Material Science – ENGG*2120: Fall 2017
LAB SUBMISSION COVER SHEET
(Must be included for all group submissions)

Lab Performed: Compressive Testing of Materials

Date Performed: Friday, September 29th, 2017

Date Submitted: Friday, October 20th, 2017

Group Number: K1

GTA Name: Oscar Valerio Gonzalez

GROUP PARTICIPATION EVALUATION FORM

*****ALL GROUP MEMBERS MUST SIGN TO RECEIVE THEIR MARKS*****

By signing the cover sheet each member is stating that they made a significant contribution to the writing of this lab report and that the distribution of sections completed is accurate.

One form is required for each group report submitted. One report is to be submitted **per group.**

All submissions to be submitted electronically to the dropbox in Courselink by **NO LATER THAN** 4:00 p.m., two (2) weeks after the assigned experiment is performed (unless otherwise indicated in the course outline).

Group Members		**Sections Completed**
Name (Printed)	**Signature**	
Noah Montag	Noah Montag	Summary, Experimental Apparatus and Procedures
Melissa Hardy	MHardy	Introduction, Conclusion, Formatting
Daniel Sherman	DSherman	Results, Discussion Question 1
Bilal Ayacche		Discussion Questions 2-7

Compressive Testing of Materials

Group K1:
Noah Montag (0975514)
Melissa Hardy (0960180)
Daniel Sherman (0954083)
Bilal Ayacche (0988616)

*ENGG*2120*

Dr. Ryan Clemmer, P.Eng. | University of Guelph SOE

Summary

Enclosed in this report are strength and ductility comparisons of four different materials; vertical grain pine wood block, horizontal grain pine wood block, aluminum can, and PVC pipe. They were tested using an Instron testing machine which pushes downwards on the samples individually until they reach a “breaking point”, or whenever the material fails to support the load and snaps. The vertical grain pine wood block was easier to split than the horizontal grain pine wood block due to cellulose within the fibers being stronger than the lignin which holds the fibers together. Pine has an approximate compressive strength of 55-100 MPa, where aluminum cans have one of about 120-415 MPa, and PVC pipe of a similar diameter to the one in our sample has a compressive strength of around 50-150 MPa.

All samples were damaged in some way shape or form. The aluminum can was slightly dented but it snapped back into basically the same shape as prior to the experiment. The PVC pipe was permanently deformed and folded in such a way that it left several triangular shapes when looked at. The two woods were also permanently deformed and were chipped and cracked. The ultimate compressive strengths measured were as follows; aluminum can: 14.43 MPa, horizontal grain pine: 4.81 MPa, vertical grain pine: 0.02 MPa, and PVC pipe: 50.66. The Young’s Modulus (MPa) were 4000.6, 202.8, 1.55, and 2000000, respectively. The 0.2% Offset Yield Strengths (MPa) were respectively 7.79, 2.59, 0.008, and 26.615.

The PVC pipe ended up being the strongest based on this experiment by a large amount. The aluminum can was second strongest, followed by the horizontal grain wood block and vertical grain wood block. The aluminum can should actually be stronger than the PVC based on the external

research that was gathered. This may be because the aluminum can is on the lower end of its strength range, whereas the PVC pipe is on the higher end, and the exact alloy of aluminum was unknown so the exact compressive strength is actually unknown and it could be less than the type of aluminum can whose compressive strength was found in external research.

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Introduction

In this experiment, four materials with distinct characteristics were tested to determine their respective strength and ductility. This was done through the use of an Instron testing machine, which tested each material individually by providing a downwards force upon the sample until a “breaking point” was reached. This “breaking point” refers to the moment when the material fails and is detected by the instrument when there is a sudden movement of the press, indicating to the machine to cease the compression and data records.

