More glue strength testing data

Jim Blilie, Barbarossa Guitars

In *American Lutherie #126*, I presented a proposed stand glue strength test method and reported the results of testing various glue types and wood species.

This article assesses the effect of wood grain direction on glue joint strength: This set of data has samples made from Sitka spruce and Honduran mahogany. The previous article drew some questions regarding method: Specifically, I tested longitudinal grain direction in my sample (the glue for the tensile testing joined the end grain of the samples). I was suggested that this does not represent the typical use case for guitar making (we rarely glue to end grain). It was also suggested that glue bonds would be stronger when glued to other than end grain.

Therefore, this test expands the previous data to include samples where the glue face was oriented to the tangential and radial directions of the wood in the sample. Refer to Figure 1 for the definition of these grain directions.

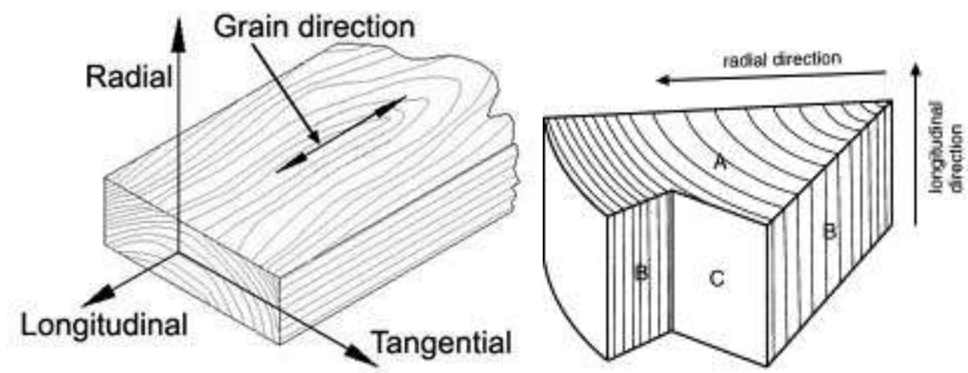

Figure 1: Grain Direction Definition for Wood Structure

Figure 2 shows a radial grain direction sample. Figure 3 shows a tangential grain direction sample. Note that the test section is the only place where the grain runs in the defined direction. The rest of the sample is longitudinal. Otherwise, the samples would be too fragile to handle and test (which tells you something about the strength of those grain directions).

