

EIERA - Final Report

**COMPOSITE STRUCTURES USING ASPHALT BASED ROOFING SCRAP
MATERIALS**

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EXECUTIVE SUMMARY

The uses of recycled materials in composites provide the potential for large cost savings and a solution to the ever-growing disposal problem. Shingles contain petroleum based binders and fillers, which used as a valuable resource in composite production. Composites offer inherent advantages over traditional materials in regard to corrosion resistance, design flexibility and extended service life. Use of scrap-roofing shingles as a core material in glass fiber reinforced composite materials offer potential low cost composite products such as sound barrier system, railroad ties and other building materials including blocks. In the present work, processes have been developed for shredding scrap roof shingles, for making shingle blocks, and for filling hollow composite tubes. Mechanical testing was performed to compare the performance of filled composite tubes to hollow tubes and oak wood beams. Filled tubes show improvement in ultimate flexural strength by preventing buckling and crushing. Tests were also conducted to evaluate the sound attenuation capability of recycled shingle walls. It was observed that the mean sound level at the backside of the wall, measured in decibels, was greatly reduced and shows potential use for recycled shingles in a sound barrier system. University of Missouri-Rolla has collaborated with Future Tek Inc. and Lemay Center for Composites Technology for successful completion of this project. The economic benefits are truly immense. This project will impact the community by diverting thousands of tons of shingles into usable products with a real economic impact.

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1. INTRODUCTION

Reuse of scrap asphalt roof shingles can reduce the problems in landfill disposal, can be used for producing blocks used in railroad ties, decorative arrangement and sound barriers. Railroad ties, sound barriers and decorative blocks show promise for such products. Railroad ties have traditionally been made from wood, but recent research has focused on alternate designs and materials. Although inexpensive, wood has many disadvantages and makes the use of alternative materials feasible and more affordable over the long term. These disadvantages include rot, insect attack, tie plate cutting, failure by degradation of mechanical properties, and future lumber regulations [1]. Wood railroad ties are soaked in creosote to protect them from environmental conditions, such as insects and rot. Creosote is a hazardous material known to cause cancer and must be safely disposed of when the tie is removed, adding to the cost of the railroad tie. Additionally, a period of time the creosote begins to seep out of railroad ties causing damage to the environment [2]. Several research groups have designed new railroad ties using materials such as plastic/wood composite and co-mingled plastics and reinforced concrete railroad ties.

Qiao et.al [3] have modeled a composite reinforced wood railroad tie. Research focuses on improving the mechanical properties of the railroad tie with a composite wrap of E-glass fibers and vinyl ester resin matrix. To minimize cost, a parametric study was performed to minimize the volume of the composite wrapping while maintaining improved mechanical properties. A partial glass reinforced plastic composite covered wooden railroad tie was modeled, tested, and found to improved mechanical properties when compared to traditional wooden ties. Although strengthening a railroad tie will

result in fewer failures due to fatigue, other failure modes were not addressed. It is expected that rot, insect attack, and creosote seepage will remain as major factors in the failure of wooden railroad ties.

Nosker et. al [4] developed and field-tested a recycled plastic composite railroad tie. The composite tie is manufactured with plastics and fiberglass that would have otherwise been placed in a landfill, and the majority of the plastics used are high-density polyethylene from milk and detergent bottles, etc. Visual inspections of field-tested ties have resulted in no apparent damage, such as tie plate cutting. Due to the short field test period, the failure modes of a recycled plastic composite railroad tie are not yet known. It is suspected that a railroad tie manufactured from recycled plastics will be subject to attack by fungi due to the residual protein remaining from the recycling process [5]. A recycled shingle core composite railroad tie is not expected to be susceptible to rot, attack from fungi or insects because of its inability to absorb moisture and absence of protein or other easily decomposed material in the manufacturing process. The composite tie consists of two components, the recycled shingle core and the composite material covering. The composite covering will bear the load imparted on the structure while the shingles form the low cost core.

