Analyzing the Acoustical Properties of Alternative Materials in Guitar Soundboards to Reduce Deforestation

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June 7, 2013
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Date Submitted: June 7, 2013

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Faculty Advisor

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Acknowledgements

I would like to thank Ernie Ball Music Man in San Luis Obispo for providing samples of all twelve woods currently used in their guitar production. I would like to recognize the Cal Poly music department for allowing me to conduct all testing within their practice facilities. Finally, I would like to thank Dr. Linda Vanasupa for her acceptance in taking on this unique and intriguing project, as well as all of her guidance, expertise, and inspiring enthusiasm throughout the entire year.
Abstract

To mitigate the effects of deforestation, man-made alternative materials were analyzed and tested for potential use in the soundboards of acoustic guitars. The materials evaluated included 0.06 in. foamed polycarbonate, 0.12 in. single-ply honeycomb fiberglass, and 0.04 in. epoxy fiberglass. The properties of Sitka spruce, the most common tonewood, were used as a benchmark. The Young’s modulus to density ratio found in Sitka spruce is relatively high, making its properties ideal for soundboard applications. Both Young’s modulus and density were necessary to calculate the acoustic constant of each material that was tested. The samples were subject to the impact of an 8 oz. lead sphere, which struck the center points with a constant force of 0.25N. The collisions resulted in the propagation of sound waves within the structure. Materials were characterized by the resonating frequencies that they displayed between 50Hz and 20,000Hz. The tests were conducted in an anechoic chamber using an MXL 992 large-diaphragm condenser microphone. The microphone was held in a shock absorbent mount placed 12 in. from the center of each sample. The microphone’s built-in 20dB low-pass filter was activated to compensate for near-field-effects. The microphone signals were digitized with a PreSonus FirePod 96k audio interface with 24 bit resolution and 44100 Hz sampling rate. Incorporating Young’s modulus, shear modulus, internal friction, static mechanical properties, and testing results, the most suitable alternative to spruce was determined.

Keywords:
Materials, Engineering, Music, Guitar, Soundboard, Acoustic, Deforestation, Honeycomb, Composite, Spruce, Wood
Introduction

Every year it becomes more and more difficult for the makers of musical instruments (luthiers), to acquire the high quality materials that they find necessary to craft elite products. The traditional materials used for soundboards, spruce and cedar, are often over 200 years old\(^1\). Rosewood, the standard choice for side and back material, is now protected as an endangered species. The National Association of Music Manufacturers (NAMM) estimated the about 813,000 acoustic guitars were sold in 2005 alone and the rate is constantly increasing\(^2\) (Figure 1).

![Graph showing annual increase in guitar sales and associated costs](image)

**Figure 1 – An annual increase in guitar sales averaged 15%, while the cost associated with production actually decreased**

While the number of units sold annually is drastically increasing, the cost to manufacture each guitar is actually remaining fairly constant. An increase in offshore manufacturing has allowed for the prices to remain steady\(^1\). The identification and usage of sustainable materials is crucial to allowing the industry to maintain it’s current growth rate. The current custom of crafting guitars from Rosewood and Mahogany is not realistic because they are not sustainable products.
The CITES treaty is helping to preserve the biodiversity of the World’s forests by limiting access to the species of wood traditionally used for stringed instruments\(^1\). Along these same lines, as of April 2012, the Lacey Act has been regulating wooden instruments upon entering the United States. Originally initiated to limit the sales of wild birds, the act has been expanded to include the likes of many rare woods\(^3\). Companies, like Taylor Guitars, are attempting to reverse some of the early problems involving deforestation and sustainability. Specifically, Taylor is dealing with black ebony, a prized material for guitar fretboards that is nearing the verge of extinction (Figure 2)\(^4\). Currently, Cameroon is the last country in the world in which ebony can be legally harvested. According to CEO Bob Taylor, the harvesters explained that only one of every ten trees cut down had the potential of being sold due to their color impurities\(^4\). This practice was depleting the last stockpile on earth ten times faster than was necessary.