Figure 2: Test Sample: Radial Grain Loading Direction

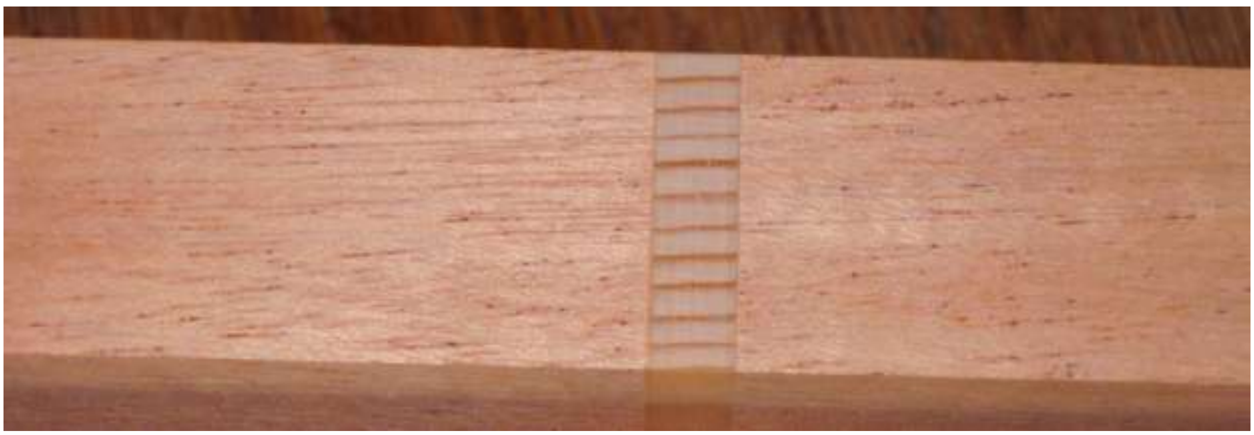

Figure 3: Test Sample: Tangential Grain Loading Direction

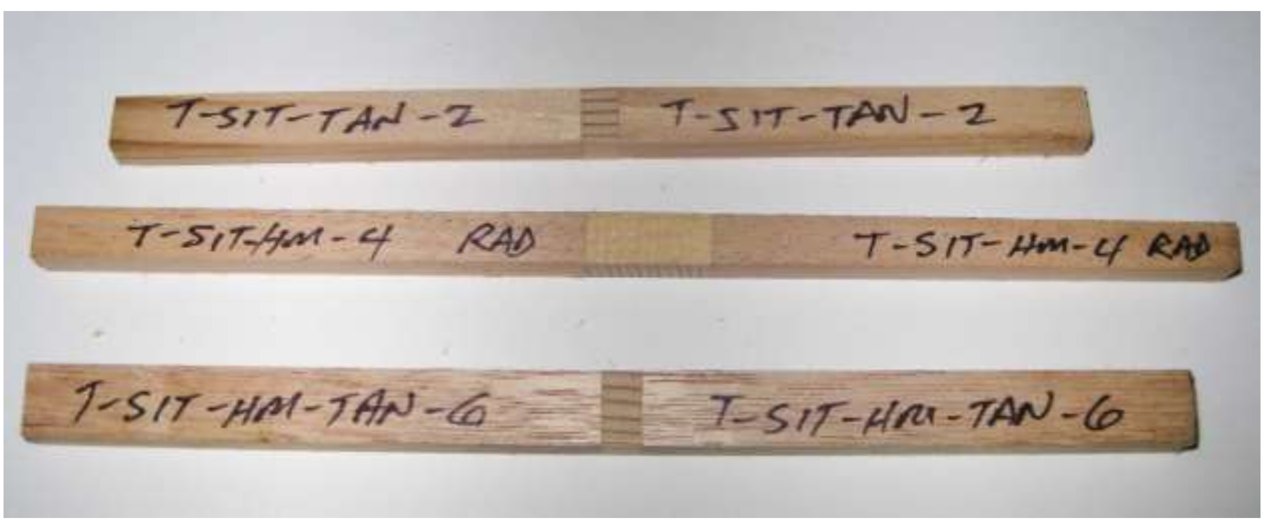

Figure 4: Several Test Samples, Top to Bottom: Tangent, Radial, Tangent

Results

Below are presented the new set of test data I gathered and statistical analysis of those data. As in *American Lutherie #126*, I test all samples on a calibrated INSTRON testing machine.

Tests performed:

Table 1: Summary of Sample Size for All Tests

Sample Description	**Code**	**Tension Test**
Titebond, Tangential grain, Sitka test section, mahogany grip section	T-SIT-HM-TAN	18 samples
Titebond, Tangential grain, Sitka test section, Sitka grip section	T-SIT-TAN	18 samples
Titebond, Radtial grain, Sitka test section, mahogany grip section	T-SIT-HM-RAD	24 samples
Total Samples		**60**

All samples used fresh Titebond wood glue.

Overall results are shown in Table 2 and Table 3. The elapsed time for each test was about 10 seconds from start to failure. The loading rate (displacement control) was 0.3mm per second (quite slow, nothing like a sharp blow; but also nothing like long-term creep.) These tests showed brittle failure, just like those in *American Lutherie #126*.

As I predicted in *American Lutherie #126*, grain directions other than longitudinal result in wood failure, not glue failure.