In the present work, two stages of research sections were performed, first section dealt with small-scale samples (4"x 4"x 40") of filled composite tubes were fabricated and tested. The flexural tests were performed to evaluate the performance of shingle core filled composite tubes. Also, the sound attenuation capabilities of the filled tubes are investigated. The second section was performed to identify a practical full scale method of manufacturing a composite wrapped recycled shingle railroad tie and further research

was performed to evaluate the feasibility of applying the composite wrap to the recycled shingle core by hand. 4" x 8" x 40" samples were manufactured by hand lay-up and 3-point flexure tests were performed using an Instron 4485.

2. SECTION A

2.1 Shingle Shredding and Filling

2.1.1 Shingle Shredding Machine

An asphalt roof shingles in their original form are not useful in this study, they must first be cut into small pieces. The shingles pieces can then be compressed or molded into a useable form. The cutting of shingles is performed by custom-designed shingle-shredding machine (Figure 2), Figure 1 shows the shredding section designed and developed by Future Tek Inc. in Springfield, MO. Once inserted into the machine the shingles enter the cutting section, which consists of steel blades welded to two bars that rotate at high speeds tearing the shingles into pieces. The cutting section normally reduces the shingles to a particle, Figure 4, less than a 1/2" x 1/2" in size. To increase processing efficiency, conveyor belts are used to feed the hopper and transport shredded shingles from the machine. Once the asphalt roof shingles are shredded the pieces can be used with the tube-filling machine and shingle extruder (Figure 5 & 3).

2.2 Tube-filling Machine and Filling Processes

2.2.1 Tube-filling Machine

Filling the composite tubes with shingles requires a special machine designed at the Lemay Center for Composites Technology in St. Louis, Missouri. The design and function of the tube-filling machine is similar to a hydraulic ram press. It consists of three sections: spine, sled, and ram. The spine is an I-beam, which provides support to the remainder of the structure and, during the filling process, holds a composite tube in

place using an 8" by 12" plate welded at the end. Holes drilled into the I-beam's flange permit the sled to lock into different positions. The sled is a C-channel that rests over the flange of the I-beam and can be moved to several locations along the spine. It is then locked into place with a 3/4" pin through the holes drilled into the I-beam flange. This permits either a multi-step filling process or filling tubes of different lengths. The ram consists of the ram extension, hydraulic cylinder, hydraulic power unit, and reservoir. The cylinder and valve are bolted to the sled. Figure 5 contains all three sections of the Tube-filling Machine. The spine and ram section, when fully extended, are shown in Figure 6. All the steel used is A36 hot rolled plate and joints are welded using a Lincoln Wirematic MIG welder. A Haldex power unit provides power. A standard 4-way valve is used to provide power in the extension and retraction stroke.

2.2.2 Filling Procedure 1

The initial step in filling the tube is to loosely fill the heated shingles into the tube and compressing the fill in tube using the press. This process is repeated until the entire composite tube is filled with compacted recycled shingles. Preheating the shingles increases their pliability and ease of compression. Care must be taken not to overheat the shingles because excessive heat will damage the composite tube. Also, too much compaction pressure will split the composite tube. This process is time consuming because the filling steps must be repeated several times per tube.

2.2.3 Filling Procedure 2

For the second filling procedure, hot shingles are compressed into a steel mold to make blocks that will slide snugly inside the composite outer tube. Several shingle blocks are then packed into a composite tube. The mold and composite tubes have equal interior dimensions to ensure that the compressed shingle blocks will fit properly. The mold can be seen in Figure 7.

The tube filling machine and filling procedure 1 are used to compress shredded recycled shingles into the mold. Once filled, the mold is opened to remove the block, which is then used to fill the composite tubes. Several blocks are used to fill each composite tube. This procedure was developed to improve bonding between the composite tube and recycled shingles and improve the consistency of the shingle core by eliminating any air pockets that may be produced by first filling procedure 1.