Figure 2 - Ebony, Maple, & Rosewood are the most common woods used for the fingerboards of guitars

Regarding their soundboards, Taylor still uses an incredible amount of spruce. The company currently makes about 300 guitars per day, and although availability of materials is not yet a problem, this will not always remain true (Figure 3)\(^4\). Taylor has attempted to mitigate these issues by implementing buyback programs, but this will only delay the real problems.
Traditional Materials

The traditional method of acoustic guitar construction uses spruce wood to craft the soundboard and rosewood to make the back and sides of the instrument (Figure 4). This tradition has stuck since the modern classical guitar was established in the middle 1800s. The range of alternative materials used in guitar fabrication is still quite limited to this day. It appears that this is due to the public’s resistance to change, as opposed to a lack of potential in new materials.
The ideal method for converting logs into guitar pieces is known as “quarter-sawing” (Figure 5)\(^1\). When logs are quarter-sawn, they are cut in such a manner that the grain is perpendicular to the longer side. In contrast, an alternative method of cutting is known as “slab-sawing” (Figure 5)\(^1\). Due to the reduction of waste, much of the commercially processed lumber is slab-sawn. Unfortunately, as the wood ages, the grain lines begin to straighten and the board starts to warp. This negatively affects the mechanical properties of the board as the grain angles change over time.

![Quarter-Sawn vs Slab-Sawn Lumber](image)

**Figure 5 – Quarter-Sawn lumber versus Slab-Sawn Lumber**

The highest quality instrument grade woods have certain assets that differentiate them. Most importantly, the grain lines of these woods are closely spaced together. Since every grain line represents approximately one year, these trees need to grow quite slowly. In order for a tree to be capable of yielding a piece of wood large enough for an acoustic guitar soundboard, it must often be extremely old. It is not uncommon to use trees that are over 200 years old in the production of high-end instruments\(^1\). Sitka spruce of the Pacific Northwest is an extremely popular choice because it fits these categories. Long and cold winters lead to slow growth rates and compact grain lines. Unfortunately, these trees are not always being harvested in a sustainable manner.
The first issue of harvesting 200-year-old trees begins with Mother Nature. The natural cycles of large forest areas include periodic fires and natural disasters that kill off many old trees. Most suitable forests simply do not contain enough of the old and large trees that the industry desires. The second issue is that many of the old growth forests in the United States have been heavily logged since the early 1700s\textsuperscript{5}. The old growth forestland that does still exist is now likely protected from any cutting. These high quality woods cannot be replaced at the same rate that they are being expended.

It is generally accepted that the material selection involved in the soundboard of the guitar is far more important than that of the back and sides. Known as the father of the modern guitar, Antonio de Torres (1817-1892) set out to prove this point by crafting a guitar with a spruce top, but a back and sides made from paper maché\textsuperscript{6}. The results were astonishing as his creation was said to have a tone that could match his other “wood-only” instruments. Tradition still remains faithful to this day, where soundboards are made almost exclusively from wither Engelmann spruce, Sitka spruce, or Western red cedar\textsuperscript{1}.

**Mechanical Requirements**

It appears that the industry has focused on spruce and rosewood as suitable materials mostly to comply with tradition and customer expectations. Although the properties of current materials are widely regarded, alternative material choices need not be eliminated without some further inspection. Some craftsmen like Jose Oribe, a world-renowned luthier, argue that only the best traditional materials are suitable for a high quality instruments\textsuperscript{7}. Yet others such as Bob Benedetto, another distinguished craftsman, argue that a skilled luthier can make a respectable instrument out of almost any wood\textsuperscript{8}. Enforcing Benedetto’s point, Bob Taylor of Taylor guitars crafted an extremely popular guitar using only scrap wood salvaged from a shipping yard (Figure 6)\textsuperscript{1}. It was so prevalent that a limited edition version went into production and immediately sold out.
It is probable that material selection is flexible if luthiers are able to successfully create adequate instruments from inferior materials. We can also infer that the mechanical properties are, to an extent, variable. While different areas of the guitar require different mechanical properties, the back and sides of the instrument are the least demanding\(^1\). The soundboard is the most likely to be affected by poor mechanical properties. It has been shown that the bending process can severely impact the mechanical and acoustical properties of wood (Figure 7)\(^9\).
The ideal soundboard is stiff and light. In order to achieve the best results, it is important to find a material with high ratio of Young’s Modulus (E) versus Density (ρ). The speed of sound through wood can be modeled separately for various materials (Equation 1).