Table 2: Basic Statistics for the Tests Performed (US Units)

Code	**N**	**Max (psi)**	**Min (psi)**	**Mean (psi)**	**Median (psi)**	**Std. Dev. (psi)**	**Percent of samples showing WOOD failure**
T-SIT-HM-TAN	18	177	59	107	101	39.6	100%
T-SIT-TAN	18	351	57	191	185	72.4	100%
T-SIT-HM-RAD	24	171	9	73	67	39.8	100%

Table 3: Basic Statistics for the Tests Performed (Metric Units)

Code	**N**	**Max (MPa)**	**Min (MPa)**	**Mean (MPa)**	**Median (MPa)**	**Std. Dev. (MPa)**	**Percent of samples showing WOOD failure**
T-SIT-HM-TAN	18	1.224	0.403	0.736	0.696	0.273	100%
T-SIT-TAN	18	2.419	0.396	1.317	1.275	0.499	100%
T-SIT-HM-RAD	24	1.177	0.063	0.500	0.461	0.274	100%

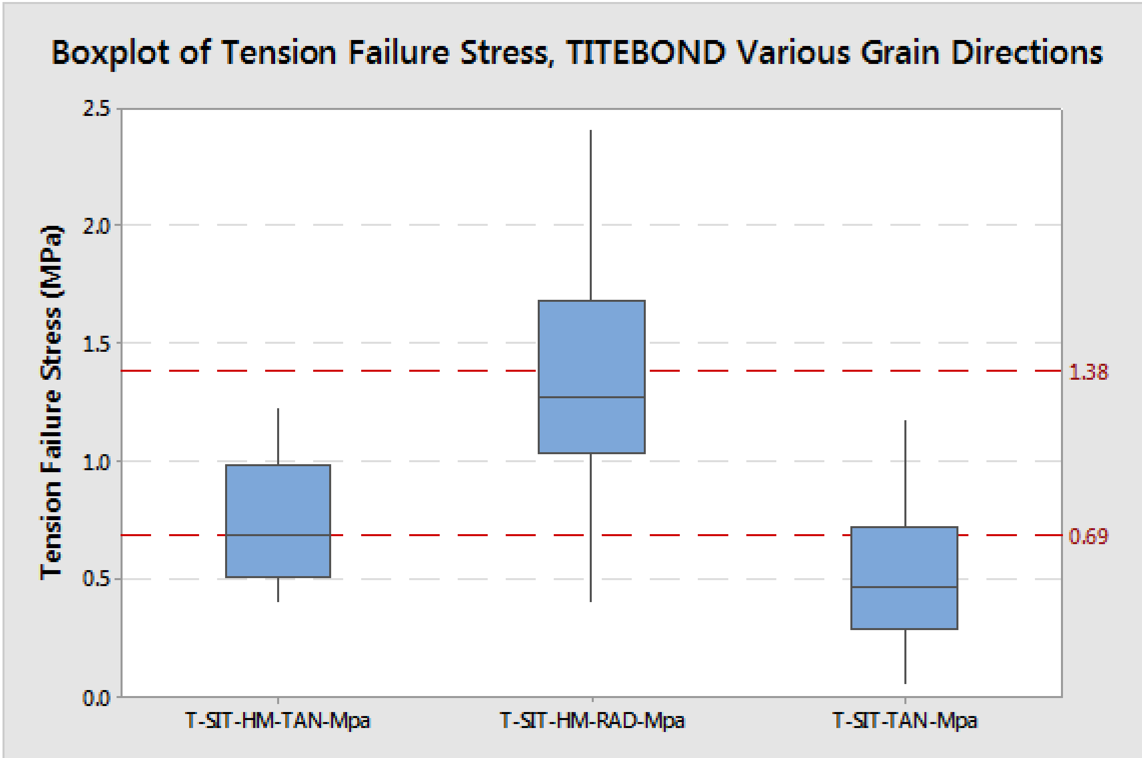

Figure 5: Grain Directions Compared – This Dataset, Titebond