2.3 Shingle Extruder

A machine was developed to extrude recycled shingle blocks by FutureTek Inc. in Springfield, Missouri. The shingle extruder can be run in series with the shingle shredding machine or stand-alone. If run in series the outgoing conveyor belt of the Shingle Shredding Machine is run into the shingle extruder feed hopper. If not, the shingles must be hand fed into the extruder. The shingles are then simultaneously heated using an open flame and compressed through a die using a power screw. The die also aids in the compression by slightly decreasing its cross-section while at the same time giving the shingle block its shape. The blocks produced by this machine are used in the sound testing and will be used in future research.

2.4 Experimental Testing

2.4.1 Flexure Testing

A three point flexure test was performed, with dimensions 4" x 4" x 40", on filled and hollow composite tubes and solid oak beams using an Instron 4485 universal test machine. The two separate procedures described above were used to fill the composite tubes. A total of twenty-three specimens were tested; five unfilled composite tubes, six composite tubes filled with procedure 1, four composite tubes filled with procedure 2, and eight solid oak beams.

Figure 8 shows the typical test apparatus. The samples are simply supported with the load applied to the center span in a downward direction. The load is applied using the 15/16" diameter steel rod backed up with a 5/8" x 4 5/8" x 5 3/4" flat plate to prevent premature failure of the composite tubes due to crushing. A 5" flange steel I-beam was centered on the lower test machine crosshead, and the simple supports, with small plates to prevent failure by crushing, were placed 40" apart. A linear variable displacement transducer, (LVDT) was used to measure the displacement of the steel I-beam during a flexure test of hollow tubes. Crosshead movement was taken as the displacement of the load point. All specimens were loaded at a constant rate of 0.667 inches per minute until failure. Data was collected from the Instron 4485 using its data acquisition system.

2.5 Sound Testing

The noise levels can be reduced at their source or blocked with the use of sound barriers [6-9]. Sound testing was performed to qualify the ability of a recycled shingle wall to act as a sound barrier. A wall was constructed by stacking five extruded shingle

blocks, produced by the shingle extruder, with dimensions 12” by 8” by 4”. The height, width, and thickness of the wall were 40”, 12”, and 4”. Wall thickness of 8” and 12” were also tested. A wall constructed from recycled shingle core-filled wood sleeves and a wall made of stacked cinder blocks, used as a basis of comparison, was also tested. A point sound source was placed 10’ in front of each of the shingle walls. A sound level indicator was used to measure the maximum decibel level (dB) over a four second interval at several locations behind the shingle wall. Data was taken at five locations parallel and six locations perpendicular to the shingle wall. Parallel readings were taken 2”, 4”, 6”, 8”, and 10” from the left side of the wall opposite the point sound source. Perpendicular readings were taken 0”, 2”, 4”, 6”, 8”, and 10” from the shingle wall opposite the point sound source. All readings were taken at a height of 20” from the ground. Table 3 contains data for a wall thickness of 4”.

2.6 Results and Discussion

2.6.1 Flexure Testing

Flexure testing was performed on two materials; composite tubes and oak beams. The maximum load (ML) within the linear-elastic region of the stress-strain curve will be used for comparison. This is the largest load at which both materials act similarly. The ML corresponds to the load at which the first fiber within an oak beam fails and the ultimate load of a composite tube. Although the oak beams at this point don’t fail, the stress-strain relation becomes unpredictable. The use of the ML is admissible because most structures are designed to take loads only within the linear-elastic region of the stress-strain curve.

The mean ML and standard deviation of the hollow tubes, composite tubes filled with procedure 1, composite tubes filled with procedure 2, and the oak beams are 17368 and 308, 19053 and 1819, 18365 and 580, and 7314 and 714 lbs., respectively. The standard deviations of each constitute 1.77, 9.55, 3.16, and 9.76 % of their own ML. The large standard deviation of the composite tubes filled with procedure 1 is assumed to be a result of varying degrees of bonding between the recycled shingle cores and the composite tubes and voids in its recycled shingle core. In an attempt to improve bonding and eliminate voids, the second filling procedure was developed. Tables 1 through 4 contain more detailed information than given above.