\[ c = \sqrt{\frac{E}{\rho}} \]  

(1)

There is a fundamental difference between longitudinal waves and bending waves in an elastic material\(^1\). The longitudinal waves act as pressure waves propagating through the back plate or soundboard. They are labeled as non-dispersive waves because their speed is not a function of frequency\(^10\). Bending waves on the other hand are labeled dispersive waves and their plane displacement and propagation speed are functions of the frequency\(^10\).
When developing a soundboard, material selection should also be dependent on the materials acoustic constant (\(A\)). The acoustic constant can be modeled using the elastic modulus and the density (Equation 2)\(^1\). The ideal samples of traditional spruce have been analyzed and have average values of \(\rho = 427 \text{ kg/m}^3, A=13.2 \text{ m}^4/\text{kg·s}, E=13.6 \text{ GPa}\).

\[
A = \frac{c}{\rho} = \sqrt[3]{\frac{E}{\rho^3}}
\]  \(\text{(2)}\)

It is important that the non-isotropic nature of the wood is considered. The material properties will always vary in the directions parallel and perpendicular to the grain. This is actually a benefit to the guitar making process. Because the microstructures can be aligned so that the stronger axis can withstand the force and tension from the guitar strings, the instrument is less likely to warp or bow in the future. The fact that wood is able to resist the string tension while remaining flexible across a separate axis is extremely important in allowing the propagation of sound waves\(^1\).

**Lifecycle**

Lifecycle management techniques must be implemented into the guitar manufacturing industry in order to allow for the longevity of future instrument production. If enforcing lifecycle management requires more acoustic guitars to be made from alternative “non-traditional” materials, those materials must first be investigated. Recycling and reusing materials are always an option, but if an equally suitable and sustainable material does exist, now is the time to discover it. While many overharvesting regulations are in place within the United States, it is unfortunately not the case worldwide (Figure 8). Countries, such as Cameroon, are not able to stop the deforestation of even their most precious rare hardwoods. These effects from overharvesting could be catastrophic.
Figure 8 – Lack of sustainability regulations abroad have the potential to wipe out precious hard woods such as ebony

**Alternative Materials**

With an end goal of finding a non-wooden material that will adequately replicate the supreme properties of Sitka spruce, four man-made alternatives were theorized to be suitable soundboard candidates. The first material speculated was foamed polycarbonate. While foamed polycarbonate has previously been implemented in guitar manufacturing, it has yet to be used for the application of a soundboard. Standard epoxy fiberglass was considered as well due to its low density, sufficient modulus, and low cost. Last, fiberglass honeycomb composite was included as an option since it’s mechanical properties perfectly fit into the desirable range.

**Foamed Polycarbonate**

Foamed polycarbonate is a tough versatile polymer used in a wide range of applications. Polycarbonate can be found anywhere from bulletproof windows to patio roofing (Figure 9). The material is ideal due its high strength to weight ratio. While thick polycarbonate is nearly unbreakable, it weighs just 1/6 that of glass. Foamed polycarbonate yields a density of only 0.65 g/cm³, yet maintains an elastic modulus value of approximately 13.5 GPa. Among these positive qualities, foamed polycarbonate is also relatively cheap, helping its potential to function an acceptable soundboard replacement.
Epoxy Fiberglass

Epoxy Fiberglass is a fiber-reinforced polymer consisting of glass fibers residing in an epoxy matrix (Figure 10). Applications include boat hulls, surfboards, bathtubs, and much more\textsuperscript{11}. The glass fibers lining the interior of the material provide the majority of the strength, while the epoxy matrix serves to protect the glass and keep everything in order. Epoxy fiberglass is lightweight, extremely strong, and relatively robust\textsuperscript{10}. While the strength values may seem low when compared to materials such as carbon fiber, epoxy fiberglass is normally far less brittle and much cheaper\textsuperscript{11}. Although the density is more than twice the value of foamed polycarbonate at 1.41 g/cm\textsuperscript{3}, the elastic modulus is a staggering 55 GPa in the direction of the glass fibers\textsuperscript{1}. 