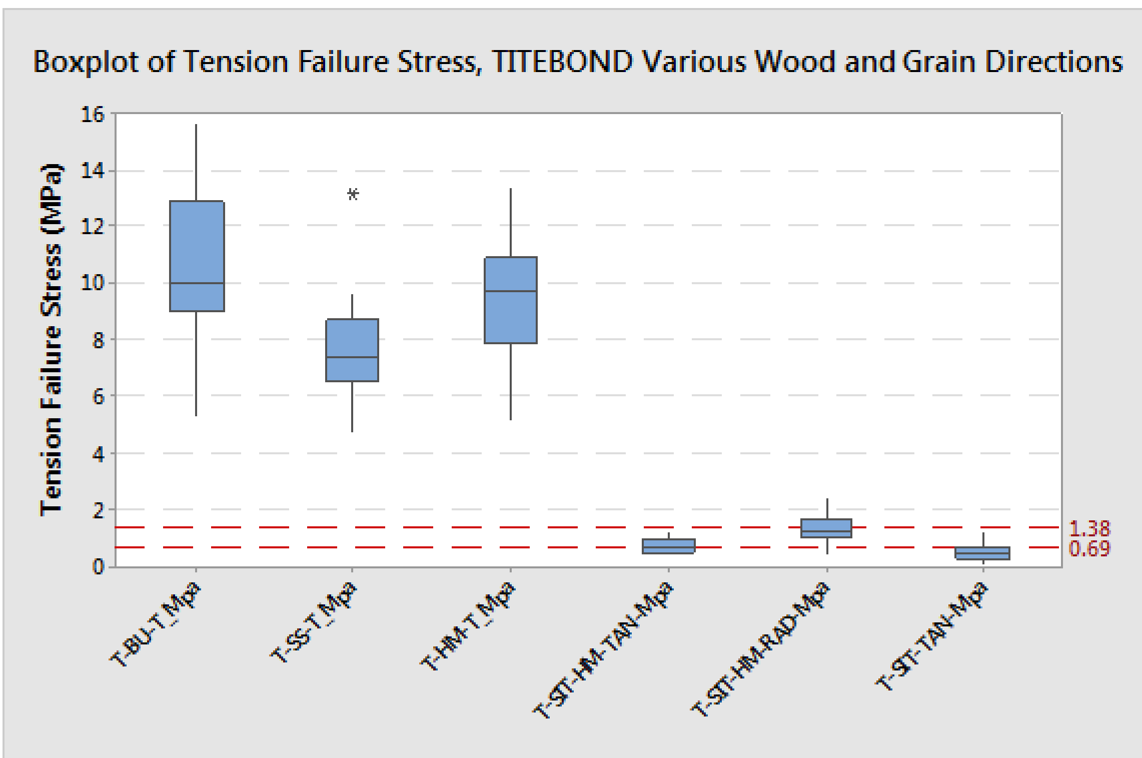

Figure 6: All Tensile Results for Titebond Compared

Figure 5 shows the comparison of the failure stresses for the various types of specimens. Figure 6 shows a comparison of the failure stress for all tensile tests of Titebond. Note the following: The longitudinally-loaded samples had much higher failure stresses than the tangentially or radially loaded specimens. That is, the longitudinal samples were *much stronger* than the other grain directions. All the samples failed in the wood rather than in the glue for both the radial and tangential grain directions. Note that the samples in the longitudinal direction (data from the article in *American Lutherie #126*) all failed in the glue.