The composite tubes filled with procedure 1 and 2 have a mean ML 9.7% and 5.7% greater than the hollow tubes. The composite tubes filled using procedure 1 had a greater mean ML than those filled with procedure 2, while the composite tubes filled with procedure 2 had a standard deviation 1/3 of those filled with procedure 1. The mean ML of the hollow tubes, composite tubes filled with procedure 1 and procedure 2 were 137, 160.5, and 151 % greater than the ML of the oak beams.

Displacement of the steel beam used was found be insignificant compared to that of the specimens tested. Table 5 contains the displacement of the steel I-beam for four separate tests. Figure 9 shows a hollow composite after failure.

2.6.2 Sound Testing

The mean point sound source was measured at 97.57 decibels. Table 6 contains all point sound source readings taken. Since all readings for each wall configuration are approximately equal, a single mean decibel reading is used to characterize them. Figures

9 and 10 are of decibel level behind the 4" thick shingle wall versus location. Table 7 contains the decibel readings taken behind the 4" thick shingle wall. No trends can be seen in the data. The four shingle wall configurations had mean decibel readings of 86.19, 88.40, 86.84, and 88.99 decibels. The mean of all four-shingle wall configurations is 87.61 decibels. This compares to a mean decibel reading of 85.77 for the cinder block wall. The difference between the mean of all four configurations and the cinder block wall is 1.84 decibels. This difference is less than the standard deviation, 2.22 decibels, of the cinder block wall. Table 8 is an overview of all sound testing results.

2.7 Conclusions

Flexure testing of the composite tubes and oak beams allow several conclusions to be made. First, composite tubes have a much greater ML than oak beams. Individual composite tubes demonstrated an improvement in ML of 25% when compared to hollow composite tubes and an improvement in ML of 189% compared to the oak beams. This suggests that a composite railroad tie can withstand much greater loads, and thus have a greater lifespan, than an oak railroad tie. Second, recycled shingles can be used as a core material in a composite tube to further improve its ML. This will allow a composite railroad tie to withstand greater loads and have a greater lifespan than before. For current testing, the procedure used to fill the composite tubes greatly affected both their mean ML and standard deviation. Both the void percentage of the recycled shingle core and the bonding between the core and composite covering appear to greatly affect the flexure strength of a recycled shingle core filled composite tube. It is hoped that this problem will be eliminated during the manufacturing process of a full-scale composite railroad tie.

The results of the sound testing showed that a recycled shingle block wall and a cinder block wall, concrete, could reduce the decibel levels of a point sound source approximately equally.

3. SECTION B

3.1 Manufacturing

As per previous research, asphalt roof shingles were shredded using the shingle shredding machine and compressed into blocks using shingle extruder. Using an industrial strength asphalt-bonding agent two recycled shingle blocks were bonded end to end. The resulting block was then covered with a glass fiber mat and commercially available Bondo Epoxy resin was applied. Pressure was applied to all side of the composite wrapped recycled shingle block to prevent resin from flowing away from the block during curing.

3.2 Flexure Testing

A three point flexure test was performed, with dimensions 4" x 8" x 40", on hand lay-up composite wrapped recycled shingle beams and solid oak beams using an Instron 4485 universal testing machine, figure 10. The solid oak and the composite wrapped recycled shingle beams were manufactured as per the above section. A total of seven specimens were tested; two composite wrapped recycled shingle beams and five solid oak beams. All samples were loaded on the 4" wide side of the beams, giving the beams maximum flexure strength. A central load, placed on the 15/16" diameter steel rod, was used with all specimens. A 5/8" x 4 5/8" x 5 3/4" flat plate placed below the steel rod was used to prevent premature failure of the composite tubes due to crushing. Supports, with small plates to prevent failure by crushing, were placed 40" apart on a 5" flange steel I-beam. All specimens were loaded at a constant rate of 0.667 inches per minute

until failure. Data was collected from the Instron 4485 using its data acquisition system and personal computer. During previous research an LVDT, linear variable displacement transducer, was used to measure the displacement of the steel I-beam during the flexure testing. The machine and materials used during previous testing were used during the current round of testing, thus it was unnecessary to re-measure the deflection of the steel I-beam.

