any physical and mechanical properties that were reported. It should be noted that subsequent to the completion of Phase I, other products have continued to enter the market. While the researchers have attempted to update the list in several application areas (e.g., offset blocks and guardrail posts), the list may not be all-inclusive in some areas.

For some of these devices, information regarding long-term performance and durability is lacking. It is therefore recommended that these products initially be implemented and monitored on an experimental basis. If in-service performance is judged to be satisfactory, the devices could then be upgraded to full operational status.

Factors such as cost, availability, and ease of handling should be considered in the final selection of products for applications in which more than one product is recommended. These factors were not considered in the initial evaluation due to lack of information in these areas.

Although suitable from the standpoint of safety performance, the products recommended for use as guardrail posts may not have immediate application in Texas. The deflections observed in tests of the Trex guardrail post were approximately twice those typically observed with standard strong-post guardrail systems. Therefore, it is not considered to be a direct substitute for conventional wood and steel posts. However, the Trex post should be suitable for use at sites that can accommodate the additional dynamic deflection.

The post manufactured by Recycled Technology, Inc., is considered to be a satisfactory substitute for use in strong-post systems. However, problems associated with differential thermal expansion of the composite plastic/steel section have raised durability concerns that need to be addressed before it is used on a widespread basis.

Table 1. Roadside Safety Products Containing Recycled Materials.

Manufacturer	Product Name	Material Type
Barricades		
Bear-A-Cade	-	HDPE, virgin
Recycled Plastic Products	Plasti-Rail	HDPE
Bollards		
Plastic Pilings, Inc.	-	HDPE, LDPE, PP shell, steel core
Delineators - Traffic Cones		
Work Area Protection	-	PVC
Delineators - Channelizing Drums		
Plastic Safety Systems, Inc.	Lifeguard Channelizer	Drum: LDPE, HDPE, Base: rubber tires
Delineators - Flexible Posts		
Carsonite	Carsonite Survivor Post	Post: recycled thermoplastic Anchor: steel
Davidson Plastics Co. (DAPCO)	Flexi-Guide	Engineered, recycled thermoplastic
Flexstake	Flexible and Type III Bridge Marker, One-Piece, Two-Piece, Bi-Directional Channelization, Surface Mounted	Polycarbonate
	HD 400 (unhinged), now called HD 300	Polycarbonate
	HD 600 (ground mounted)	Polycarbonate
	Polyflex	HDPE
Plastic Safety Systems	The Gripper	Drum: LDPE, HDPE Base: rubber tires

Table 1. Roadside Safety Products Containing Recycled Materials (Continued).

Manufacturer	Product Name	Material Type
Greenline	One Piece	Engineered, recycled thermoplastic
	Surface Mount	
	Two Piece Highway, Guardrail Mount	
Kennco, Inc.	-	Tires
Environmental Transportation	-	Recycled rubber blend
Guardrail Offset Blocks		
Mobil Oil Corp.	Trex	Wood Fiber and polyethylene
Collins & Aikman	ER ³	Vinyl, nylon
Recycled Technology, Inc.	-	Polyethylene
Valley Rubber, L.L.C.	-	Natural rubber, styrene butadiene rubber with 60% recycled tire cord
Millennium Plastic Wood, L.L.C.	Millennium Plastic Wood guardrail offset block	Dried wheat straw, polyethylene, polypropylene, polystyrene, color concentrate, cellulose fiber, foaming agent, and misc. plastics
CAMMCO, INC.	CAMMCO Plastic Guardrail Blockout	HDPE, LDPE, PVC polypropylene, rubber and thermal set, misc. non-polymer
R & P Products	-	Ground rubber from used tires, polypropylene, UV stabilizer
Aloha Plastic Recycling, Inc.	-	HDPE, LDPE, PET, PP
Central Fabricators, Inc.	-	HDPE, LDPE, misc. plastics

Table 1. Roadside Safety Products Containing Recycled Materials (Continued).

Manufacturer	Product Name	Material Type
Lifetime Lumber Products Division of Jomarico, Inc.	Lifetime Highway Guardrail Blockouts	Composite of recycled plastic, ground rubber tires, ¹ and waste glass fibers
Mondo Polymer Technologies, Inc.	Polymer Offset Blocks	LDPE, HDPE, trace of other plastics
Creative Building Products	CBP Recycled Plastic Hwy Spacer Blocks	HDPE, LDPE, PP, pigment, mixed plastics, etc.
Polywood Plastic and Lumber	Polywood	HDPE and Polystyrene
Mobil Oil Corp Composite Products Div.	Timbrex	Recycled plastic and sawdust
Guardrail Posts		
Mobil Oil Corp.	Trex	Wood fiber and polyethylene
Recycled Technology, Inc.	-	Polyethylene and steel core
Amity Plastics, Ltd.	-	HDPE, LDPE
Sign Blanks		
Composite Technologies	PFM Blanks	PET, glass, fiber
International Plastics	DuraPlate	Polycarbonates and fiberized signs
Signs and Blanks, Inc. (SABI)	3004-H38	Aluminum
	3016-H38	

Definitions

HDPE	high density polyethylene
LDPE	low density polyethylene
PE	polyethylene
PET	polyethylene terephthalate
PP	polypropylene
PVC	polyvinylchloride

The project's Phase I report presents further details of these and other products (3). Some recycled products lacked the desired data from which to make a conclusive decision regarding their suitability for implementation. Further evaluation of these products was conducted under Phase II.