\textbf{Figure 9 – Foamed Polycarbonate in the form of weather shielding}

\textbf{Figure 10 – Epoxy fiberglass panels}
Single-Ply Fiberglass Honeycomb Composite

A single-ply fiberglass honeycomb composite is a relatively new material currently making a name for itself in a variety of applications with special attention to aeronautical fields (Figure 11). Normally honeycomb composites contain an aramid core oriented in a honeycomb pattern, as well as fiberglass sheets that are adhered to each side using specialty adhesives. The resulting panels are extremely light weigh, yet incredibly strong and stiff. One of the most traits of honeycomb panels can be seen in their resilience to heat. High temperature applications up to 400 °F can benefit from the properties found in this material. With a density of only 0.28 g/cm³, the panels still manage to yield an elastic modulus of approximately 7 GPa.

![Figure 11 – Single-ply fiberglass honeycomb composite panel](image)

Carbon Fiber

Carbon Fiber is an extremely popular material containing fibers ranging from 5-10 μm in diameter (Figure 12). These tiny fibers are normally suspended in an epoxy matrix resulting in a light and strong final product that also happens to be quite aesthetically pleasing. Although the mechanical properties, popularity, and attractiveness of carbon fiber make it an obvious choice for guitar fabrication, it was not used as a sample. Carbon fiber has previously been crafted into acoustic
instruments and there are currently issues that plague the design. Carbon fiber is much more expensive when compared to any of the other alternative materials proposed; yet the sound does not justify the cost increase. The tones of carbon fiber instruments are described as “bright” and “tinny”. This is directly associated with the increased projection of frequencies above 15,000 KHz.

Figure 12 – Acoustic guitar made from a carbon fiber composite

**Experimental Procedure**

For decades the process for testing the acoustic properties of different materials has always been purely qualitative. Luthiers have analyzed resonance and sound propagation using nothing more than their ears. It was important that the experimental procedure being implemented here introduced quantitative techniques and methods to help aide in selecting the proper final result.

The first step in developing a testing method was determining what qualities superior soundboards holds. Because the goal of the procedure was to find what material best replicates Sitka spruce, the natural occurring waveform of Sitka spruce was used as a benchmark. In theory, a material that has a low density, a high elastic modulus, and a naturally occurring waveform comparable to Sitka spruce is most likely to function as a quality acoustic soundboard. The frequencies that naturally resonated through each
sample were observed along with the amplitude of each peak wave.

Initially, fifteen different materials were formed into identical samples and arranged for the testing process (Figure 13). The samples were cut to dimensions of 6” x 3” x 0.5”. Two small holes were drilled at the top corners of each sample for hanging purposes. Samples were accurately measured and weighed in order to calculate actual densities as well as acoustical constants.

![Figure 13](image)

**Figure 13 – Samples listed from top left to bottom right. (Row 1) Ash, Ebony, Rosewood, Pau Ferro, Mahogany. (Row 2) Basswood, Yellow Poplar, Spruce, Koa, Maple. (Row 3) Alder, Honduran Mahogany, Foamed Polycarbonate, Honeycomb Composite, Epoxy Fiberglass.**

A stable PVC (polyvinyl chloride) apparatus was constructed in order to facilitate the testing of samples (Figure 14). The structure was 2.5’ x 2.5’ at the base and rose approximately 3’ in height. A 12” piece of fishing line, rated at 6 lbs., was suspended from the center of the PVC crossbar. An 8 oz. lead ball was attached to the end of the fishing line and was allowed to freely hang. A protractor was fixed in place atop the crossbar in order to conveniently maintain a consistent drop force among all samples. The 8 oz. weight was released from an angle of 45°, striking with a force of approximately 0.25 N at the center point of each sample. Samples were strung via fishing line at the 1/3-point and 2/3-point of the PVC crossbar. Again fishing line was used in order to limit interruptions in the natural resonating frequencies and vibrations propagating through the samples.
Figure 14 - Complete testing apparatus containing PVC frame, lead weight, condensor microphone, and free hanging sample