3.3 Results

Flexure testing was performed on two materials; composite wrapped recycled shingle beams and oak beams. The maximum load within the linear-elastic region of the stress-strain curve, ML, will be used for comparison. This is the largest load at which both materials act similarly. The ML corresponds to the load at which the first fiber within an oak beam fails and the ultimate load of a composite tube. Although the oak beams at this point don't fail, the stress-strain relation becomes unpredictable. The use of the ML is admissible because most structures are designed to take loads only within the linear-elastic region of the stress-strain curve.

The average ML of the five wooden beam samples tested was approximately 25 kips. Although the wooden beams themselves didn't completely fail at this point the wooden beams were significantly weakened by the failure of some of the fibers within the beams.

Unfortunately during the curing process much of the resin was able to flow away from the recycled shingle block, create large voids and irregularities. Only two of the bonded blocks and wrapped blocks were in sufficient condition to continue testing. Both

of the two composite wrapped recycled shingle blocks tested failed prematurely. The composite wrapping pulled away from the recycled shingle blocks.

3.4 Conclusions

Hand lay-up is not good manufacturing technique to use when covering recycled shingle blocks with composite materials. The weight of the recycled shingle blocks pushes resin from beneath the blocks during the curing process. This creates large sections of irregular resin thickness or even voids. Even though weight was applied to all sides of the blocks during the curing process resin can seep through a very small absence. Future research can look at the possibility of using a conforming die to prevent resin loss. Resin transfer molding may hold great promise to manufacture to full-sized composite wrapped recycled shingle railroad tie.

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Figure 1: Cutting section of the shingle-shredding machine.



Figure 2: Shingle Shredding Machine



Figure 3: Shingle Extruder



Figure 4: Shredded shingles.



Figure 5: Tube-filling machine spine, sled, and ram.