Of the four materials tested, two were made of wood, pine specifically. However, the grain structures of these samples differed; one was vertical-grain, and the other, horizontal. Pine is relatively weak in comparison to other wood species (compressive strength of ~55-100 MPa), and furthermore, it is much easier to split wood along the direction of the grain than it is to break it perpendicular to the grain direction, due to the cellulose within the fibers having a greater strength than that of lignin (which holds the fibers together).[1]

The other two materials were: a) aluminum alloy sheet metal in the form of a cylindrical can, and b) PVC formed into a pipe. Generally, the aluminum alloy which beverage cans are composed of in North America include 3400, 3105, or other 3xxx/5xxx series aluminum, which include small percentages of manganese, magnesium, and chromium.[2] The varying percentages of these other metals significantly improve the tensile strength of aluminum, with the tensile strength of the alloys (directly related to the compressive strength) ranging from ~120-415 MPa.[3] Moreover, PVC pipe with a diameter of ~82 mm (very close to that of the sample) has a compressive strength of ~50-150 MPa.[4]

Experimental Apparatus and Procedures

The experimental apparatus and procedures outlined in the ENGG*2120 Lab Manual were followed exactly to perform this lab. Refer to that to recreate the lab.

Results

Material	**Before Dimensions (mm)**	**Deformation**	**Failure**	**Rate of Compression (mm/min)**	**After Dimensions (mm)**
Metal Can	Diameter = 57.02 Height = 138.78 Thickness = 0.1	– Dented, but not permanently deformed	Sudden	5	Negligible differences
PVC Pipe	Outer diameter = 82.26 Inner diameter = 76.79 Height = 126.93	– Permanently deformed in triangular at bottom of pipe – No deformation at top of pipe.	Gradual (bending)	40	Outer diameter = 86.45 Inner diameter = 75.71 Height = 125.31
Vertical-Grain Pine Wood	Length = 22.09 Width = 21.43 Height = 67.1	– Permanently deformed/broken along lines (not grain) of wood – Triangular crack along bottom.	Sudden	10	Length = 28.79 Width = 23.59 Height = 44.76
Horizontal-Grain Pine Wood	Length = 43.01 Width = 41.17 Height =132.55	– Permanently deformed/broken along lines (not grain) of wood – Bent sideways at top – No deformation at bottom	Sudden	10	Length = 42.83 Width = 45.26 Height = 130.54 Crack width = 38.1 Crack length = 28.8

TABLE 1: GENERAL OBSERVATIONS

Material	**Ultimate Compressive Strength (MPa)**	**Young's Modulus (MPa)**	**0.2% Offset Yield Strength (MPa)**
Metal Can	14.43	4000.6	7.79
Horizontal-Grain Pine	4.81	202.8	2.59
Vertical-Grain Pine	0.02	1.55	0.008
PVC Pipe	50.66	2.00E+06	26.615

TABLE 2: COMPILED RESULTS FROM ALL TESTING

UCS (Decreasing order): PVC Pipe, Metal Can, Horizontal-Grain Pine, Vertical-Grain Pine

Young's Modulus (Decreasing order): PVC Pipe, Metal Can, Horizontal-Grain Pine, Vertical-Grain Pine

0.2% Offset Yield Strength (Decreasing order): PVC Pipe, Metal Can, Horizontal-Grain Pine, Vertical-Grain Pine