All samples were struck at their center point five separate times with a constant force. An MXL 992 large-diaphragm condenser microphone was placed 12 in. from the center of each sample (Figure 15). The microphone was placed within a shock absorbent mount and the built-in 20dB low-pass filter was activated to compensate for near-field-effects. The microphone signals were digitized with a PreSonus FirePod 96k audio interface with 24 bit resolution and 44100 Hz sampling rate (Figure 16). The average taken from a combination of strikes was combined into a single waveform for each of the fifteen samples. The resonance was analyzed and plotted using Spectra Frequency Analyzing software. The software was able to determine the exact amplitude of every frequency that resides in the spectrum of human hearing. The human ear ranges in wave detection from approximately 50 Hz to 20,000 Hz. A graphical interpretation was created in order to help better visualize exactly what was occurring within each sample.
Results

Once all samples were scaled to the proper dimensions, basic measurements were taken and recorded. The weight and volume of each sample was used in order to determine the actual densities of the materials. This was important due to the key role that density plays in determining the acoustic constant (Table 1).

Table 1 – Samples (Physical Properties)

<table>
<thead>
<tr>
<th>Wood</th>
<th>Weight (g)</th>
<th>Height (cm)</th>
<th>length (cm)</th>
<th>width (cm)</th>
<th>Volume (cm³)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>African Mahogany</td>
<td>46.93</td>
<td>0.90</td>
<td>15.40</td>
<td>7.80</td>
<td>108.11</td>
<td>0.43</td>
</tr>
<tr>
<td>Alder</td>
<td>42.79</td>
<td>0.70</td>
<td>15.50</td>
<td>7.70</td>
<td>83.55</td>
<td>0.51</td>
</tr>
<tr>
<td>Ash</td>
<td>41.23</td>
<td>0.70</td>
<td>15.40</td>
<td>7.80</td>
<td>84.08</td>
<td>0.49</td>
</tr>
<tr>
<td>Basswood</td>
<td>67.41</td>
<td>1.00</td>
<td>15.60</td>
<td>8.80</td>
<td>137.28</td>
<td>0.49</td>
</tr>
<tr>
<td>Figured Maple</td>
<td>36.96</td>
<td>0.50</td>
<td>15.50</td>
<td>7.80</td>
<td>60.45</td>
<td>0.61</td>
</tr>
<tr>
<td>Ebony</td>
<td>98.95</td>
<td>0.70</td>
<td>15.50</td>
<td>6.90</td>
<td>74.87</td>
<td>1.32</td>
</tr>
<tr>
<td>Epoxy Fiberglass</td>
<td>16.33</td>
<td>0.10</td>
<td>14.80</td>
<td>7.80</td>
<td>11.54</td>
<td>1.41</td>
</tr>
<tr>
<td>Foamed Polycarbonate</td>
<td>14.22</td>
<td>0.20</td>
<td>14.60</td>
<td>7.50</td>
<td>21.90</td>
<td>0.65</td>
</tr>
<tr>
<td>Honduran Mahogany</td>
<td>42.74</td>
<td>0.50</td>
<td>15.30</td>
<td>7.80</td>
<td>59.67</td>
<td>0.72</td>
</tr>
<tr>
<td>Honeycomb Composite</td>
<td>13.67</td>
<td>0.40</td>
<td>15.50</td>
<td>7.80</td>
<td>48.36</td>
<td>0.28</td>
</tr>
<tr>
<td>Koa</td>
<td>30.02</td>
<td>0.40</td>
<td>15.40</td>
<td>7.80</td>
<td>48.05</td>
<td>0.62</td>
</tr>
<tr>
<td>Pau Ferro</td>
<td>75.40</td>
<td>0.70</td>
<td>15.60</td>
<td>6.90</td>
<td>75.35</td>
<td>1.00</td>
</tr>
<tr>
<td>Piano Action Maple</td>
<td>58.47</td>
<td>0.70</td>
<td>15.30</td>
<td>7.80</td>
<td>83.54</td>
<td>0.70</td>
</tr>
<tr>
<td>Poplar</td>
<td>42.26</td>
<td>0.70</td>
<td>15.40</td>
<td>7.80</td>
<td>84.08</td>
<td>0.50</td>
</tr>
<tr>
<td>Rosewood</td>
<td>62.84</td>
<td>0.70</td>
<td>15.40</td>
<td>6.90</td>
<td>74.38</td>
<td>0.84</td>
</tr>
<tr>
<td>Sitka Spruce</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
After the densities were calculated, the elastic modulus value was obtained for all materials using CES software. Using Equation 2, the acoustic constant could be computed and recorded (Table 2).

