4.0 MECHANICAL TESTS

4.1 Basis for the test methodology

The essence of deterioration is that while it may be caused by insects, weather, fungi or bacteria, the decay is not identical. Further, no two physical circumstances are identical and so precisely identical specimens of deteriorated wood are not found in the field. Even in the laboratory under precisely controlled conditions, different pieces of wood do not decay in an identical manner. This is clearly due to the fact that wood is a product of nature, and no two pieces are identical. This lack of reproducibility of specimens of decayed wood has made any scientific study of restoration products impossible until now.

It has recently been discovered that the common cedar shingle has a surprisingly consistent physical structure and density, with an open porosity of about twenty percent by volume. This is similar to most deteriorated wood in its intermediate state of decay, where substantial damage has occurred to the cellulosic structure (the summer growth rings) but no appreciable delignification of the winter growth rings has taken place.

It was therefore decided to evaluate a prepared specimen of a cedar shingle as a surrogate standard for deteriorated wood. Treatment of reproducible specimens of wood with a product and technology known, historically, to have been used successfully for restoration of deteriorated wood would be expected to yield specimens of treated wood whose properties can be measured and compared with untreated wood. Restoration, by definition, means a return towards the original or attaining something similar to the original. The effectiveness of historically viable technology in doing this can thus be quantified in a way never before possible.

The moisture absorption tests of section **3.0** show that this technology has some intrinsic validity and viability. We therefore proceeded to design a mechanical test procedure.

4.2 Structural tests of cedar shingles

Grade A cedar shingles were cut into 1.7 inch widths. Lengths were cut slightly to conform to a standard fifteen inches and to eliminate the few specimens which were cut so thin that the thickness was less than a tenth of an inch at the thin end.

A representative group of samples were untreated. Each was weighed, and the weight stamped on the wide end. A similar group were impregnated by being submerged in groups of five in a 1000 mL laboratory graduate for twenty minutes. They were removed, allowed to stabilize for some days, and the impregnated weight noted.

All samples were epoxy bonded at the thin end to a notched wooden block with a steel rod at the base of the notch, where the shingle tip was inserted and glued. The thicker end was compressed between two wooden blocks and held to the testing frame. The test fixture is shown in appendix section 8.1.

An aluminum weight pan was suspended from the metal rod at the free end by four small steel cables, two on each side of the specimen. Weights were added in 500 gram increments to the pan which caused the sample to bend. A weight was added, the deflection observed and written down, and another weight added. This was continued until the sample broke. Deflection was measured by sighting past a scale (counterweighted to hang vertically) to a black-on-white horizontal reference line behind the scale.

Graphs were developed, showing the properties of the group. Scatter-plots were done, showing the value of each wood specimen, so that the properties of treated and untreated wood specimens could be presented and easily compared.

4.3 The reasoning behind the design of the mechanical test and the fixture

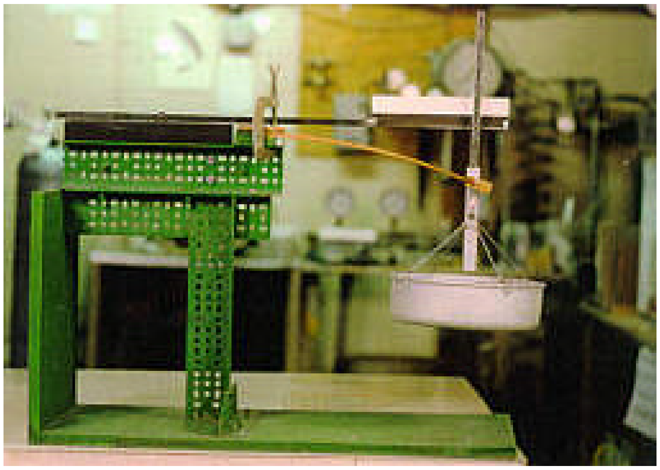
It was desired to have both a surrogate standard which others could obtain easily and a simple means of testing mechanical properties of prepared specimens. Since cedar shingles are inherently tapered, no existing ASTM test seemed appropriate for mechanical tests of an inherently non-uniform specimen. Cedar shingles are a low-value article of commerce and readily available. Thus, we needed a test which would show the deflection under load in some simple, easily measurable way, since wood used for structural purposes is often stressed in flexure. While there are many other stresses (tensile, compressive, shear, torsion) to which wood may be subject, we desired for this first study to keep it simple.

It was also desired to stress the wood specimens to ultimate failure, in order to see whether there was any relationship between impregnation treatment and failure stress. Again, the simple flexural test afforded that opportunity.

The fact that the wood specimens were tapered made the test inherently nonlinear, and thus made it impractical to confirm published data for the flexural modulus of cedar. However, this was not an objective of this test. The mechanical properties of cedar are well-known and we stipulate to them. The tapered specimen had the serendipitous property that we could easily measure deflection as a function of force in a way that was simple, reproducible, and used easy-to-handle weights (500 gram, 1 and 2 kilogram). Further, the specimens could all easily be broken with a range of weights (under 20 kg) and a fixture that could be placed on a table. The width of 1.7 inches was obtained from the criterion that all specimens break under 20 kg. The method of measuring deflection was again arrived at from the idea that the experimenter should be able to add weight and make a quick visual observation, write down a number and add another weight.

It would have been a straightforward matter to make a computer-controlled hydraulic pump and piston arrangement to provide deflection and a pressure gauge to measure the force, or other arrangement. These would require specialized expertise to build and would cost many thousands of dollars. This test fixture with counterweighted pivoting ruler on the pin from which the weight pan hangs, on the tip of the wood specimen, is so simple it can be built from common parts available at a hardware store for less than fifty dollars. Making it possible for anyone to easily reproduce the test fixture was, we felt, of overriding importance when standardizing and formalizing technology such as we are doing here.

The test fixture is shown in section 8.1.



4.4 Experimental procedure

Test specimens were fabricated according to the drawing of section 8.2. Those specimens to be tested, with or without impregnation, were prepared according to the procedure of section 8.3. Both natural and impregnated specimens had fixture adapters installed according to the drawing of section 8.4. The test procedure is described in section 4.2.

4.5 Experimental data

Applied stress at failure was tabulated for 31 untreated wood specimens and 53 impregnated wood specimens.

The natural wood specimens failed at a mean stress of 8.3 kg. The standard deviation of the failure stress level was 2 kg, or 24%.

The impregnated wood specimens failed at a mean stress of 11.84 kg with a standard deviation of 1.6 kg, or 13 %. One specimen (of the 53) failed at 6 kg, and had a deflection under stress of 160% of the mean. Examination showed it to be a flawed specimen, with grain direction at an angle of more than 45° to the axis. It was therefore deleted from the test data. This does not significantly affect the conclusions either way. Figure 1 shows the percentage of units that failed at a given stress level for both natural wood and impregnated wood specimens. It is noteworthy that the abnormally weak natural wood specimens (over two standard deviation units below the mean) were strengthened approximately double to triple, while the mean increase in failure stress level was increased from 8.3 to 11.8 kg, or 142%.