PHASE II

The second phase of the research program was intended to evaluate the use of recycled materials in roadside safety devices. Seventeen different recycled material manufacturers having one or more products with potential application in the areas of interest agreed to collaborate with TTI on this project. Full-scale specimens were obtained in order to account for size effects and the non-homogeneous nature of the materials. The products consisted of various different compositions and shapes including the following:

- plastic and wood fiber mixture
- plastic and glass fiber mixture
- commingled plastics
- 100% HDPE
- HDPE - LDPE mixture
- steel-reinforced plastics
- concrete filled fiberglass tubes
- solid and hollow shapes

Received materials and products were sorted according to their potential use for roadside safety applications. After the classification, the testing focused primarily on the applications of Type III barricades, guardrail posts, guardrail offset blocks, and sign supports, which were all identified in Phase I as areas with high potential that lacked suitable recycled alternatives.

To assist with the evaluation of these recycled products, a series of laboratory tests were performed. Basic physical and mechanical properties of the recycled products were determined through static tests such as flexure, compression, creep, and density. Response to environmental variables such as temperature, moisture, and freeze/thaw were investigated through exposure tests. The dynamic behavior of the materials was examined using gravitational pendulum tests. A unique test matrix was established for each application area. Tests on conventional wood and steel products currently used for the selected roadside safety applications provided baseline performance data. The materials were screened based on their ability to meet basic service

requirements prior to running any dynamic test. Based on the results obtained from the Phase II test program some general observations can be made:

- The products showed a wide range in behavior due to the different material compositions. It was determined that some of the mechanical properties of the recycled materials did not compare favorably to the conventional wood or steel baseline materials; stiffnesses were much lower and the tendency to creep was much greater. However, a number of products displayed satisfactory performance for different applications.
- Temperature has a significant effect on the mechanical properties of recycled materials. Research indicated the load capacity, energy dissipation characteristics, and the initial stiffness for most recycled plastics are inversely proportional to the temperature. This behavior was not observed for materials containing concrete cores.
- Virtually none of the materials were adversely affected by the hydrothermic cycling process.
- The energy absorption capacity of the guardrail post specimens tended to increase when shallower embedment depths were used. Deeper embedment depths frequently resulted in post fracture rather than soil failure. More tests need to be performed to establish more conclusive results.

The results of the Phase II evaluation were used to develop ranking tables for each application. These ranking tables were used to assist in the selection of products for full-scale crash testing under Phase III. Further details and test data from the laboratory investigation are presented in the Phase II report (4).

It was recommended that the most promising products identified under Phase II be subjected to full-scale crash testing to assist with the development of standards and specifications for recycled materials and products. Applications recommended for crash testing were (1) guardrail posts, (2) sign supports, and (3) offset blocks.

It should be noted that under Phase I, several proprietary Type I and Type II barricades were identified for implementation consideration. However, no generic Type III barricades manufactured from recycled materials were available. This promising application was therefore selected for further investigation under Phase II. Several recycled products were identified and

evaluated for use as vertical supports and rail members in Type III barricades, and designs incorporating these products were developed.

During this same period of time, crash testing indicated that the standard wooden Type III barricades were unacceptable. Therefore, it became imperative for TxDOT to identify crashworthy alternatives for this application. A separate research project (5) was funded with this objective. When alternate funding became available, the crash testing of the recycled Type III barricade designs developed under this project was conducted under another project in order to permit the funds to be used in other application areas (e.g., guardrail posts, offset blocks, and sign supports).

The Type III barricade designs manufactured from recycled materials were successfully crash tested (5, 6). The same recycled products and design concepts used for the Type III barricades were subsequently extended to generic Type I barricades and short-duration temporary sign supports (7). These designs have been implemented by TxDOT through revised “Barricade & Construction (BC) Standards” and the “Compliant Work Zone Traffic Control Device List.”

PHASE III

Researchers used results from the Phase II laboratory and dynamic tests to evaluate and prioritize the candidate recycled products. The project advisory panel used these data along with other pertinent information such as cost, availability, recycled content, etc. to select several products for full-scale crash testing under Phase III. The purpose of the full-scale crash tests was to validate laboratory results, evaluate the crashworthiness of the selected products and their suitability for implementation, and provide additional data for use in developing performance specifications for the selected applications. Three products were evaluated for use as temporary sign supports. Another product was evaluated for use as guardrail posts and offset blocks in strong post W-beam guardrail systems.

Sign Supports

The recycled products tested and evaluated for use as temporary sign supports included an extruded 90 mm × 90 mm × 3810 mm (3.5 in × 3.5 in × 148.6 in) post comprised of high density polyethylene (HDPE), a molded 86 mm × 86 mm × 3658 mm (3.3 in × 3.3 in × 143 in) post comprised of a blend of polyethylene plastics, and an extruded 90 mm × 140 mm × 4570 mm (3.5 in × 5.5 in × 178 in) long post manufactured from HDPE. These posts correspond to product designations 17.D.1, 3.D.1, and 17.D.2 from the Phase II investigation, respectively. For each test, the support post was directly embedded in standard soil as defined within *National Cooperative Highway Research Program (NCHRP) Report 350 (8)* following TxDOT standards for temporary sign support installations. A 16 mm (0.6 in) thick plywood sign panel was bolted to each recycled support post at a mounting height of 2134 mm (83 in) from the ground to the bottom of the sign. The area of the sign panel varied for the different support posts.

All crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Each product was subjected to crash tests corresponding to *NCHRP Report 350* Test Designations 3-60 and 3-61. These tests involve an 820 kg vehicle impacting the support head-on (i.e., zero degrees) at speeds of 35 km/h (21 mph) and 100 km/h (62 mph), respectively.

All three of the candidate sign supports performed acceptably according to the evaluation criteria in *NCHRP Report 350*. Thus, from a crashworthiness perspective, the recycled posts are considered suitable for use as temporary sign supports. However, it should be noted that the Phase II laboratory evaluation indicated that these posts as well as most of the other plastic products submitted for evaluation for this application have a relatively low modulus of elasticity compared to a conventional wood post. Therefore, while the ultimate loads are somewhat comparable, a recycled plastic post will permit greater deflections under service loads for a given sign area than a comparably sized wood post. This tendency to deflect may require that allowable sign area be determined based on serviceability rather than strength requirements. That is, the maximum allowable sign area for a recycled sign support should be the minimum area required to meet both strength and serviceability criteria. The serviceability criteria should be based on a maximum permissible post deflection at sign height when subjected to the design wind load. The permissible post deflection should be appropriately selected based on sign legibility and

reflectivity considerations. A recommended performance specification for recycled content sign supports is presented in Appendix B.