Table 2 – Samples (Mechanical Properties and Wave Analysis)

<table>
<thead>
<tr>
<th>Wood</th>
<th>Peak Freq (Hz)</th>
<th>Peak Amplitude (dB)</th>
<th>Power (dB)</th>
<th>Actual Spec. Grav</th>
<th>janka Hardness (N)</th>
<th>Elastic Modulus (GPa)</th>
<th>Modulus of Rupture (MPa)</th>
<th>Acoustic Constant (m²/kg*s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>African Mahogany</td>
<td>1736.99</td>
<td>-67.51</td>
<td>-56.88</td>
<td>0.55</td>
<td>4040</td>
<td>9.54</td>
<td>84.40</td>
<td>7.57</td>
</tr>
<tr>
<td>Alder</td>
<td>1464.26</td>
<td>-65.82</td>
<td>-57.71</td>
<td>0.50</td>
<td>2890</td>
<td>8.99</td>
<td>75.90</td>
<td>8.48</td>
</tr>
<tr>
<td>Ash</td>
<td>1302.76</td>
<td>-56.27</td>
<td>-51.61</td>
<td>0.45</td>
<td>3780</td>
<td>11.00</td>
<td>86.90</td>
<td>10.99</td>
</tr>
<tr>
<td>Basswood</td>
<td>1922.00</td>
<td>-65.20</td>
<td>-59.31</td>
<td>0.43</td>
<td>1824</td>
<td>10.70</td>
<td>60.00</td>
<td>11.60</td>
</tr>
<tr>
<td>Figured Maple</td>
<td>1378.13</td>
<td>-40.22</td>
<td>-38.65</td>
<td>0.55</td>
<td>3780</td>
<td>10.00</td>
<td>73.80</td>
<td>7.75</td>
</tr>
<tr>
<td>Ebony</td>
<td>1376.00</td>
<td>-69.38</td>
<td>-58.54</td>
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<td>14320</td>
<td>17.20</td>
<td>167.60</td>
<td>3.97</td>
</tr>
<tr>
<td>Epoxy Fiberglass</td>
<td>1324.29</td>
<td>-45.96</td>
<td>-44.63</td>
<td>1.82</td>
<td>55.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foamed Polycarbonate</td>
<td>635.23</td>
<td>-58.26</td>
<td>-51.33</td>
<td>0.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Honduran Mahogany</td>
<td>1498.00</td>
<td>-65.50</td>
<td>-57.34</td>
<td>0.66</td>
<td>4000</td>
<td>9.56</td>
<td>80.40</td>
<td>5.77</td>
</tr>
<tr>
<td>Honeycomb Composite</td>
<td>1397.00</td>
<td>-61.07</td>
<td>-53.74</td>
<td>0.32</td>
<td></td>
<td>7.00</td>
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<td>2270.00</td>
<td>13.60</td>
<td>2270.00</td>
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The acoustic constant values of each material were plotted against their measured densities. The non-wooden alternative materials were then labeled in comparison to the wooden Sitka spruce benchmark (Figure 17). As expected, the graph produced a linear result directly proportional to density.
The waveform of Sitka spruce was analyzed and used as a benchmark for all other samples (Figure 18). The most significant results of the fifteen tested materials are displayed. Also, the waveform of a material with good natural resonance is displayed in order to compare similarities between Sitka spruce and itself (Figure 19). The waveform of a material with very poor natural resonance is shown as well (Figure 20).