Figure 2 compares the flexural modulus of both natural wood and impregnated wood specimens. The bar limits show one standard deviation unit either side of the mean. It is particularly noteworthy that this impregnating compound increased the mean stiffness by about ten percent but that it did this by dramatically increasing the stiffness of the more flexible specimens. Both natural wood and impregnated wood specimens had virtually the same stiffness at one standard deviation unit below the mean.

This shows that impregnation with Smith & Co. Professional Version Clear Penetrating Epoxy Sealer improves the properties of weakened wood, but does not make it brittle and allows the wood to behave in a mechanically similar manner to sound wood.

Figure 3 shows the measured relationship between deflection, applied force and failure level for natural wood specimens. As tabulated previously, the mean failure stress was 8.3 kg. 50% of the units had failed at that stress level. At 4 kg, 8.6% of the units had failed.

Figure 4 shows the measured relationship between deflection, applied force and failure level for impregnated wood specimens. Note that the comparable (8.6%) failure level would be slightly over 9 kg. Thus, the strength of the weakest specimens is more than doubled by impregnation with the new Smith & Co. product.

4.6 Stress level at failure and the evaluation of grain direction

A visual observation during the tests indicated that a large percentage of failures in the lower weight ranges occurred at incipient knot formations. The shingles are manufactured using a large diameter saw blade. Cuts near knots are tolerated in the grade used for these tests provided that actual knots are not visible, but it is possible to see a slight color change related to grain direction change. Cuts near knots tend to have an abrupt change in grain direction through the width of the shingle in contrast to the more normal grain along its length. Failure was observed to occur at grain changes.

Similar shingles, impregnated, did not tend to fail at these points at low stress levels. If they did fail at abrupt grain direction changes it was at much higher stress levels. The Professional Version of Clear Penetrating Epoxy Sealer appears to strengthen wood fiber bonds at the tension and compression planes, causing the structural forces to act more evenly.

