Balsawood Structure Design Essay, Research Paper

1. Introduction:

This report is the first stage of the design, construction and testing

of a balsa wood structure. In April, the design will be tested against

classmates? designs, where the design with the highest load/weight ratio

wins. The information gained from this report will be used in the

construction of the structure. The report is composed of two sections.

The first is an evaluation of material properties of balsa, glues and

different joint configurations. The second section consists of a

discussion on a preliminary design that is based on conclusions drawn

from the testing section.

Common material tests of tension, compression and bending were

performed and analyzed. The qualities of three different adhesives were

tested and evaluated, and finally, three different joint configurations

were tested. Illustrations of each test setup are included. Whenever

possible, qualitative results will be given as opposed to strictly

quantitative values. A qualitative result is much more useful in

general design decisions. Experimental results from the testing stage

combined with experiences is working with the materials offered clues

for the preliminary design.

The design section mixes both practical and experimental experience

together to present the best possible solution for the structure. It

also offers additional insights that were not considered in the initial

material testing procedure. The design presented in the this section,

is likely to be similar the final model, however modifications may be

needed for the final design that were unforeseeable at the time of this

report.

This report generally functions as a guide for the construction stage of

the project. Its role is to provide useful information and a basis for

the final design. Before the final design is tested, prototypes will be

constructed to test the principles discussed in this report. The goal

of this report is to combine the results from testing and experience to

produce a working preliminary design.

2. Material Testing

All standard testing was performed on the Applied Test System located in

room XXXXXXXXXXXXXX. The goal of this section is to determine the

material strengths of balsa, and how balsa responds to different

loading. Before testing, the basic structure of balsa needs to be

considered. Wood grain is composed of bundles of thin tubular

components or fibers which are naturally formed together. When loaded

parallel to this grain, the fibers exhibit the greatest strength. When

loaded perpendicular to the grain, the fibers pull apart easily, and the

material exhibits the least strength.

Generally, for design considerations, the weakest orientation should be

tested. However, testing procedure called for testing of the material

in the greatest strength orientations; torsion and compression, parallel

to the grain, and bending with the shear forces perpendicular to the

grain. Testing the materials for their “best direction” characteristics

can produce results that are not representative of real behavior. To

expect uniform stress distributions and to predict the exact locations

of stresses prior to testing prototypes is generally not a good idea.

However the values obtained from these tests can give a general idea of

where the structure may fail, and will display basic properties of the

material.

Tension Test

In tension testing, it is important to have samples shaped like the one

in Figure 1, or the material may break at the ends where the clamps are

applied to the material. Failure was defined to occur when the specimen

broke in the center area, and not near the clamps. The machine records

the maximum load applied to the specimen and the cross sectional area

was taken of the central area prior to testing. These two values are

used to compute the maximum stress the material can withstand before

failure.

Figure 1: Sample Torsion Specimen

In general, the material failed at the spaces with the smallest

cross-sectional areas, where imprecisions in cutting took place or the

material was simply weaker. It took many tests to get breaks that

occurred in the center section instead of at the ends, perhaps with an

even smaller center section this would have been easier. It should also

be noted that two different batches of balsa were tested and there was a

notable discrepancy between the results.

Table 1: Tension Tests Results

Specimen # Strength (psi)

1 1154

2 1316

3 1830

4 1889

Specimens 3 and 4 were from a different batch of balsa and were thicker

pieces in general, although thickness should have had no effect on

maximum stress, it is assumed that the second batch simply has a

greater density than the first one, or perhaps that it had not been

affected by air humidity as much as the first batch. (See the design

concepts section for more discussion of moisture content in the

specimens.)

Compression

Compression testing was also performed parallel to the wood?s grain

(See Figure 2). The specimen used must be small enough to fail under

compression instead of buckling. For analysis of compression tests,

failure was defined as occurring when little or no change in load caused

sudden deformations. This occurs when the yield strength is reached and

plastic behavior starts.

Figure 2: Compression Testing Setup

Failure was taken at the yield strength because the material is no

longer behaving elastically at this point and may be expanding outside

of the design constraints. It should be noted that original specimens

proved to be too tall and they failed in buckling (they sheared to one

side), instead of failing under simple compression.

Table 2: Compression Test Results

Specimen # Strength (psi)

1 464

2 380

3 397

Average 414

Under tension, the pieces all had similar strength values. This took

many tests, but in every other test, the material exhibited buckling as

well as compression. The three tests which ran the best were used for

Table 2.

Since the test of the design will be under compression, this data is

very relevant for the final design. Apparently balsa can withstand

approximately 3 times more load under tension than under compression.

However, much like in these test, buckling is likely to occur in the

final design. This fact should be of utmost consideration when

designing the legs of the structure.

Three Point Bending

This test is performed by placing the specimen between two supports,

and applying a load in the opposite direction of the supports, thus

creating shear stress throughout the member. Much like the tension

test, the wood will deform and then break at a critical stress. Figure

3 shows how this test was setup. The data obtained form this test can

be used in design of the top beam in the final design. This part of the

structure will undergo a similar bending due to the load from the

loading cap.

Unfortunately, the data obtained from these tests was not conclusive of

much. The test was flawed due to a bolt which stuck out and restricted

the material?s bending behavior in each test. The two sets of data taken

for this test varied greatly (as much as 300%), and therefore this data

is likely to be very error prone.