Guardrail Posts

TxDOT guardrail systems are categorized as strong-post guardrail systems. In a strong-post guardrail system, the guardrail posts are relied on as an integral part of the system to help dissipate the energy of an impacting vehicle and control lateral deflections. For a recycled guardrail post to be a viable alternate in strong-post guardrail applications, it must be capable of providing continuity of dynamic deflections with conventional wood and steel posts.

The Phase II testing program indicated product 3.C.3 had desirable characteristics for use as a guardrail post in strong-post guardrail applications. The post is comprised of recycled HDPE with recycled chopped fibers added for additional strength and stiffness. The dimensions, strength, and energy dissipation characteristics of this recycled post were found to be similar to those of conventional wood guardrail posts. Moreover, flexure tests performed on 3.C.3 posts indicated a high degree of performance consistency both within and between two different shipments of posts from different production runs. Although stronger recycled guardrail candidates were identified under Phase II, most of these were not considered to be economically viable alternatives to standard wood and steel guardrail posts.

The 152 mm × 203 mm × 1830 mm (6 in × 8 in × 71 in) long recycled posts were installed in *NCHRP Report 350* standard soil at a standard embedment depth of 1100 mm (43 in). Recycled plastic offset blocks were used to offset the W-beam guardrail from the face of the line posts to reduce the potential for wheel-post interaction. The offset blocks were manufactured from 100 percent recycled HDPE and measured 152 mm × 203 mm × 356 mm (6 in × 8 in × 14 in). The W-beam rail was mounted at a height of 550 mm (21 in) to the middle of the rail. Recycled plastic posts and blockouts were used in the entire length-of-need section.

In accordance with *NCHRP Report 350* Test Designation 3-31, a 2000 kg (4404 lb) pickup truck impacted the guardrail system at a speed of 100 km/h (62 mph) and an angle of 25 degrees. Several recycled plastic posts fractured at ground level in advance of the vehicle, causing the vehicle to pocket into the guardrail system. The W-beam rail subsequently ruptured at a splice and the vehicle penetrated the test installation.

A total of eight posts fractured during the test. Analysis of the high-speed film indicated that most of the posts failed prematurely about the strong axis in advance of the vehicle. A high percentage of void space was evident in the cross sections of the failed posts. These observations called the flexural strength of the posts into question. Subsequent to the test, three relatively undisturbed posts away from the impact region were removed from the test installation and subjected to static cantilever flexure tests. Results showed that the shipment of posts received for the crash test did not possess the same flexural strength as the previous two shipments tested in the laboratory under Phase II. The flexural strength of the posts used in the crash test was 30 percent lower than expected and the associated reduction in energy dissipation capacity was more than 50 percent.

An inspection of fractured test specimens revealed that their cross sections contained voids and impurities such as small pebbles, dirt, and unmelted pieces of plastic. The size of these impurities ranged from 3 mm (0.1 in) to 12 mm (0.5 in). The presence of these voids and impurities effectively reduced the cross-sectional area and section modulus of the posts and created stress concentrations. Thus, during the full-scale crash test, the posts fractured at lower loads than expected without dissipating much energy.

The manufacturer was unable to provide a satisfactory explanation regarding why the strength and condition of the posts supplied for the crash test varied from those previously supplied for the laboratory investigation. The results of the crash test emphasize the need for close monitoring and quality control of structural products manufactured from recycled materials.

Unfortunately, resources were not available for conducting another test with recycled posts conforming to the draft performance specifications. Because the post used in the crash test did not conform to the desired properties, the validity of the proposed performance specification cannot be evaluated. At this time, sufficient test history and data are not available to accurately evaluate the performance of recycled guardrail posts in the absence of a full-scale crash test. While a performance specification comprised of conventional static and dynamic laboratory tests may in the future be sufficient for evaluating the suitability of recycled guardrail posts, a higher level of confidence must be established before this can occur. Therefore, at this time, full-scale crash tests are recommended for evaluating recycled content guardrail posts. The performance specification for recycled content guardrail posts presented in Appendix C can be used to guide

the development and evaluation of recycled content guardrail posts prior to full-scale crash testing.

Guardrail Offset Blocks

Testing in Phase II indicated several recycled plastic products will likely perform acceptably as offset blocks in guardrail applications. During an impact, offset blocks are primarily subjected to compressive loads and plastics typically have significant compressive strength compared to conventional timber products. Only one recycled offset block was crash tested under this project. The offset blocks measured 152 mm × 203 mm × 356 mm (6 in × 8 in × 14 in) and were manufactured from 100 percent recycled HDPE. These blockouts were incorporated into the guardrail test described above. During the full-scale test, the integrity of the offset blocks was maintained and their performance was judged to be satisfactory. A recommended performance specification for recycled offset blocks is presented in Appendix A.

Several other recycled offset blocks have received federal approval for use in strong-post guardrail systems. These are included in the list of recycled roadside safety products presented in the implementation recommendations of this report.

Further details of the crash tests conducted on recycled sign supports, guardrail posts, and guardrail offset blocks under this project are presented in the Phase III report (9).