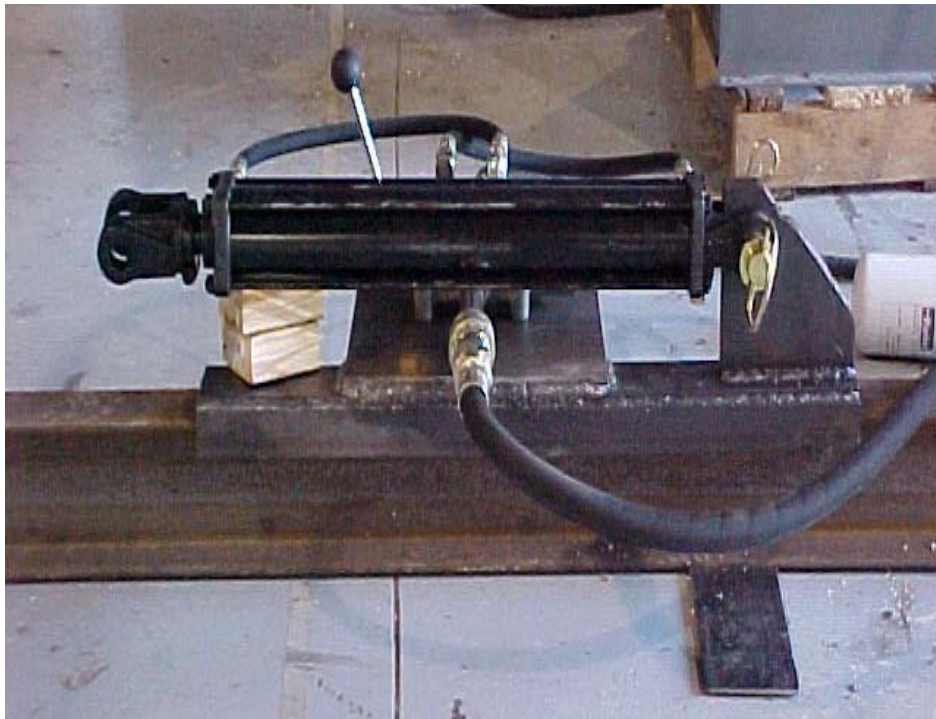


Figure 6: Tube-filling machine spine and ram when fully extended.



Figure 7: Mold for filling procedure 2.

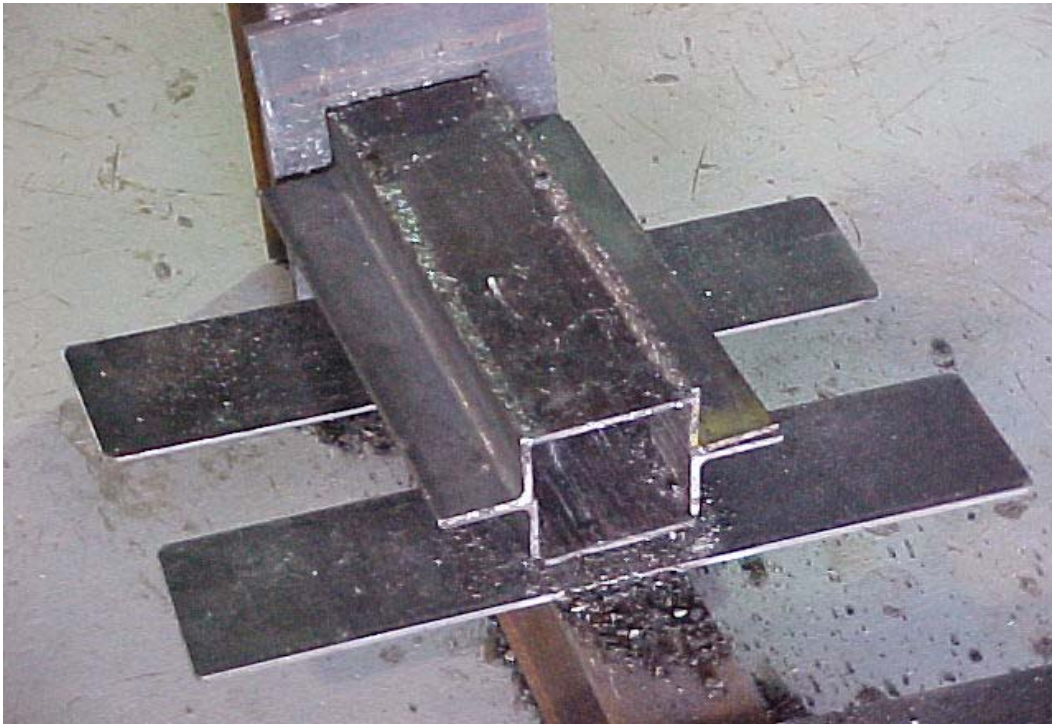


Figure 8: Testing of hollow composite tube using Instron 4485 machine.



Figure 9: Hollow composite tube after failure.