Figure 3: Three Point Bending Specimen

Table 3: Bending Data

Specimen # Rupture Load (lb) Elastic Modulus (lb/in)

1 26.6 120,000

2 62.5 442,000

Included in the Appendix is a graph of load versus displacement for the

first test, it shows how the experiment was flawed at the end when the

material hit the bolt which was sticking out of the machine, thus

causing stress again. It also shows the slope from which the elastic

modulus of the material was taken.

Ideally, four point bending tests should have been performed, where the

material is subject to pure bending, and not just shear forces. Further

tests need to be performed using this test, on materials ranging from

plywood style layered balsa, (with similar grains, perpendicular grains,

etc.) This would have been a more useful test if stronger pieces of

balsa had been tested.

3. Glue Testing

The final structure will consist of only balsa wood and glue, thus the

choice of glue is a crucial decision. Glue is weakest in shear, but as

before and to simplify the testing process, specimens will be tested in

torsion, normal to the glue surface. In the actual design, the glue

will mostly be under shear, notably when used to ply several layers of

wood together. However this test yields comparative results for each

glue and has an obvious best solution. It is assumed that the results

would be similar for testing in shear.

Sample specimens were broken in two, and then glued back together, see

Figure 4. Next, the specimen were tested under tension to determine

which glue was the strongest. Three glues were tested, 3M Super

Strength Adhesive, Carpenter?s Wood Glue, and standard Epoxy.

Figure 4: Glue Test Specimen

Table 4: Glue Testing Results

Ironically, the cheap Carpenters? Wood Glue is the best glue to use.

Both the Wood Glue and the Epoxy both were stronger then the actual

wood, and the wood broke before the glued joint did. The so called, 3M

Super Strength Adhesive proved to give the worst results, and gave off a

noxious smell both in application and in failure. Since price is also

an important design consideration, and drying time is not of the utmost

importance, the Carpenters? Wood Glue was used in joint testing, and

will most likely be used in the final design. Another factor that

wasn?t considered is that the Wood Glue is also easy to sand, which

makes shaping the final design much easier.

4. Joint Testing

At first, basic joint testing was done, three different connections were

glued together using carpenters? wood glue as shown in Figure 5 and

loaded until failure of either the joint or the material.

Figure 5: Joints Tested

The finger joint (Figure 5-c) was the only of the above joints found to

fail before the actual wood. This is simply a continuation of the glue

test. The finger joint is likely to have failed because it has the most

area under shear force and as stated earlier, glue is weaker in shear

than in normal stress. Thus a more advanced form of joint testing was

needed.

Figure 6: Advanced Joint Testing

Load was applied evenly along the horizontal section of the joint,

creating a moment and vertical force at the joint. Failure was

determined to occur when the joint either snapped or would not hold any

more load. Each joint?s performance was rated in accordance with the

maximum load it held.

Table 5: Joint Testing Results

Joint Type Load Performance Results of Test

6-a good glue peeled off

6-b better reinforcement crushed

6-c best joint crushed

The scarf joint held the most load, and therefore was rated as best.

This may be because the scarf joint has the highest amount of surface

area that is glued. Therefore requiring more glue and reinforcing the

joint more. In general joint construction this should be kept in mind,

while not all joints will occur at 90 degree angles, it should be noted

that there was a definite relationship between surface area glued and

strength of joint. Discussed in the design section are special self

forming joints that occur only under load, these special type of joints

should be kept in mind for the design as well.

5. Design Concept

Among issues not previously discussed in this report is the effect of

baking the structure. Since balsa, like most woods, is high in water

content, and the goal of this project is to win a weight versus load

carrying capacity competition, the effects of baking out some of the

water were tested. It was apparent that a decent percentage of the

design?s weight could be removed using this method without seriously

effecting the strength of the material.

Another issue to consider is the appearance of “self forming” joints

during testing. Often a vertical piece of balsa would bite in to a

horizontal piece, thus creating a strong joint that was better than most

glued joints simply because the material had compressed to form a sort

of socket for the joint. Although it is doubtful that this would be a

part of the design, it is important to take this in to consideration in

the design, and hopefully take advantage of this type of behavior.

The use of plywood-style pieces of balsa was not tested, but it needs

to be considered. Where the load and stresses are known it would be

best to form the plys in a unidirectional grain orientation, where the

strongest orientation is used. However, where the stresses are unknown

it would be better to use a criss-cross pattern in the balsa plys to

produce a strong, general purpose material in these regions.

Now to discuss the initial design. Figure 7 shows a basic design. The

grain representations are accurate for the lower portion. However, in

the top section where the arch is horizontal, and the load will be

applied, this section will be in bending and therefore requires a

horizontal grain. (This inaccuracy is due to limitations in the graphics

package used for the figure.) Note that the bottom support piece is

thick at the ends to encourage the self forming joints previous

discussed, and since the bottom piece is believed to be subject to

tension, the middle section is made thinner to cut down on material

weight.

The loading cap will need to be constrained so it will not slide down

the side of the structure, so added material needs to be place in those

points. In testing prototypes, the effects of the grain orientation

needs to be observed. In the top most sections, strictly horizontal

grains will be used, but as the arch curves to a vertical orientation,

vertically oriented grains need to be used. This gradual change in

grain will be possible with plywood style layering of the balsa.

Until further testing of prototypes is possible, this is all of the

relevant information available. Ideally, a structure such as this one

should perform well, but that remains to be seen.

Figure 7: Basic Design (Code name: Arch)

6. Appendices

Figure 8: Bending Test Results