REFERENCES

1. Collins, R.J., and Ciesielski, S.K. (1994). "Recycling and Use of Waste Materials and Byproducts in Highway Construction." *Synthesis of Highway Practice 199*, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C.
2. Bloomquist, D., Diamond, G., Oden, G., Ruth, B., and Tia, M. (1993). "Engineering and Environmental Aspects of Recycled Materials for Highway Construction." *Research Report No. FHWA-RD-93-088*, U.S. DOT, Federal Highway Administration.
3. Bligh, R.P., Alberson, D.C., and Butler, B.G. (1995). "Applications of Recycled Materials in Roadside Safety Devices." Research Report No. FHWA/TX-95/1458-1, TxDOT, FHWA.
4. Bligh, R.P., Alberson, D.C., Atahan, A.O., and Bowen, A.R. (2000). "Laboratory Testing of Recycled Materials in Roadside Safety Devices." Research Report No. FHWA/TX-00/1458-2, TxDOT, FHWA.
5. Mak, K.K., R.P. Bligh, and Menges W.L. (1996). "Evaluation of Work Zone Barricades and Temporary Sign Supports," Research Report 5388-1F. Texas Transportation Institute, College Station, TX.
6. Mak, K.K., Bligh, R.P., and Menges, W.L. (1997). "Evaluation of Work Zone Barricades," Research Report 3910-S. Texas Transportation Institute, College Station, TX.
7. Bligh, R.P., Bullard, D.L., Menges, W.L., and Schoeneman, S.K. (2001). "Impact Performance Evaluation of Work Zone Traffic Control Devices," Report No. FHWA/TX-01/1792-2.
8. Ross, H.E. Jr., Sicking, D.L., Zimmer, R.A. and Michie, J.D. (1993). *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, NCHRP Report 350, Transportation Research Board, Washington, D.C.
9. Bligh, R.P., Menges, W.L., and Alberson, D.C. (2001). "Testing and Evaluation of Recycled Materials in Roadside Safety Devices," Research Report No. FHWA/TX-01-1458-3, TxDOT, FHWA.

**APPENDIX A. RECOMMENDED PERFORMANCE-BASED
SPECIFICATION FOR RECYCLED CONTENT
GUARDRAIL OFFSET BLOCKS**

RECOMMENDED PERFORMANCE-BASED SPECIFICATION FOR RECYCLED CONTENT GUARDRAIL OFFSET BLOCKS

1. SCOPE

This specification covers the recommended material requirements and performance specifications for use of recycled materials in guardrail offset block applications. Pertinent physical and mechanical properties have been listed, along with the test standards and performance requirements for rectangular guardrail offset blocks made from recycled materials.

2. DEFINITIONS

- a. Recycled Material:** The recycled materials shall be composed of post-consumer material or recovered industrial material only, or both that may or may not have been subjected to additional processing.
- b. Post-Consumer Materials:** Those products generated by a business or consumer that have served their intended end use and that have since been separated or diverted from solid waste for the purpose of collection and/or recycling.
- c. Recovered Industrial Material:** Materials and by-products that have been recovered or diverted from solid waste, but not including those materials and by-products generated from, and commonly used within, an original manufacturing process.

3. REFERENCES

This specification refers to the following standards, specifications or publications:

American Society for Testing and Materials Standards:

D6108-97	Standard Test Method for Compressive Properties of Plastic Lumber and Shapes
D543-95	Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents
D1525-00	Standard Test Method for Vicat Softening Temperature of Plastics
D2017-81	Standard Test Method for Accelerated Laboratory Test of Natural Decay Resistance of Woods
G152-00	Standard Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials

4. SUBMISSION AND DESIGN REQUIREMENTS

Recycled content guardrail offset blocks meeting the requirements of this specification may be substituted on a one-for-one basis with like guardrail offset blocks in standard guardfence applications.

5. MATERIALS

5.1 Physical Properties

5.1.1 General

The physical requirements of recycled content guardrail offset blocks should conform to Table 2.

5.1.2 Material Requirements

Recycled content guardrail offset blocks shall consist of no less than 50 percent recycled materials and shall be uniform in composition throughout the length of the offset block. The block shall contain no more than 20 percent voids over its length. The recycled guardrail offset block shall have no cracking, chipping, flaking, peeling, or splintering in the final product. Only chemicals, including fillers and colorants, designed to inhibit photo degradation, biological and/or biochemical decomposition, insect infestation, or burning will be permitted to enhance durability.

5.1.3 Appearance and Size

Recycled guardrail offset blocks shall exhibit a homogeneous surface finish and be relatively free of indents or other surface imperfections. The offset depth shall not be less than 150 mm (6 in).

5.1.4 Predicted Service Life

In-service offset blocks shall provide a minimum acceptable performance life of 20 years. Conditions to be considered in establishing the minimum acceptable life shall include, but are not limited to, the following:

- insect infestations, especially by fire ants and termites causing a weight loss resulting in a loss of strength; and
- any breaks or cracks.

5.1.5 Toxicity

Recycled content guardrail offset blocks shall not contain any chemicals toxic to animals. The components of any leachate shall be determined by an approved testing organization and shall be at a level acceptable to TxDOT.

5.1.6 Combustion By-product Requirements

Combustion of recycled content guardrail offset blocks shall not produce any toxic gases.

5.1.7 Chemical Resistance

Recycled content guardrail offset blocks shall not be adversely affected by exposure to salt, gasoline, or motor oil when tested in conformance with ASTM D543-95.

5.1.8 Workability

Recycled content guardrail offset blocks shall be capable of being drilled and cut with wood-working tools.

5.1.9 UV Resistance

Recycled content guardrail offset blocks shall not be adversely affected by ultraviolet (UV) light. No fading, splintering, or cracking should occur when tested in conformance with American Society for Testing and Measurement (ASTM) G152-00.