STRESS AT FAILURE

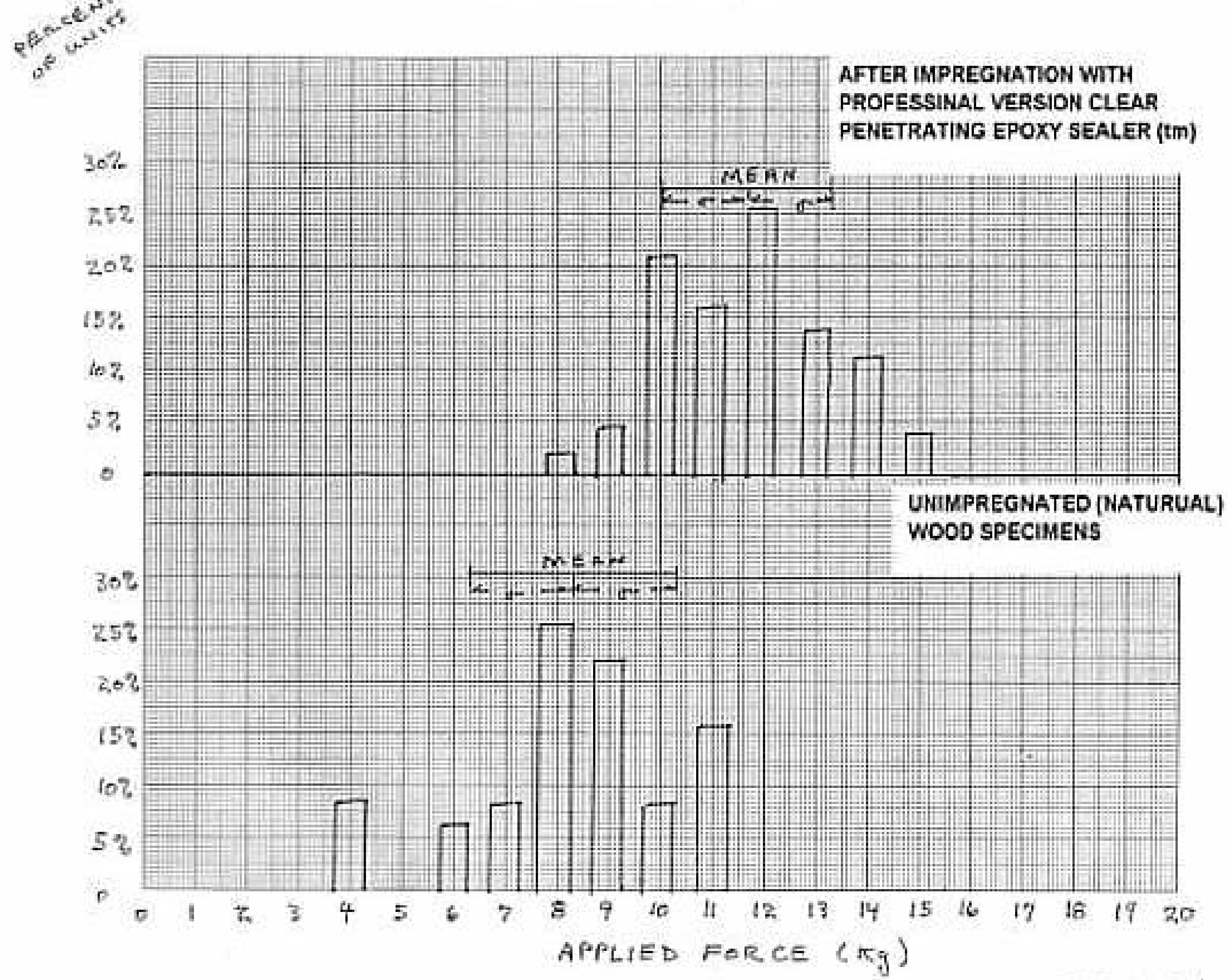


FIGURE 1
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STEVE SMITH

FLEXURAL MODULUS

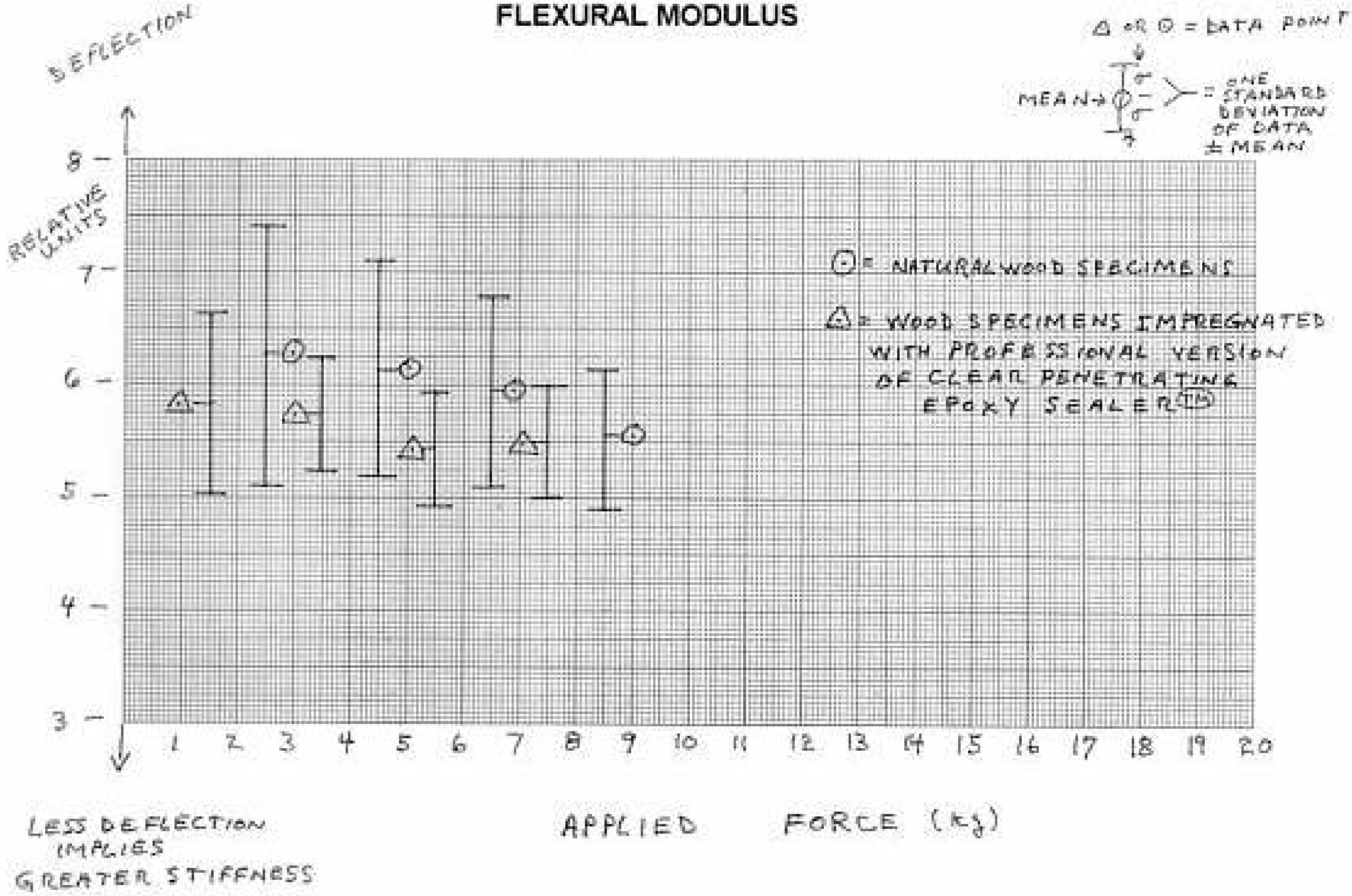

FIGURE R
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PROPERTIES OF NATURAL WOOD SPECIMENS

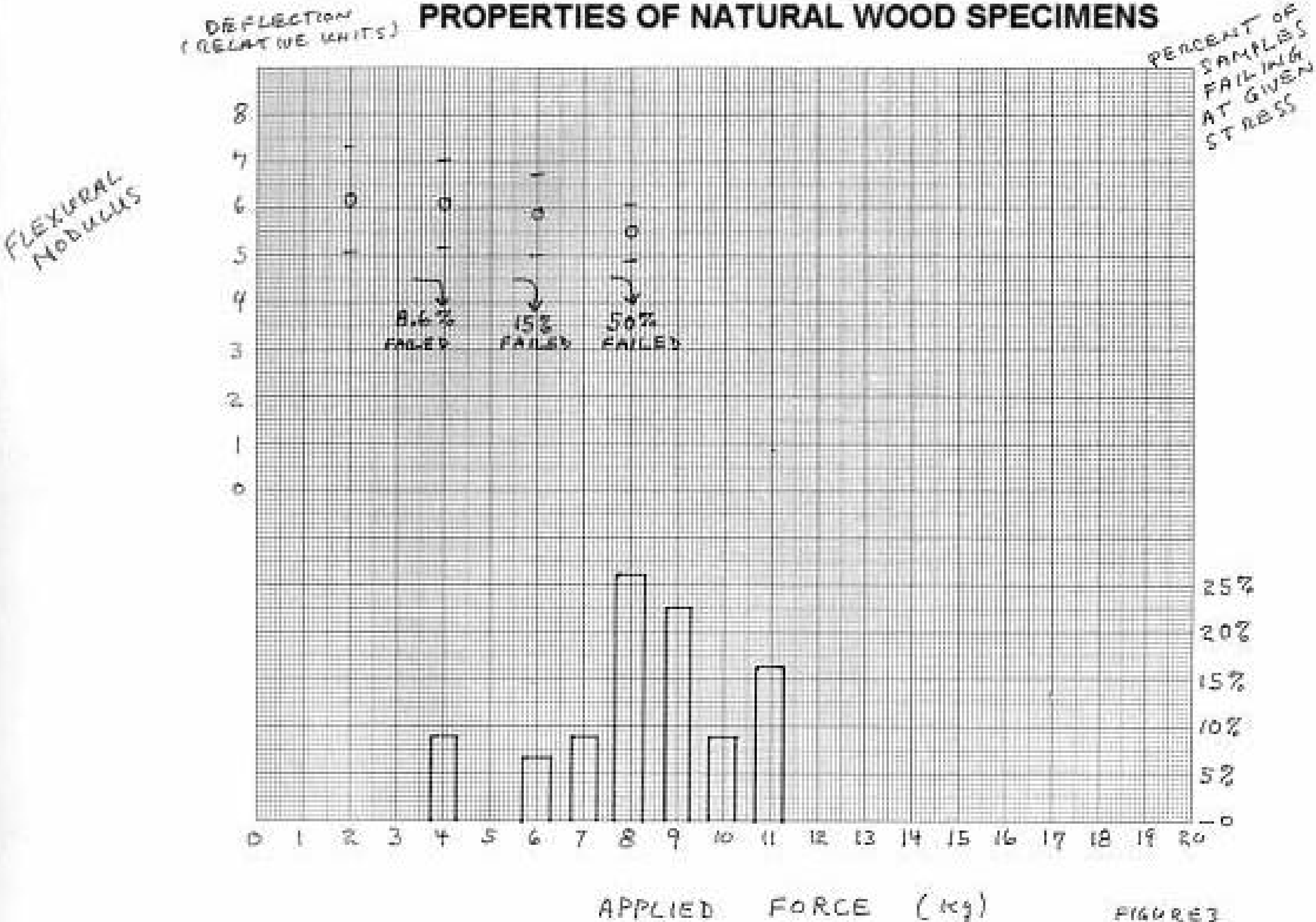

FIGURE 3
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PROPERTIES OF IMPREGNATED WOOD SPECIMENS

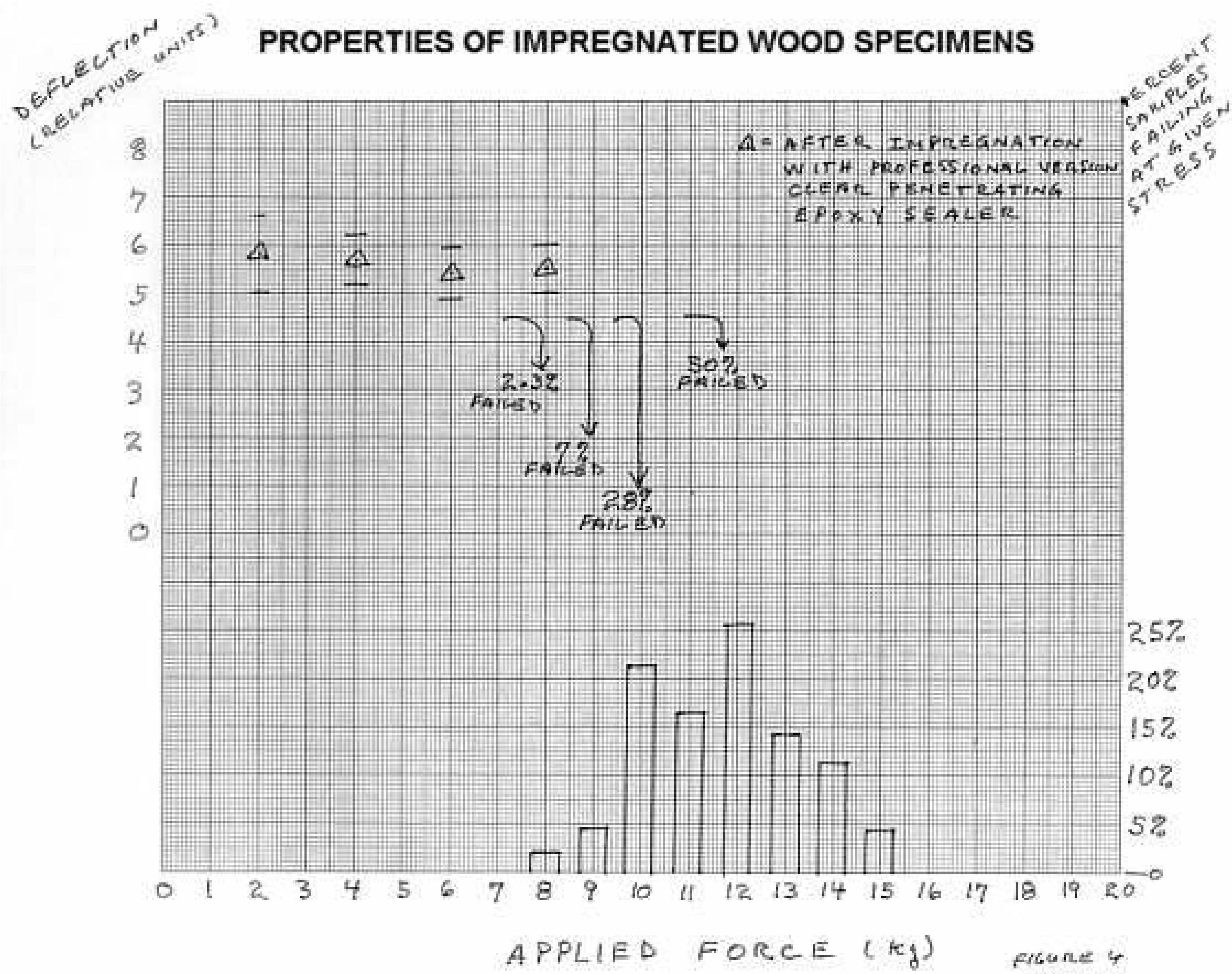

FIGURE 4
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4.7 Correlation of Experimental Data with Natural Wood Properties