Figure 7: Tangential Specimen Under Test – Typical Failure

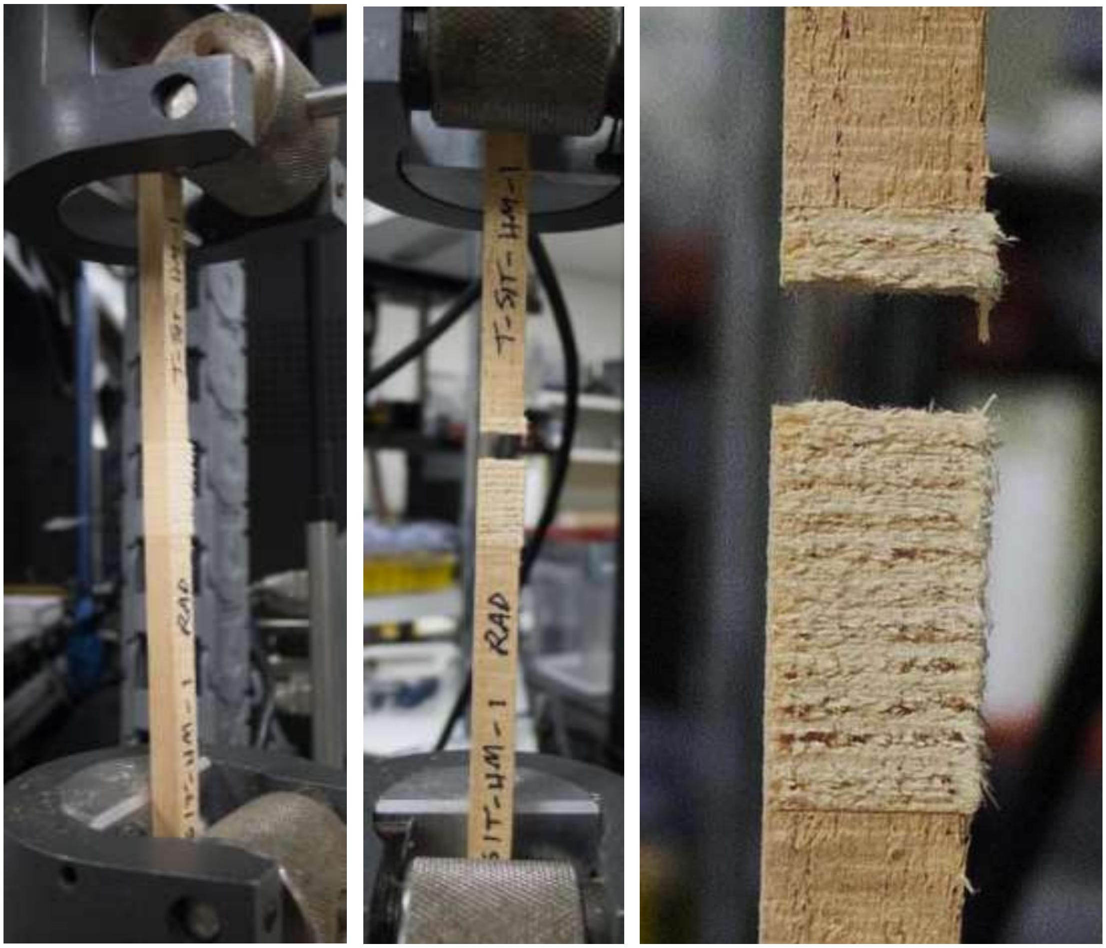

Figure 8: Radial Specimen Under Test – Typical Failure

Figure 7 shows a tangentially-loaded specimen before and after failure testing. The specimen failed in the wood, as all of these did. Figure 8 shows a radially-loaded specimen before and after failure testing. The specimen failed in the wood, as all of these did.

I had two samples, T-SIT-HM-RAD-3 and T-SIT-HM-RAD-17, that failed so close to the glue joint, I assumed that they had failed in the glue rather than the wood.

I took these two samples to a laboratory with an excellent microscope to examine them. The photos from the microscope are shown in Figure 9 through Figure 12.

In Figure 9 and Figure 10, notice that the entire face of both halves of the specimen T-SIT-HM-RAD-3 is covered by wood fibers. This shows that the failure, though close to the glue, was, in fact, in the wood.

In Figure 11 and Figure 12, notice that there is a small area of glue failure in specimen T-SIT-HM-RAD-17. The glue failure areas are indicated by the arrows. Although there is a small area of the specimen that failed in the glue, I scored it as a wood failure because about 90% of the failure was in the wood. (Mixed failures like this are not uncommon in strength testing of bonded specimens.)