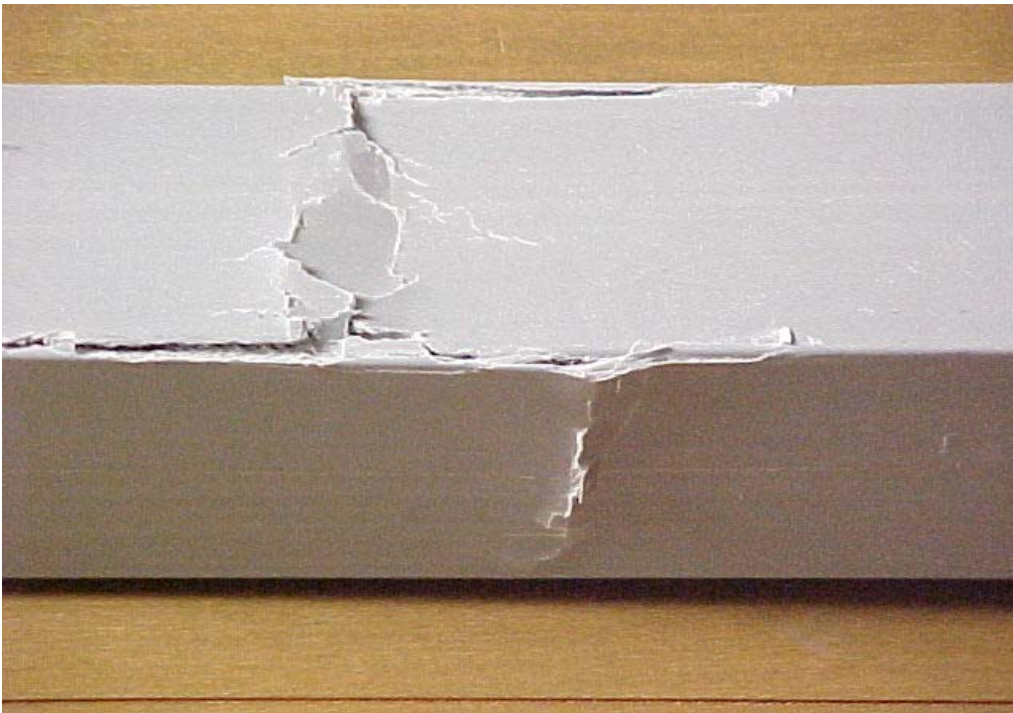
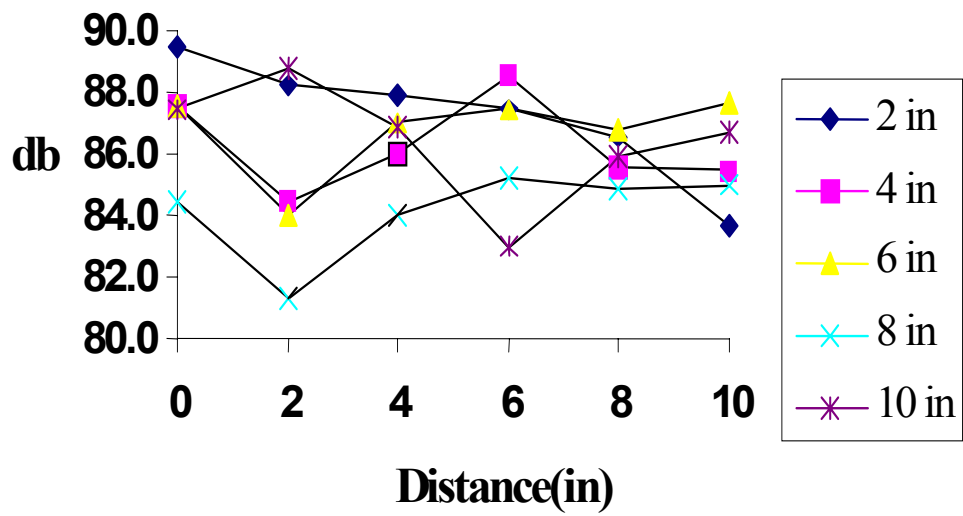


Figure 10: Three point bend test of 4" x 8" x 40" wooden beam.



Graph 1: Maximum decibel levels perpendicular to shingle wall with a thickness of 4".



Graph 2: Maximum decibel level parallel to shingle wall with a thickness of 4".