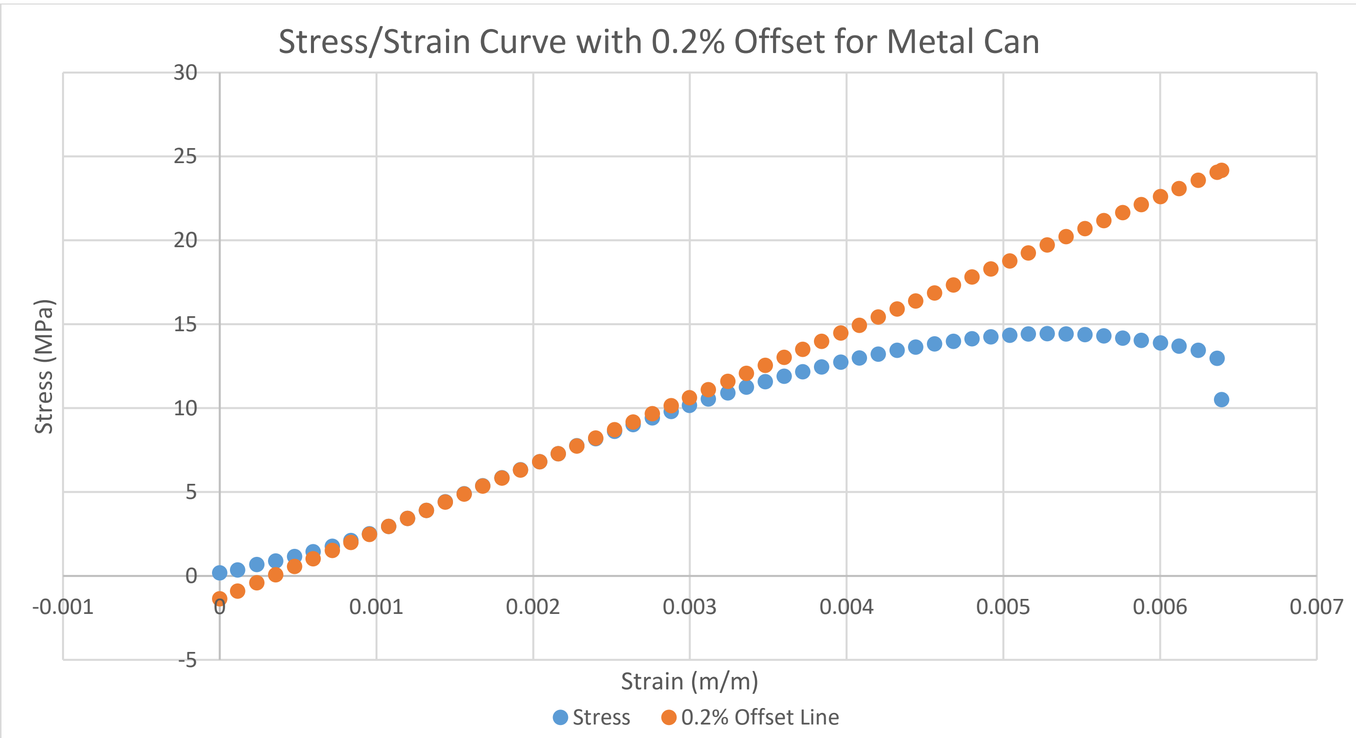

FIGURE 1: STRESS/STRAIN CURVE WITH 0.2% OFFSET FOR METAL CAN

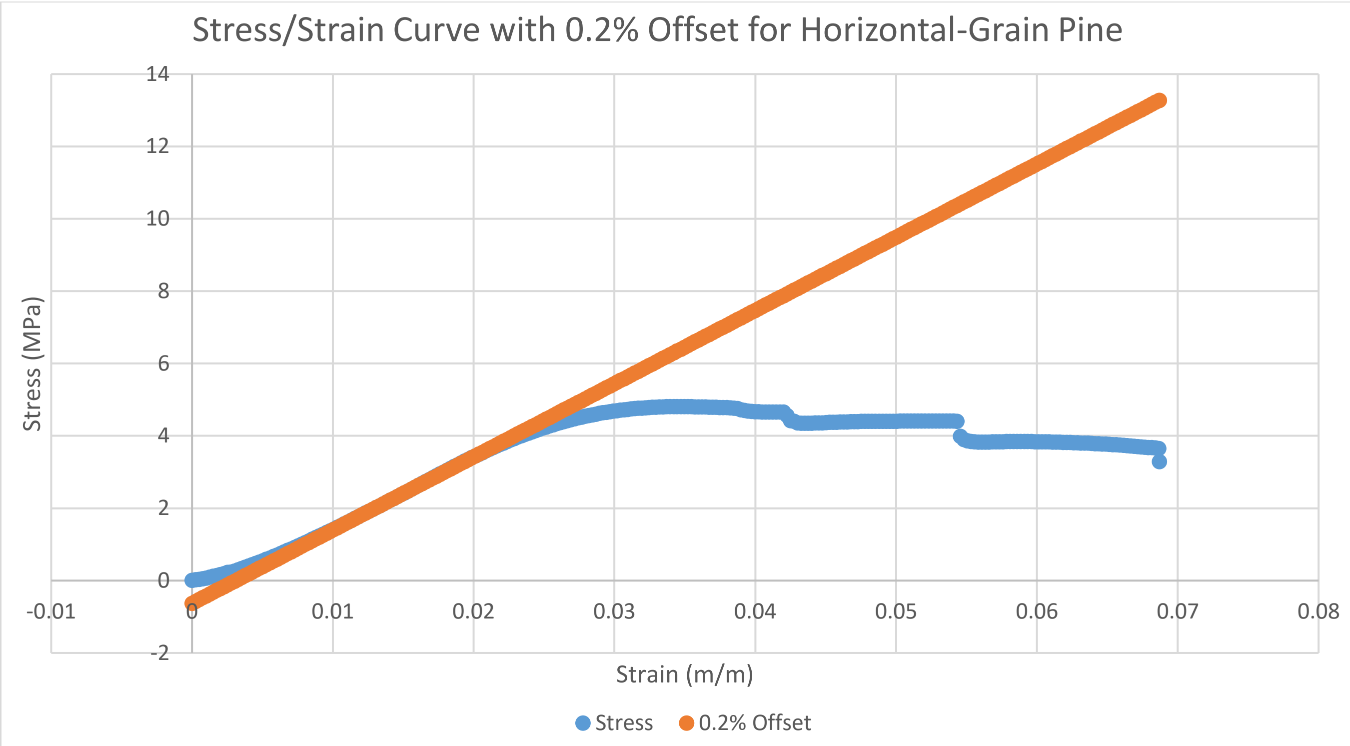

FIGURE 2: STRESS/STRAIN CURVE WITH 