Figure 9: Sample T-SIT-HM-RAD-3, Sitka Face (L) and Mahogany Face (R), 30X Magnification

Figure 10: Sample T-SIT-HM-RAD-3, Mahogany Face, 100X Magnification

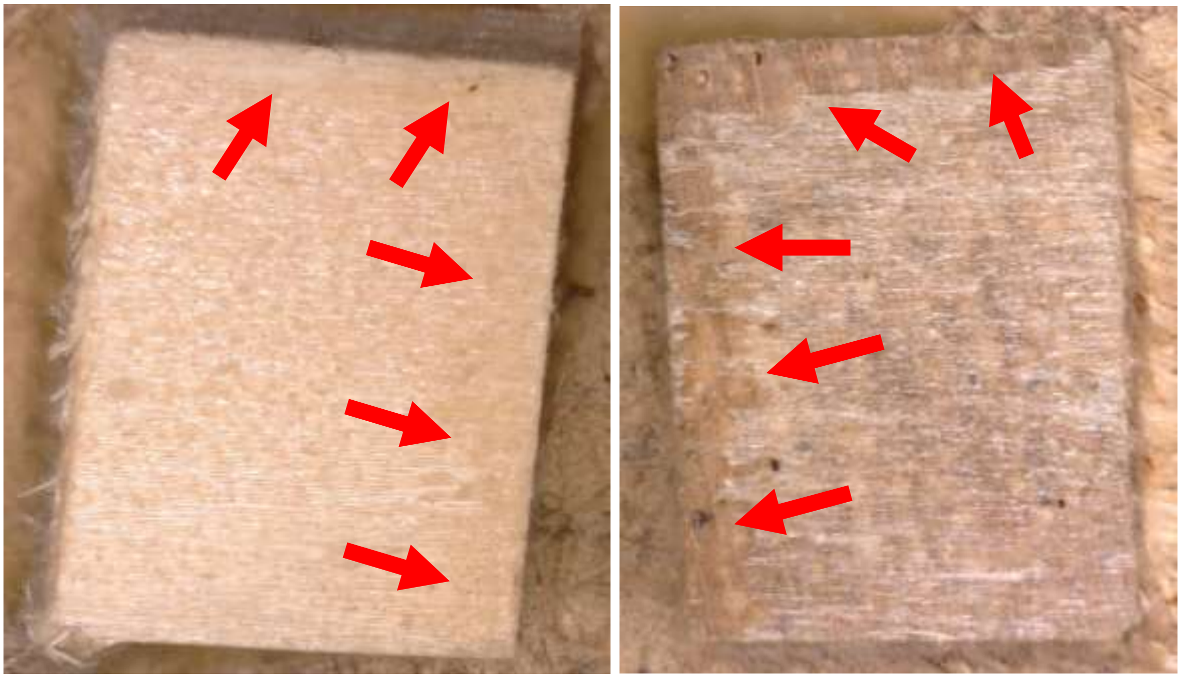

Figure 11: Sample T-SIT-HM-RAD-17, Sitka Face (L) and Mahogany Face (R), 30X Magnification