The three measurable characteristics of the natural wood specimens are (1) Weight (indicating relative density of the heavily lignified winter growth rings, although the shingle thickness does vary noticeably due to the manufacturing process), (2) Deflection at a stress level, and (3) Stress level which caused specimen failure.

Figure 5 is a scatter plot of initial sample weight versus failure level, and shows no discernible relationship.

Figure 6 is a scatter plot of deflection under a given force (2 kg) versus applied force at failure ranging from 4 kg to 11 kg. There is a weak correlation between stiffer specimens (less deflection) and failure level, in that stiffer specimens tend to fail at a higher stress level.

Figure 7 is a scatter plot of deflection at 2 kg versus initial sample weight. This shows a moderate correlation between deflection (over a range of more than double) with initial sample weight (over a much smaller range - about 133%).

It may be concluded that there are other structural variables responsible for the range of parameter variation. More than likely, a substantial percentage of these variables are related to the grain changes noted in section 4.7.

The most important observation that can be made from these plots is that natural wood displays a distribution of properties and that the range of this distribution is characteristic of natural wood.

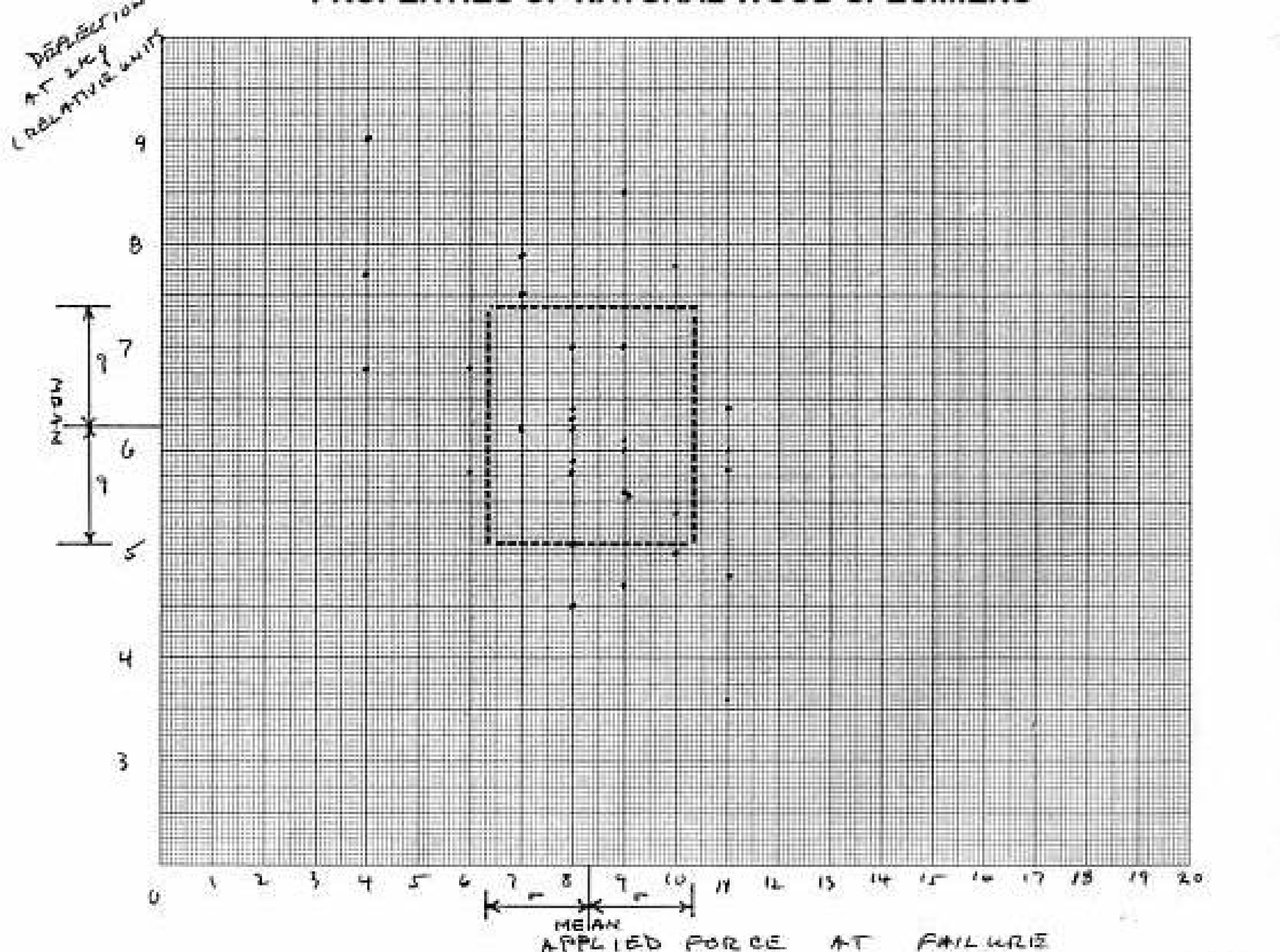
4.8 Characterization of impregnated wood specimens.