0.2% OFFSET FOR HORIZONTAL-GRAIN PINE

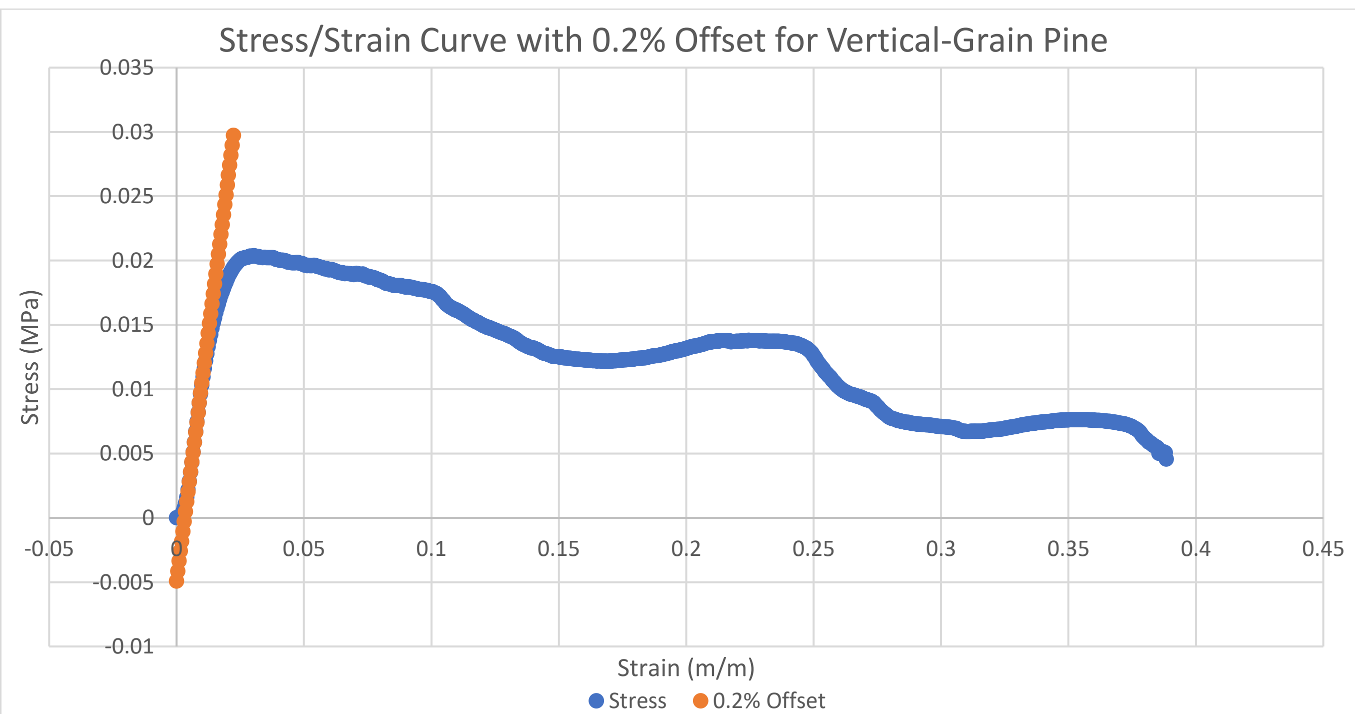

FIGURE 3: STRESS/STRAIN CURVE WITH 0.2% OFFSET FOR VERTICAL-GRAIN PINE

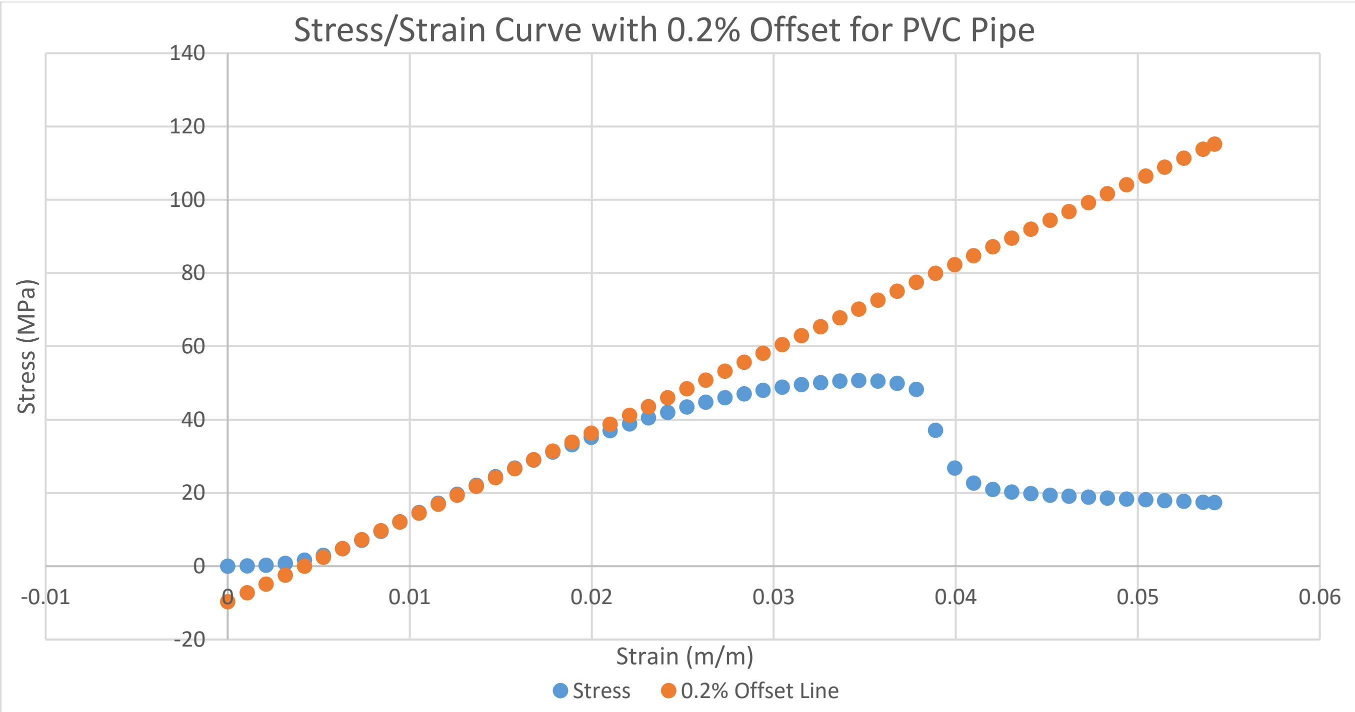

FIGURE 4: STRESS/STRAIN CURVE WITH 0.2% OFFSET FOR PVC PIPE

Sample Calculation:

To plot the Stress/Strain curve, the data collected needed to be treated heavily.