5.2 Mechanical Properties

Recycled content guardrail offset blocks shall be subjected to gravitational pendulum or bogie vehicle tests at 35 km/h (21.7 mph). The mass of the impactor should be 820 kg (1805 lb). TxDOT requires the testing of a minimum of two guardrail offset blocks. The offset block should be connected to a standard support, such as a Lowfill Culvert Post as outlined in TxDOT Standard Detail MBGF-95A, using standard guardfence hardware. A standard W-beam backup plate (TxDOT Standard Detail MBGF-95A) should be mounted on the traffic face of the offset block. It is recommended the support post be rigidly fixed to eliminate variations in soil interaction with the support post. Guardrail offset blocks maintaining their integrity and nominal pretest dimensions after testing when the support post has failed, shall be deemed acceptable under this specification. Acceptable component failures are post buckling, post fracture not at a weld, or bolt failures. Crushing or buckling of offset block constitutes failure.

**Table 2. Physical and Mechanical Requirements for
Recycled Content Guardrail Offset Blocks.**

Properties	Testing	Performance Limits	Comments
Physical			
Softening Point	D1525-00	$\geq 60^{\circ}\text{C}$ (140°F)	Set greater than temperature expected in the field.
Decay Resistance	D2017-81	<10% loss in compressive strength	To retain required levels of mechanical properties. After exposure evaluate compressive strength in accordance with D6108-97
UV Resistance	G23	No fading, splintering, or cracking	UV stabilizers should be added, as needed, to achieve UV resistance.
Mechanical			
Compression	D 6108-97	$\geq 250\text{ kN}$ > 150 mm (5.85 in) depth	At 250 kN load, depth of offset block should not be less than 150 mm (5.85 in)

**APPENDIX B. RECOMMENDED PERFORMANCE-BASED
SPECIFICATION FOR RECYCLED CONTENT
SIGN SUPPORT POSTS**

RECOMMENDED PERFORMANCE-BASED SPECIFICATION FOR RECYCLED CONTENT SIGN SUPPORT POSTS

1. SCOPE

This specification covers the recommended material requirements and performance specifications for use of recycled materials in sign support post applications. Pertinent physical and mechanical properties have been listed, along with the test standards and performance requirements for rectangular, square, or round posts made from recycled materials used in sign support applications.

2. DEFINITIONS

- a. Recycled Material:** The recycled materials shall be composed of post-consumer material or recovered industrial material only, or both that may or may not have been subjected to additional processing.
- b. Post-Consumer Materials:** Those products generated by a business or consumer that have served their intended end use and that have since been separated or diverted from solid waste for the purpose of collection and/or recycling.
- c. Recovered Industrial Material:** Materials and by-products that have been recovered or diverted from solid waste, but not including those materials and by-products generated from, and commonly used within, an original manufacturing process.

3. REFERENCES

This specification refers to the following standards, specifications or publications:

American Society for Testing and Materials Standards:

D6109-97	Flexural Properties of Unreinforced and Reinforced Plastic Lumber
D543-95	Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents
D1525-00	Standard Test Method for Vicat Softening Temperature of Plastics
D2017-81	Standard Test Method for Accelerated Laboratory Test of Natural Decay Resistance of Woods

D638-99	Standard Test Method for Tensile Properties of Plastics
G152-00	Standard Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials
D 6112-97	Standard Test Method for Compressive and Flexural Creep and Creep-Rupture of Plastic Lumber and Shapes

4. SUBMISSION AND DESIGN REQUIREMENTS

Recycled content sign support posts meeting the requirements of this specification may be substituted on a one-for-one basis with equivalent sign supports if mechanical properties are within 10 percent of currently accepted equivalents.

5. MATERIALS

5.1 Physical Properties

5.1.1 General

The physical requirements of recycled content sign support post shall conform to Table 3.

5.1.2 Material Requirements

Recycled content sign support posts shall be uniform in composition throughout the length of the post. The recycled sign support post shall have no cracking, chipping, flaking, peeling, or splintering in the final product. Only chemicals, including fillers and colorants, designed to inhibit photo degradation, biological and/or biochemical decomposition, insect infestation, or burning will be permitted to enhance durability.

5.1.3 Appearance

Recycled sign support post shall exhibit a homogeneous surface finish and be relatively free of indents or other surface imperfections.

5.1.4 Predicted Service Life

In-service posts shall provide a minimum acceptable performance life of 20 years. Conditions to be considered in establishing the minimum acceptable life shall include, but are not limited to, the following:

- insect infestations, especially by fire ants and termites, causing a weight loss resulting in a loss of strength;
- rotting or erosion due to soil micro-organisms; and
- any breaks or cracks.

5.1.5 Toxicity

Recycled content sign support posts shall not contain any chemicals toxic to animals. The components of any leachate shall be determined by an approved testing organization and shall be at a level acceptable to TxDOT.

5.1.6 Combustion By-product Requirements

Combustion of recycled content sign supports shall not produce any toxic gases.

5.1.7 Chemical Resistance

Recycled content sign support posts shall not be adversely affected by exposure to salt, gasoline, or motor oil when tested in conformance with ASTM D543-95.

5.1.8 Workability

Recycled content sign support posts shall be capable of being drilled and cut with wood-working tools.

5.1.9 UV Resistance

Recycled content sign support posts shall not be adversely affected by UV light. No fading, splintering, or cracking should occur when tested in conformance with ASTM G152-00.

5.2 Mechanical Properties

5.2.1 General

The mechanical properties of recycled content sign support post shall conform to Table 3. Mechanical properties listed in this table shall be maintained within the temperature range of 0 to 50 °C (32 to 122 °F).

5.2.1.1 Acceptance/Rejection Criteria

The acceptance/rejection criteria will be based on the flexural strength characteristics described in Sections 5.2.2 through 5.2.5. Unless otherwise specified, a minimum of three flexural tests should be conducted. The three samples shall be randomly selected, one each from the beginning, middle, and end of the production run being evaluated.

If the flexural strength characteristics for all three specimens are above the minimum specified value, the batch is considered acceptable. If the crush force characteristics for two or three of the three specimens are below the minimum acceptable value, the batch is considered unacceptable.