The initial weight, deflection under load and stress at failure were measured and tabulated. These parameters are displayed in Figures 1,2 and 4. The impregnated specimens have the additional variable of specimen porosity and added impregnant, which we have analyzed both as added impregnant in grams and added impregnant as a percentage of initial specimen weight. Two-dimensional scatter plots were made of all these parameters in order to discover whether there was any close-coupled relationship between any of these variables. Expanded scales were used on some of these plots in order to see the data distribution more clearly. These are Figures 8 through 14.

IN EVERY CASE THERE IS A DISTRIBUTION OR SCATTER OF DATA WITHIN A MODERATE RANGE, AND THIS DISTRIBUTION IS STRIKINGLY SIMILAR TO THE CORRESPONDING PLOTS FOR NATURAL WOOD.

THE DATA PLOTS CONSISTENTLY SHOW IMPROVEMENTS IN TREATED WOOD PROPERTIES BUT DO NOT SHOW ANYTHING UNUSUALLY DIFFERENT FROM SOUND WOOD.

PROPERTIES OF NATURAL WOOD SPECIMENS



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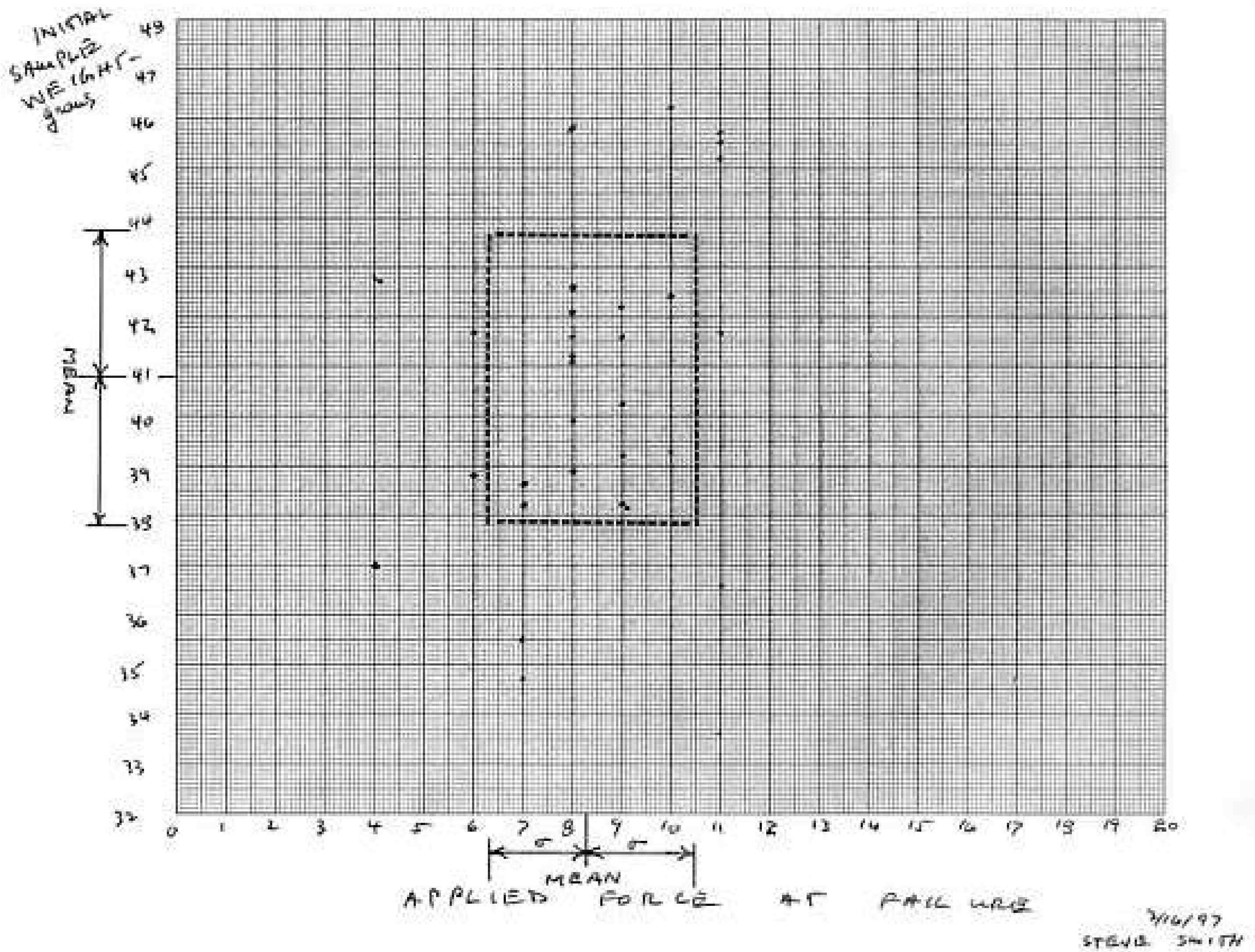
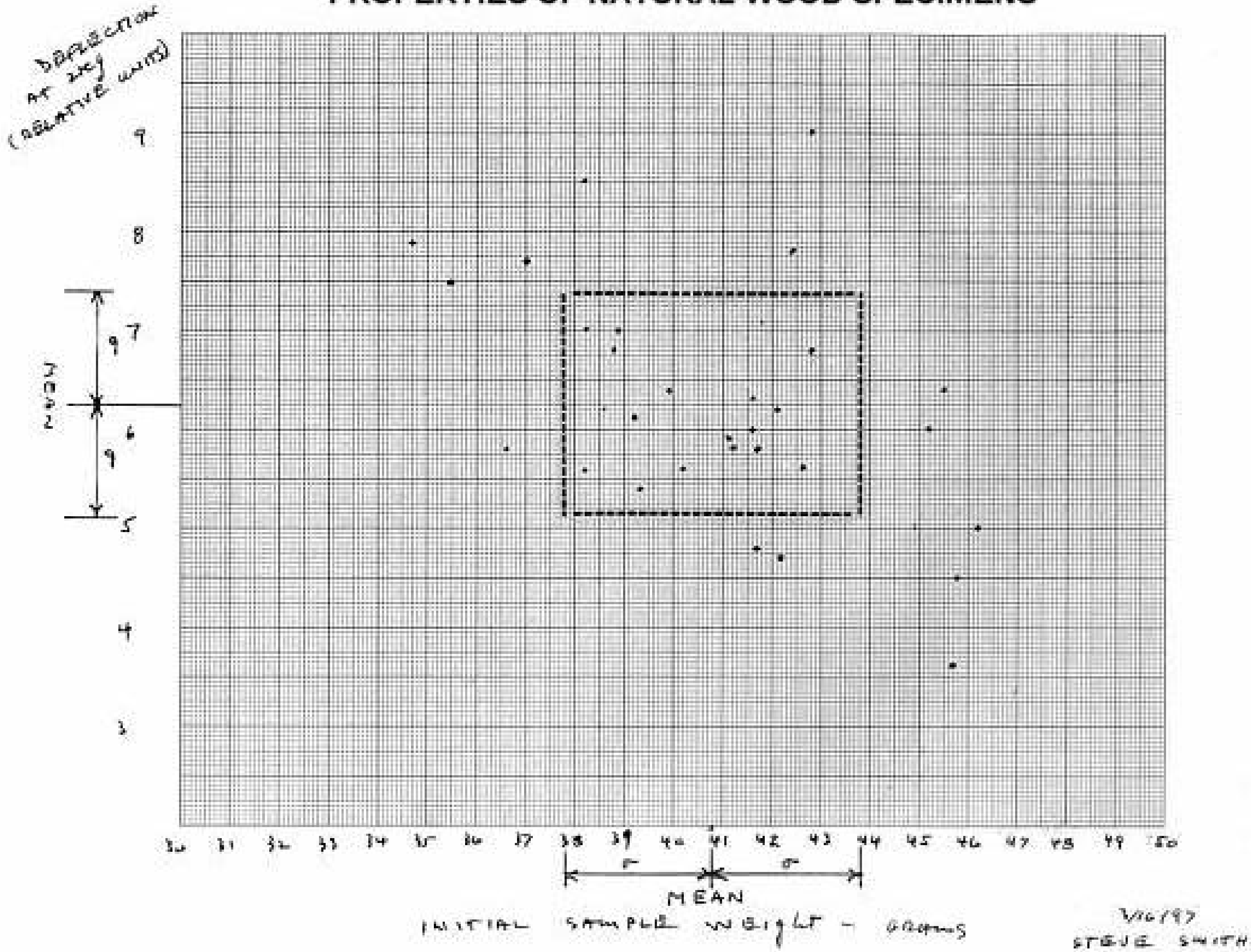
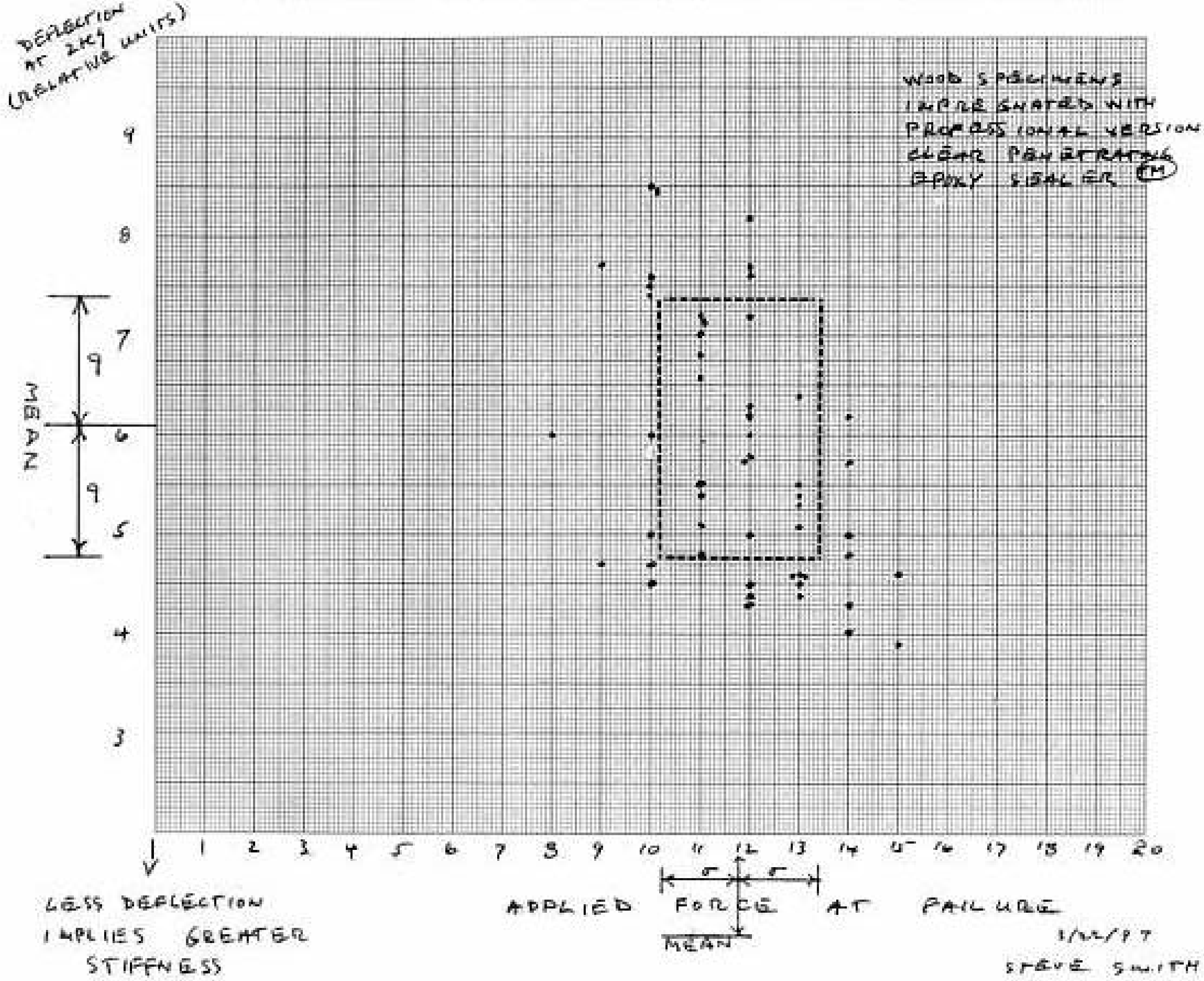
PROPERTIES OF NATURAL WOOD SPECIMENS