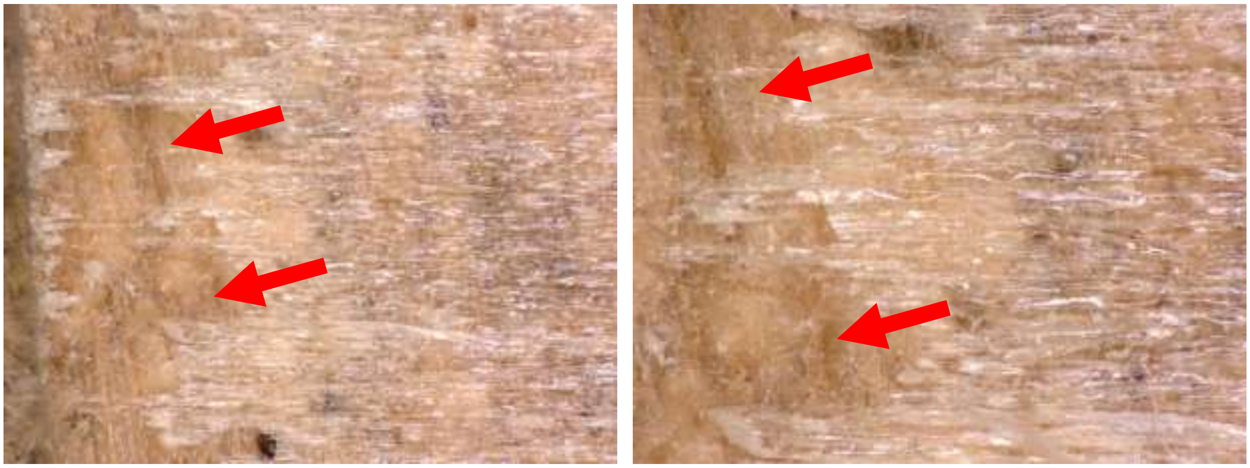

Figure 12: Sample T-SIT-HM-RAD-17, Mahogany Face, 100X Magnification (L), 200X Magnification (R)

Figure 13: Pile of Failed Specimens Following Testing

Conclusion: What does all this mean?

My conclusions from this test are:

1. For the radial and tangential grain directions in glue joints (at least for Titebond and Sitka Spruce), the glue will always be stronger than the wood.
2. Wood is much stronger in the longitudinal direction than in the other two directions. The test data show this. The microscope photos show why: The fibers all run in the longitudinal direction; and the fibers are what give wood its strength. (The results also match published data on wood strength and microstructure.)

Good glue joints

I want to reiterate what I said in *American Lutherie #126*: Many factors may contribute to the strength of the glue joint Most luthiers attempt to make joints that are tightly fitted, with smooth and clean surfaces that are well-clamped and are allowed to cure fully before unclamping.

Primary factors affecting glue joint strength:

a. Good glue (glue that is not too old and has been stored properly, proper mixing of epoxy, etc.)
b. The materials being joined
c. Tight joint (no gaps)
d. Good clamping during cure
e. Cleanliness (no foreign matter in the glue or on the surfaces being glued)
f. Correct temperature and humidity for curing
g. Clamping maintained until the glue is fully set or cured

It's easy to make a bad glue joint. We want to know how good a glue can be in a properly executed joint.

Areas for Further Testing

Other factors that would be useful to test and further areas for study:

More wood species
More glue types
Multiple glue lots (hard to do with off-the-shelf materials; but you could buy some from various stores significant distances apart)

Glue at various ages when used (old glue vs. new glue)
Aging the glued joints (test subsets of the samples at different times after their manufacture)
Various coupon sizes
Different dilutions of glues such as hide glue
Different curing conditions (temperature and humidity)
Different strength test conditions (temperature and humidity)
Cleaning methods for the gluing surfaces (for example with an acetone wipe – this would be important for testing glue on rosewood species)

Testing References:

The tensile method is equivalent to ASTM D 897, *Standard Test Method for Tensile Properties of Adhesive Bonds.* The specimen design is different; but the proposed coupon is equivalent and the ASTM D 897 coupon is impractical for small wooden samples.

Further reading:

https://en.wikipedia.org/wiki/Sample_size_determination (wiki on sample size)
https://en.wikipedia.org/wiki/Strength_of_materials (wiki on strength of materials)

Statistics for Dummies, Rumsey (this was used as the textbook for one stats class I took)
Statistics II for Dummies, Rumsey
The Lady Tasting Tea, Salsburg (history of statistical methods for a general audience)
Statistics in Plain English, Urdan

Structures, Or Why Things Don't Fall Down, Gordon

The NFS *Wood Handbook* (available for free download:
http://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr190.pdf