**Figure 17 - Graphical relation between acoustic constant and density**

**Sitka Spruce Waveform Analysis**

**Figure 18 - Sitka spruce, used as the benchmark in which to compare all other waveforms**
Discussion

The top alternative material for the construction of an acoustic guitar soundboard was determined to be the sample that could best replicate the properties found in Sitka spruce (Figure 21). As the industry standard for acoustic guitars, spruce has a low density but still maintains a high elastic modulus. Equation 2 incorporates both the density and elastic modulus to determine that Sitka spruce has an acoustic constant of approximately 13.22 $\text{m}^4/\text{kg} \cdot \text{s}$. The only other sample to surpass this high value was the honeycomb composite sample. The honeycomb composite yielded an acoustic constant value of 14.62 $\text{m}^4/\text{kg} \cdot \text{s}$. 

Figure 19 – Honeycomb Composite, an example of a material with ideal natural resonance

Figure 20 – Epoxy Fiberglass, an example of a material with poor natural resonance
Although the acoustic constant yields an extremely useful quantitative value, it is only a portion of all that must be considered before determining the most feasible alternative. The waveforms generated through the frequency analyzer must be compared. Because the range of human hearing spans such a large gap, 50 Hz (Hertz) – 20,000 Hz, the graph must be broken down into smaller sub categories. Anything residing below 640 Hz is referred to as the “low range”. The frequencies found between 600 Hz and 5,000 Hz are in the “mid-range”. All frequencies above 5,000 Hz are occurring in the “high range”.

First, Figure 18 was closely analyzed in order to determine which properties of Sitka spruce sound waves make it so unique. The low end has almost no definitive peaks, yet still maintains a constant linear digression that crosses the entire human audio spectrum. As the frequencies increase, the amplitude steadily decreases at a constant rate. The midrange shows an abrupt peak around 1500Hz. This can be referred to as the natural resonating frequency of Sitka spruce. Also, the high end displays even more consistency, while still demonstrating minimal distortion, or loss of clarity in the waveform.
Figure 20 shows the waveform that propagated through the epoxy fiberglass sample. It is a perfect example of a material with poor natural resonance. Epoxy fiberglass would not make an ideal guitar soundboard due to the distribution of its internal frequencies. Two main factors lead to its less than desirable tone. Within the frequency analyzer, it is clear that the waveform does not maintain a constant linear digression across the audio spectrum. The slope of the waveform even becomes positive around 10,000 Hz, while simultaneously becoming very convoluted with noise distortion. This leads to excessive projection in the high range, resulting in an unattractive tone.

The most suitable alternative to Sitka spruce can be seen in Figure 19. The single-ply fiberglass honeycomb composite does an excellent job replicating spruce, while providing an even higher acoustic constant. It is clear that the honeycomb waveform contains little to no distortion, along with a constant linear digression between the low range and the high range. The slope closely rivals that of spruce; enforcing the theory that honeycomb fiberglass composite has the potential to function as a high quality guitar soundboard (Figure 22).
Conclusion

1. Deforestation is a problem that persists across the globe. Precious hardwoods are becoming endangered due to the lack of sustainable harvesting techniques. The effects can be reduced with the implementation of non-wood alternative materials in acoustic guitar soundboards.
2. Fifteen different materials were tested. Four of the tested materials were non-wooden alternatives. All samples were analyzed in order to determine their potential in replicating the properties of Engelmann spruce, Sitka spruce, and Western Red cedar.
3. The fiberglass honeycomb composite yielded an ideal waveform similar to the natural frequencies found in Sitka spruce. The linear regressions found between 10,000 Hz and 20,000 Hz were comparable. The quantity of natural distortion between the two materials were also similar
4. The honeycomb composite was the only material with a greater acoustic constant than that of Sitka spruce. It appears that the single-ply fiberglass honeycomb composite provides the best possibility to successfully create a high quality non-wooden soundboard.
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