PROPERTIES OF NATURAL WOOD SPECIMENS



PROPERTIES OF IMPREGNATED WOOD SPECIMENS



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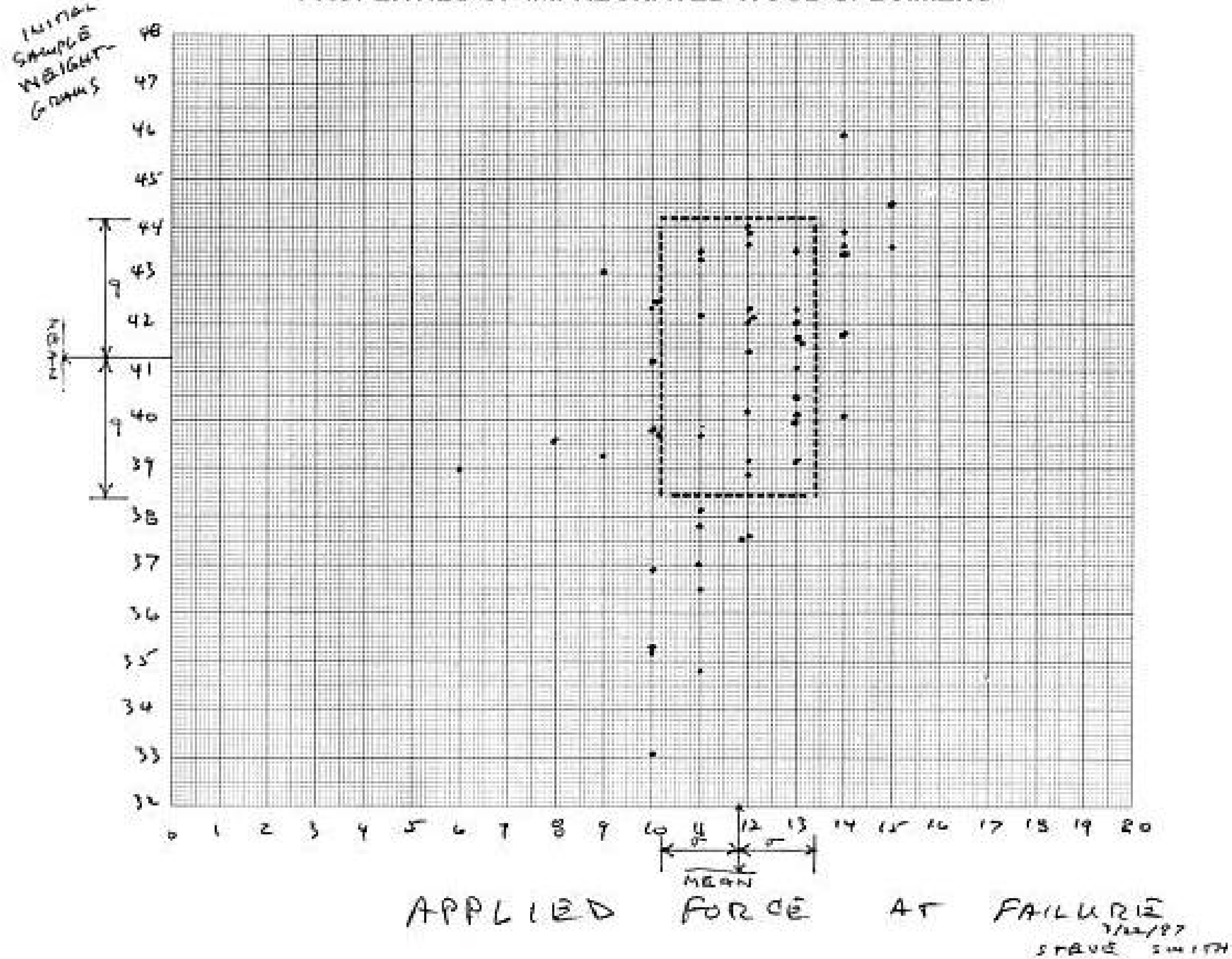

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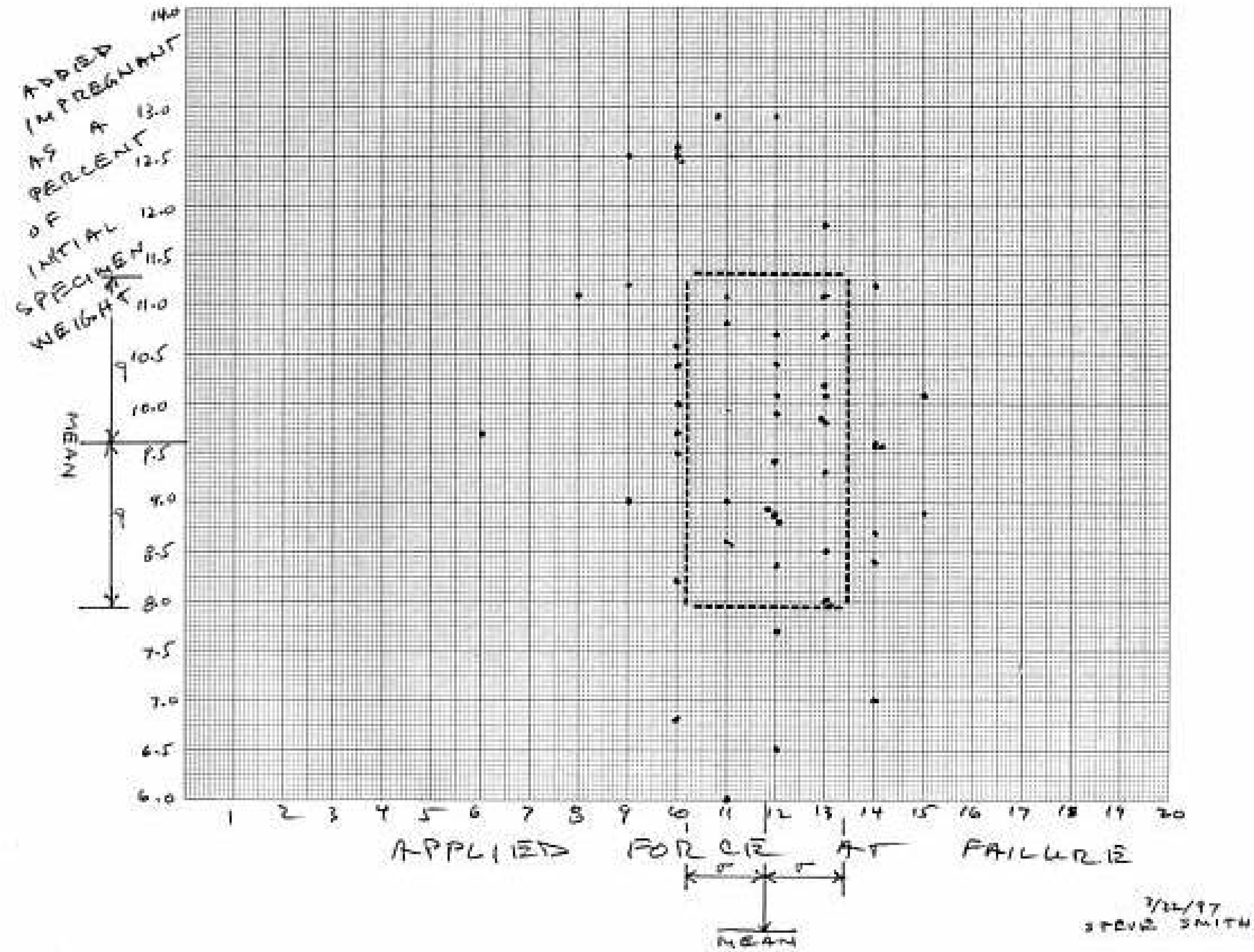