To plot the Strain, the compression values needed to be treated. To convert them to Strain values, the formula used is as follows:

$$\varepsilon = \frac{Compression}{h}$$

Where h is the height was the height of the sample. Next, the Forces needed to be converted to Stresses, to do so, the following was used:

$$\sigma = \frac{F}{A}$$

Where F is the Force and A is the cross-sectional area of the sample. Because the samples were different shapes, different formulas needed to be used for cross sectional area. Using the Maximum function in Excel, the Ultimate Compressive Strength was found, by putting all the Stress values into above mentioned function. Once the units were converted to the preferred units, the Stress/Strain curve was plotted. To find the elastic region, the domain where the rate of change was constant needed to be found. To do this the approximate derivative was taken using the formula:

$$\frac{d\sigma}{d\varepsilon} \sim \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1}$$

The region where this value was approximately the same as the adjacent values was deemed to be the Elastic region. Then, the Elastic region was plotted to its own graph and a linear trend line was found. The slope of the trend line was Young's Modulus. To find the 0.2% Offset Yield Strength, a line of the same slope of Young's Modulus needed to be shifted over by 0.2% of each corresponding Strain value. To do this, each Strain value in the Elastic region was multiplied by 1.002, to shift it over by 2%. Each of its Stress values remained untouched. Taking any of the points, a slope (Young's Modulus), and a point were given. Hinging the equation of a line, $\sigma_{ELastic} = E\varepsilon + b$, where b is the stress-intercept, the equation of a line was found and plotted on the Stress/Strain curve. Finally, the point of intersection between the line and the curve was looked at, and recorded as the 0.2% Offset Yield Stress.

Discussion

1. In general, the Ultimate Tensile Strengths were larger than the Ultimate Compressive Strengths found in the lab. The only exception to this trend was the PVC Plastic, which was right in the found

range. According to the Cambridge School of Engineering, the UTS of PVC Plastics are between 40.7 and 65.1 MPa, which fits the range that was found in the lab. However, for the Wood and the Metal Can, the UTS values that were found were all much larger, which indicates that the materials are stronger in tension than compression.

2. The physical structure of pine wood can be described as a bunch of spaghetti sticks tightly packed against each other. To analyse this analogy, imagine how much easier it is to snap a single spaghetti stick along its length than to snap it from tip to tail. When a force is applied parallel to the length of the pine wood that applied force only has to overcome the ultimate compressive strength of that one spaghetti stick. It gets harder for a force to break through the grain once the force is applied perpendicular to the length of the pinewood. When force is applied perpendicular to the length of this specific material, it would require a greater force to break through or reach failure. The orientation at which the force is applied vs the orientation of the grain structure plays a huge role in deciding how fast the material reaches its breaking point. Using the analogy mentioned above and the information provided, it is clear that the horizontal grain pine can uphold more force before breaking due to the physical structure and the orientation of the grain.
3. The strength of materials relative to the load depends heavily on the grain's orientation. Certain materials that are weaker in specific orientation have limited uses, whereas other materials that are stronger in other orientations would be a better fit to work with. For a vertical support column, the best option would be a horizontal grain orientation, because as found in the lab, the horizontal grain wood had a larger ultimate compressive strength. As for the horizontal support beam, a vertical grain orientation would be best. Vertical grains allows the load to be spread out evenly across the length of the material rather than spreading unevenly causing great amounts of shear stress

between the grains or the wood where the load or force is applied. The PVC pipe would be the best material to make a vertical support column because the PVC material was found to have the highest ultimate compressive strength. This means that the PCV material would be able to withstand greater load than the other materials.