If the flexural strength characteristics for one of the three specimens is below the minimum acceptable value, three additional specimens shall be randomly selected from the batch (one each from the beginning, middle, and end of the production) and tested. The flexural strength characteristics for all three additional specimen must be above the minimum acceptable value for the batch to be considered acceptable. If one or more of the three specimens are below the minimum acceptable value, the batch is considered unacceptable.

5.2.2 Flexural Bending Test

No less than five posts shall be loaded in bending in a cantilever manner to create the extreme bending stress at the fixed end. This may be accomplished by firmly securing one end of sign post and applying a load at a distance of 533 mm (21 in) from the fixed end. The load should be applied and remain perpendicular to the fixed end of the post. The load and deflection of each post shall be measured continuously throughout the test. Tests shall be conducted at room temperature. The minimum required load is 11 kN (2475 lb) and the deflection at the point of load application under the minimum required load is limited to 45 mm (1.75 in).

5.2.3 Dynamic Load Test

No less than three sign posts shall be subjected to dynamic load using a gravitational pendulum or bogie vehicle at an impact speed of 35 km/h (114.8 mph). The mass of the impactor should be 820 kg. (1805 lb.) The posts should be embedded following the recommended practices specified in *NCHRP Report 350*. The soil used for the tests should conform to the standard soil recommended in *NCHRP Report 350*. The post embedment depth should conform to standard TxDOT practices for temporary sign supports (TxDOT Standard Detail BC(4)-97). A plywood or aluminum sign panel should be fastened to the post at a mounting height of 2.13 m (6.98 ft) using standard hardware. The area of the sign panel will be based on the flexural capacity of the post subject to a design wind speed of 96.5 km/h (59.9 mph). The mid-height of the face of the impactor should be 550 mm (21.4 in) above ground. Honeycomb or neoprene may be placed on the face of the impactor to minimize noise in the collected data. The impactor shall be equipped with a uniaxial accelerometer oriented in the direction of impactor motion and aligned with the center of mass of the impactor. The peak force computed from the accelerometer and dissipated energy level of posts shall be reported. The sign support post should fracture or break away and not show undue potential for penetration into the occupant compartment. The measured accelerations should be used to compute Occupant Impact Velocity (OIV) and Ridedown Accelerations (RA) of *NCHRP Report 350*. The OIV should not exceed 5 m/s (5.45 ft/s) and the RA should not exceed 20 g.

5.2.4 Creep Test

No fewer than three posts shall be loaded in bending in a cantilever fashion. Progressive deformation of the post under constant stress shall be measured with respect to time. A constant load sufficient to achieve an initial flexural stress of 690 MPa (100 ksi) at the fixed end of the post shall be applied a distance of 1220 mm (47.6 in) from the fixed end of the post. The test shall be performed in a temperature controlled chamber at a constant temperature of 40 °C (104 °F). The deflection measurements shall be made immediately after the full load has been applied and at the following intervals: 1, 6, 12, and 30 minutes; and 1, 2, 5, 20, 50, 100, 200, 500, 700, and 1000 hours. It is permissible to use a power law to construct a representative model of the creep behavior of the post for purposes of extrapolating the 1000 hour response. The model coefficients should be determined to provide a best fit based on a minimum 250 hours of creep data. The measured or projected 1000 hour creep deflection should be less than 20 mm (0.78 in). The residual deflection of the post shall be measured one hour after removal of the load. The residual deflection of each post shall be no greater than 10 percent of the initial deflection when the full load was applied.

5.2.5 Hydrothermic Cycling

No less than three sign support posts shall be subjected to alternating cycles of immersion in gas-free water for a period of the 24-hour period using sinkers at room temperature. All specimens shall be weighed before immersion. At the end of 24 hours period, each sample shall be dried on the outside surface and reweighed within 5 minutes of removal from water. Samples that exceed a 1 percent weight gain as compared to the unsoaked samples shall be resoaked until the change in the weight shall be less than 1 percent in a 24-hour period. Such samples shall be considered to have reached hydraulic stability. Samples shall be then frozen to -40 °C (-40 °F) for 24 hours and then returned to room temperature. This process shall comprise one hydrothermic cycle and it shall be repeated three times; that is, all samples shall be subjected to a total of three cycles of water submersion to hydraulic stability and freezing. The

resulting reduction in flexural strength shall not be more than 10 percent of the initial flexural strength of the post as determined through testing as outlined in Section 5.2.2. In addition, the posts shall not display any significant cracking or spalling subsequent to hydrothermic cycling.

5.2.6 Full-Scale Crash Testing

Full-scale crash testing should be required if failure mode and location of the post are not readily apparent. This may be encountered when a manufacturer uses another material such as steel or fiberglass to achieve a higher stiffness than is afforded by the recycled product alone. If full-scale tests are deemed necessary, *NCHRP Report 350* tests 3-60 and 3-61 should be conducted.

6. QUALITY ASSURANCE

Random testing may be conducted at any time to verify compliance with as-tested specifications. Sign support post warpage is limited to 2 percent end offset based on post length.

7. CERTIFICATION

All batches of recycled content sign support posts shall be supplied complete with a certificate from an approved testing agency attesting that the product complies with the requirements of the specifications. A certification shall be provided for each lot of a shipment. The manufacturer shall also certify the following:

- the source of the recycled plastic waste, including the state from which the recycled plastic was obtained, and type of waste (consumer or industrial);
- the density of the post material shall be within 10 percent of the as-tested density; and
- the total percent of recycled plastic in the final product.

Any marked property variations from the original test values for a material or evidence of inadequate field performance of a material will be considered as sufficient proof to remove the material from the department's Qualified Products List.