4. The macrostructure and the microstructure of a material being used and the orientation of the grain being used is an important property for a designer to familiarise themselves with. It is important to understand how materials behave as load is applied. The macrostructure of the material and the angle at which that force is applied on the material plays a major role in deciding whether the material can resist compression. It is important to consider multiple loading conditions such as compressive vs. tensile forces in which a change in direction of load, a change in the allocation of the forces, and a change in the force's magnitude occurs. It is important to look at how the material reacts and responds after its ultimate compressive strength has been exceeded. In the case of vertical oriented wood, the ultimate compressive strength is lower than that of horizontally orientation wood. The horizontally oriented wood maintains a relatively good strength even after its limit has been reached whereas the vertical sample loses almost all resistance after initial failure. This tendency to maintain compressive strength may be desirable when crafting nonlinear structures or in a design where deformation without total catastrophic failure is important, such as designs where the loads are changing or unpredictable. It's important to consider how the material behaves in the event of failure. For instance, if a material fails and sends debris flying through the air, or splinters forming sharp edges, it presents a potential threat to bystanders. In an ideal situation, the material simply folds in on itself and absorbs the energy created from the applied destructive loads. For example, most common vehicles are built with to have crumple zones at the

front of the car. These zones surround the body of the vehicle and are made of materials that will crumple to absorb impact energy.

5. An advantage of using anisotropic materials is that these materials are naturally occurring (Such as wood). This means that the material working with is usually less expensive compared to other common isotropic materials such as metals or alloys. Also, anisotropic materials are typically strong in a specific direction, and therefore can be used to support heavy loads. Wood is used in building homes because it is cheap and strong enough to support heavy load due to their grain. The disadvantage of using anisotropic materials is that they will not function optimally in any given direction like isotropic materials will. This means that if the loading is to change such that the forces acting in the direction where material strength is weaker, the material is more likely to deform and potentially fail. Anisotropic composites can be made to act like isotropic composites by adding reinforcing fibres to weak areas of the structure making the material more uniformly strong, in all directions. Steel reinforced concrete is an excellent example of an anisotropic material being given isotropic properties.
6. Composites cover a wide range of materials, this includes carbon fibre composites, fibreglass, and fiber-reinforced plastics (FRBs). FRBs are used in fuel tanks of cars, and carbon fibre composites is used to manufacture high performance applications such as hockey sticks. Another application that employs a similar reinforcing principle is steel (rebar) reinforced concrete. Concrete, which has a high compressive strength, has relatively low tensile strength. The addition of the steel to the concrete makes up for this shortcoming of tensile strength as the steel takes the tensile forces from the steel and improves the concrete's overall tensile strength.

7. The accuracy of the results of this experiment were determined by comparing experimental values with expected values. Some systematic errors could include natural or manufacturing imperfections in the materials. This assumption could be a factor in how accurate the experiment the experiment was. These imperfections could be a reason behind the difference in values since the imperfections will cause the material to behave differently during testing. Additionally, the samples tested did not have an ideal flat surface for the compressive force to be applied to, which makes the cross-sectional areas slightly different than the ones that were used in calculation, altering the stress values. This shortcoming could cause bending and uneven loading in the material which in turn may have decreased the material's structural integrity, ultimately affecting the experimental values. lastly, only a single sample of each material was tested. If more samples were tested and more values were collected, the experimental values would likely be more accurate by averaging the results and then comparing the results to the accepted values.

Conclusions

In conclusion, the PVC pipe proved to be the strongest of all the tested materials by a tremendous amount. The second strongest material, the aluminum alloy beverage can, had an ultimate tensile strength ~35 MPa less than that of PVC, followed by ~45 MPa less for horizontal-grain pine, and ~50 MPa less for vertical-grain pine. The order of the wood samples makes sense with regards to the strength of the cellulose fibers (grain composition) having a higher strength than that of lignin ("glue" between grains).[1] This is because it implies that a load placed upon vertical-grain wood would cause the lignin to break and for grains to separate, whereas a load placed upon horizontal-grain wood would only cause the lignin to break, but the layered grains would continue to absorb the impact of the compression for a longer period of time before failing.

However, the order of aluminum alloy following PVC in order of decreasing strength contradicts the values from the data collected through research before the experiment, as aluminum alloys should have a greater compressive strength than PVC. However, the range of compressive strength of PVC overlaps slightly with that of the aluminum alloy, suggesting that the aluminum alloy was on the weaker end of its range and the PVC on its higher end. Additionally, since the exact alloy type of the metal can is unknown, it is also feasible that the aluminum alloy is not one of the 3xxx/5xxx series, but perhaps of a series with less compressive strength.

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