**Table 3. Physical and Mechanical Requirements for
Recycled Content Sign Support Posts.**

Properties	Testing	Performance	Comments
Physical			
Softening Point	D1525-00	$\geq 60\text{ }^{\circ}\text{C}$ (140 $^{\circ}\text{F}$)	Set greater than temperature expected in the field.
Freeze/Thaw (Hydrothermic Cycling)	ASTM	$\leq 10\%$ loss in flexural strength	To retain required levels of mechanical properties. After exposure evaluate compressive strength in accordance with D6109-97.
Decay Resistance	D2017-81	$<10\%$ loss in flexural strength	To retain required levels of mechanical properties. After exposure evaluate compressive strength in accordance with D6109-97.
UV Resistance	G152-00	No fading, splintering, or cracking	UV stabilizers should be added, as needed, to achieve UV resistance.
Mechanical			
Flexural Load Capacity	D6109-97	$\geq 11\text{ kN}$ (2475 lb)	Required for wood-post applications.
Flexural Deformation	D6109-97	$\leq 45\text{ mm}$ (1.75 in)	Required for wood-post applications. Measured at load of 11 kN (2475 lb).
Modulus of Elasticity	D638-99	$\geq 2000\text{ MPa}$ (290 ksi)	-
Creep	D6112-97	$\leq 20\text{ mm}$ (0.78 in)	-

**APPENDIX C. RECOMMENDED PERFORMANCE-BASED
SPECIFICATION FOR RECYCLED CONTENT
GUARDRAIL POSTS**

RECOMMENDED PERFORMANCE-BASED SPECIFICATION FOR RECYCLED CONTENT GUARDRAIL POSTS

1. SCOPE

This specification covers the recommended material requirements and performance specifications for use of recycled materials in strong-post guardrail applications. Pertinent physical and mechanical properties have been listed, along with the test standards and performance requirements for rectangular, square, or round guardrail posts made from recycled materials used in W-beam guardrail systems.

2. DEFINITIONS

- a. Recycled Material:** The recycled materials shall be composed of post-consumer material or recovered industrial material only, or both that may or may not have been subjected to additional processing.
- b. Post-Consumer Materials:** Those products generated by a business or consumer that have served their intended end use and that have since been separated or diverted from solid waste for the purpose of collection and/or recycling.
- c. Recovered Industrial Material:** Materials and by-products that have been recovered or diverted from solid waste, but not including those materials and by-products generated from, and commonly used within, an original manufacturing process.

3. REFERENCES

This specification refers to the following standards, specifications or publications:

American Society for Testing and Materials Standards:

D6109-97	Flexural Properties of Unreinforced and Reinforced Plastic Lumber
D543-95	Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents
D1525-00	Standard Test Method for Vicat Softening Temperature of Plastics
D2017-81	Standard Test Method for Accelerated Laboratory Test of Natural Decay Resistance of Woods

D638-99	Standard Test Method for Tensile Properties of Plastics
G152-00	Standard Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials

4. SUBMISSION AND DESIGN REQUIREMENTS

Recycled content guardrail posts meeting the requirements of this specification may be substituted on a one-for-one basis with standard guardfence posts.

5. MATERIALS

5.1 Physical Properties

5.1.1 General

The physical requirements of recycled content guardrail post shall conform to Table 4.

5.1.2 Material Requirements

Recycled content guardrail posts shall consist of no less than 50 percent recycled materials and shall be uniform in composition throughout the length of the post. The recycled guardrail post shall have no cracking, chipping, flaking, peeling, or splintering in the final product. Only chemicals, including fillers and colorants, designed to inhibit photo degradation, biological and/or biochemical decomposition, insect infestation, or burning will be permitted to enhance durability.

5.1.3 Appearance and Size

Recycled guardrail post shall exhibit a homogeneous surface finish and be relatively free of indents or other surface imperfections

5.1.4 Predicted Service Life

In-service posts shall provide a minimum acceptable performance life of 20 years. Conditions to be considered in establishing the minimum acceptable life shall include, but are not limited to, the following:

- insect infestations, especially by fire ants and termites, causing a weight loss resulting in a loss of strength;
- rotting or erosion due to soil micro-organisms; and
- any breaks or cracks.

5.1.5 Toxicity

Recycled content guardrail posts shall not contain any chemicals toxic to animals. The components of any leachate shall be determined by an approved testing organization and shall be at a level acceptable to TxDOT.

5.1.6 Combustion By-product Requirements

Combustion of plastic guardrail posts shall not produce any toxic gases.

5.1.7 Chemical Resistance

Recycled content guardrail posts shall not be adversely affected by exposure to salt, gasoline, or motor oil when tested in conformance with ASTM D543-95.

5.1.8 Workability

Recycled content guardrail posts shall be capable of being drilled and cut with wood-working tools.

5.1.9 UV Resistance

Recycled content guardrail posts shall not be adversely affected by UV light. No fading, splintering, or cracking should occur when tested in conformance with ASTM G152-00.

5.2 Mechanical Properties

5.2.1 General

The mechanical properties of recycled content guardrail post should conform to Table 4. Mechanical properties listed in this table shall be maintained within the temperature range of 0 to 50 °C. A full-scale crash test shall be conducted in accordance with Section 5.3 below.

5.2.1.1 Acceptance/Rejection Criteria

The acceptance/rejection criteria will be based on the flexural strength characteristics described in Sections 5.2.2, 5.2.3, and 5.2.4. Unless otherwise specified, a minimum of three flexural tests should be conducted. The three samples shall be randomly selected, one each from the beginning, middle, and end of the production run being evaluated.

If the flexural strength characteristics for all three specimens are above the minimum specified value, the batch is considered acceptable. If the crush force characteristics for two or three of the three specimens are below the minimum acceptable value, the batch is considered unacceptable.

If the flexural strength characteristics for one of the three specimens is below the minimum acceptable value, three additional specimens shall be randomly selected from the batch (one each from the beginning, middle, and end of the production) and tested. The flexural strength characteristics for all three additional specimen must be above the minimum acceptable value for the batch to be considered acceptable. If one or more of the three specimens are below the minimum acceptable value, the batch is considered unacceptable.

5.2.2 Flexural Bending Test

No less than five posts shall be loaded in bending in a cantilever manner to create the extreme bending stress at the fixed end. This may be accomplished by firmly securing one end of the guardrail post and applying a load at a distance of 550 mm (21.45 in) from the fixed end. The load should be applied and remain perpendicular to the fixed end of the post. The load and deflection of each post shall be measured continuously throughout the test. Tests shall be conducted at room temperature. The minimum required load is 55 kN (12.4 kips) and the deflection at the point of load application under the minimum required load is limited to 175 mm (6.82 in).

5.2.3 Dynamic Load Test

No less than three posts shall be subjected to dynamic load using a gravitational pendulum or bogie vehicle at an impact speed of 35 km/h (21.7 mph). The mass of the impactor should be 820 kg (1805 lb). The posts should be embedded following the recommended practices specified in *NCHRP Report 350*. The soil used for the tests should conform to the standard soil recommended in *NCHRP Report 350*. The mid-height of the face of the impactor should be 550 mm (21.4 in) above ground. Honeycomb or neoprene may be placed on the face of the impactor to minimize noise in the collected data. The impactor shall be equipped with a uniaxial accelerometer oriented in the direction of impactor motion and aligned with the center of mass of the impactor. The peak force computed from the accelerometer and dissipated energy level of posts shall be reported. The minimum peak force is 55 kN (12.4 kips), and the minimum impact energy computed over a deflection of 450 mm (17.5 in) is 8450 kN-mm (6230 lb-ft).

5.2.4 Hydrothermic Cycling

No less than three posts shall be subjected to alternating cycles of immersion in gas-free water for a period of 24 hours using sinkers at room temperature. All specimens shall be weighed before immersion. At the end of the 24-hour period, each sample shall be dried on the outside surface and reweighed within 5 minutes of removal from water. Samples that exceed a 1 percent weight gain as compared to the unsoaked samples shall be resoaked until the change in weight shall be less than 1 percent in a 24-hour period. Such samples shall be considered to have reached hydraulic stability. Samples shall be then frozen to -40°C (-40°F) for 24 hours and then returned to room temperature. This process shall comprise one hydrothermic cycle and it shall be repeated three times; that is, all samples shall be subjected to a total of three cycles of water submersion to hydraulic stability and freezing. After completion, the posts shall be loaded in a cantilever fashion as outlined in Section 5.2.2. The reduction in flexural strength shall not be more than 10 percent of the initial flexural strength of the post as determined through testing as outlined in Section 5.2.2. In addition, the posts shall not display any significant cracking or spalling subsequent to hydrothermic cycling.

5.3 Full-Scale Crash Test

A full-scale crash test shall be conducted on a standard Length of Need (LON) of guardfence fabricated with recycled content guardfence posts in accordance with *NCHRP Report 350 Recommended Procedures for the Safety Performance Evaluation of Highway Features*. Test 3-11, which involves a 2000 kg (4404 lb) pickup truck impacting the guardrail at 25 degrees and 100 km/h (62.1 mph) at the Critical Impact Point (CIP), shall be conducted. Performance of the guardfence shall be evaluated according to recommended criteria set forth in *NCHRP Report 350*. Test designation 3-10 with a small passenger vehicle may be requested at the discretion of TxDOT.

6. QUALITY ASSURANCE

Random testing may be conducted at any time to verify compliance with as-tested specifications. Guardfence post warpage is limited to 2 percent end offset based on post length.

7. CERTIFICATION

All batches of recycled content guardfence posts shall be supplied complete with a certificate from an approved testing agency attesting that the product complies with the requirements of the specifications. A certification shall be provided for each lot of a shipment. The manufacturer shall also certify the following:

- The source of the recycled plastic waste, including the state from which the recycled plastic was obtained, and type of waste (consumer or industrial).
- The density of the post material shall be within 10 percent of the as-tested density.
- The total percent of recycled plastic in the final product.

Any marked property variations from the original test values for a material or evidence of inadequate field performance of a material will be considered as sufficient proof to remove the material from the department's Qualified Products List.

**Table 4. Physical and Mechanical Requirements
for Recycled Content Guardrail Posts.**

Properties	Testing	Performance Limits	Comments
Physical			
Softening Point	D1525-00	$\geq 60\text{ }^{\circ}\text{C}$ (140 $^{\circ}\text{F}$)	Set greater than temperature expected in the field.
Freeze/Thaw (Hydrothermic Cycling)	ASTM	$\leq 10\%$ loss in flexural strength	To retain required levels of mechanical properties. After exposure evaluate compressive strength in accordance with D6109-97.
Decay Resistance	D2017-81	$<10\%$ loss in flexural strength	To retain required levels of mechanical properties. After exposure evaluate compressive strength in accordance with D6109-97.
UV Resistance	G152-00	No fading, splintering, or cracking	UV stabilizers should be added, as needed, to achieve UV resistance.
Mechanical			
Flexural Load Capacity	D6109-97	$\geq 55\text{ kN}$ (12.4 kips)	Required for strong-post applications.
Flexural Deformation	D6109-97	$\leq 175\text{ mm}$ (6.8 in)	To minimize lateral rail deflections and pocketing. Measured at load of 55 kN.
Modulus of Elasticity	D638-99	$\geq 2000\text{ MPa}$ (290 ksi)	Prevent excessive rail deflections and ramping.
Peak Impact Load	N/A	$\geq 55\text{ kN}$ (12.4 kips)	Required for strong-post applications.
Impact Energy	N/A	$\geq 8450\text{ kN-mm}$ (6230 lb-ft)	Computed over a post deflection of 450 mm (17.5 in).