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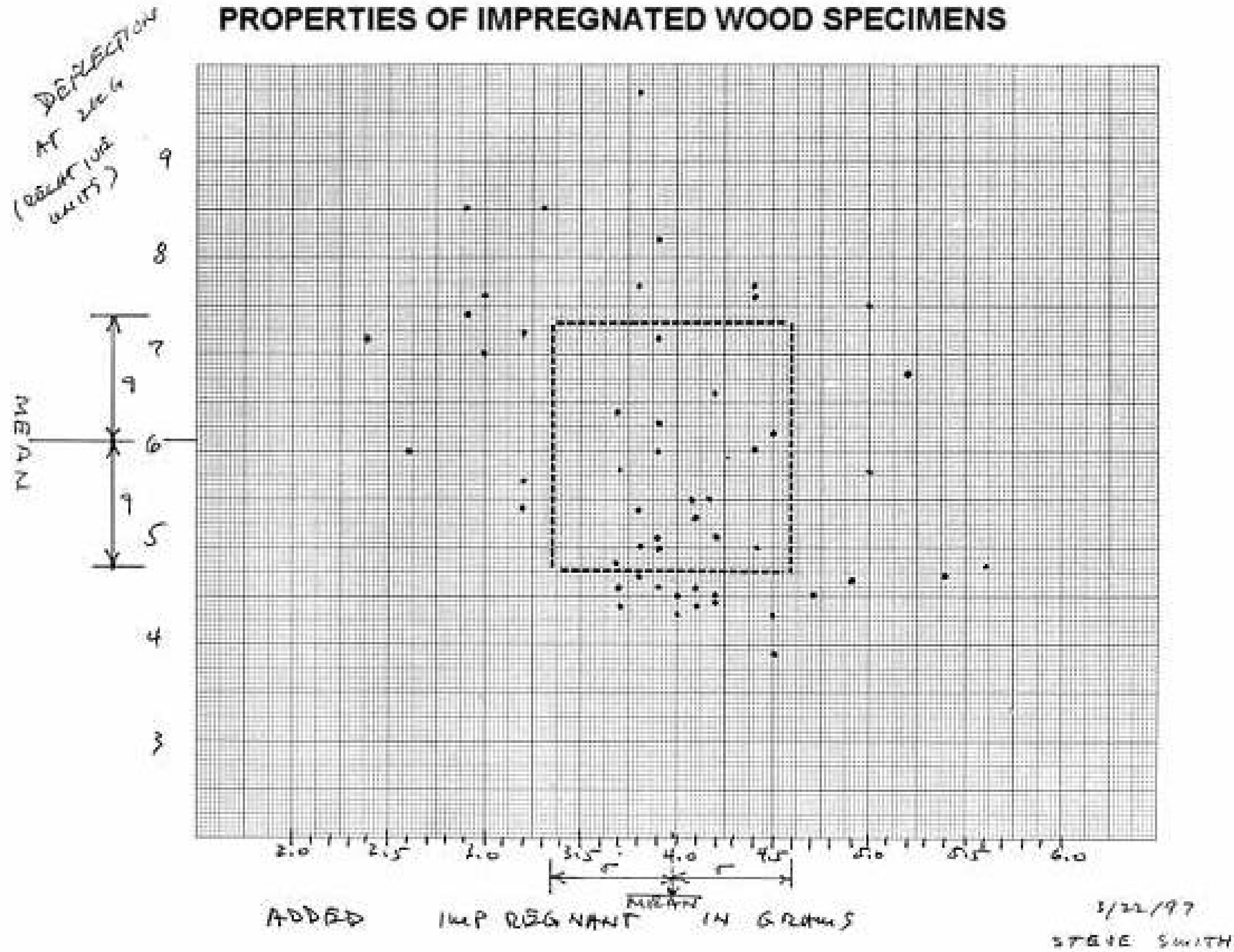

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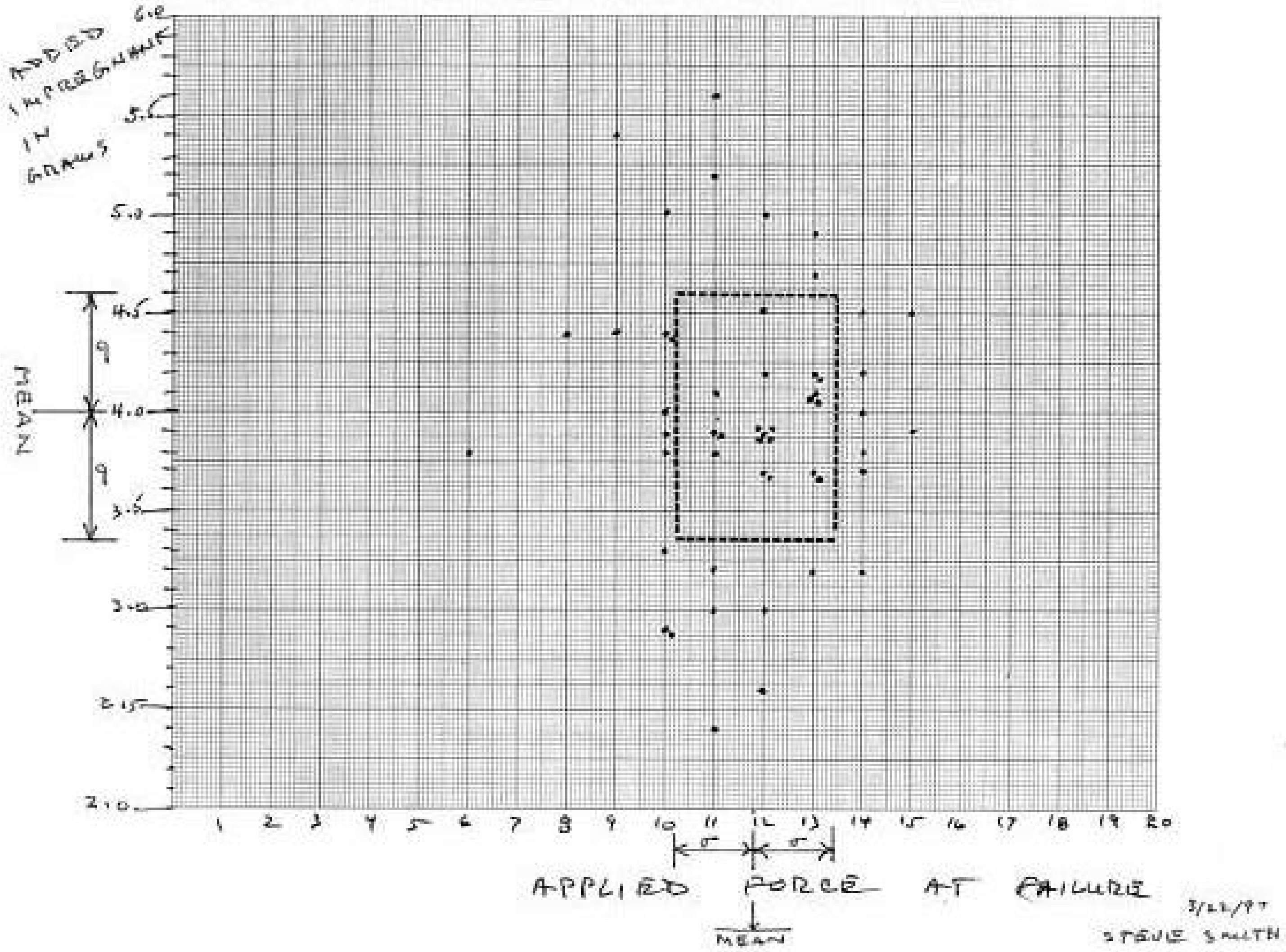
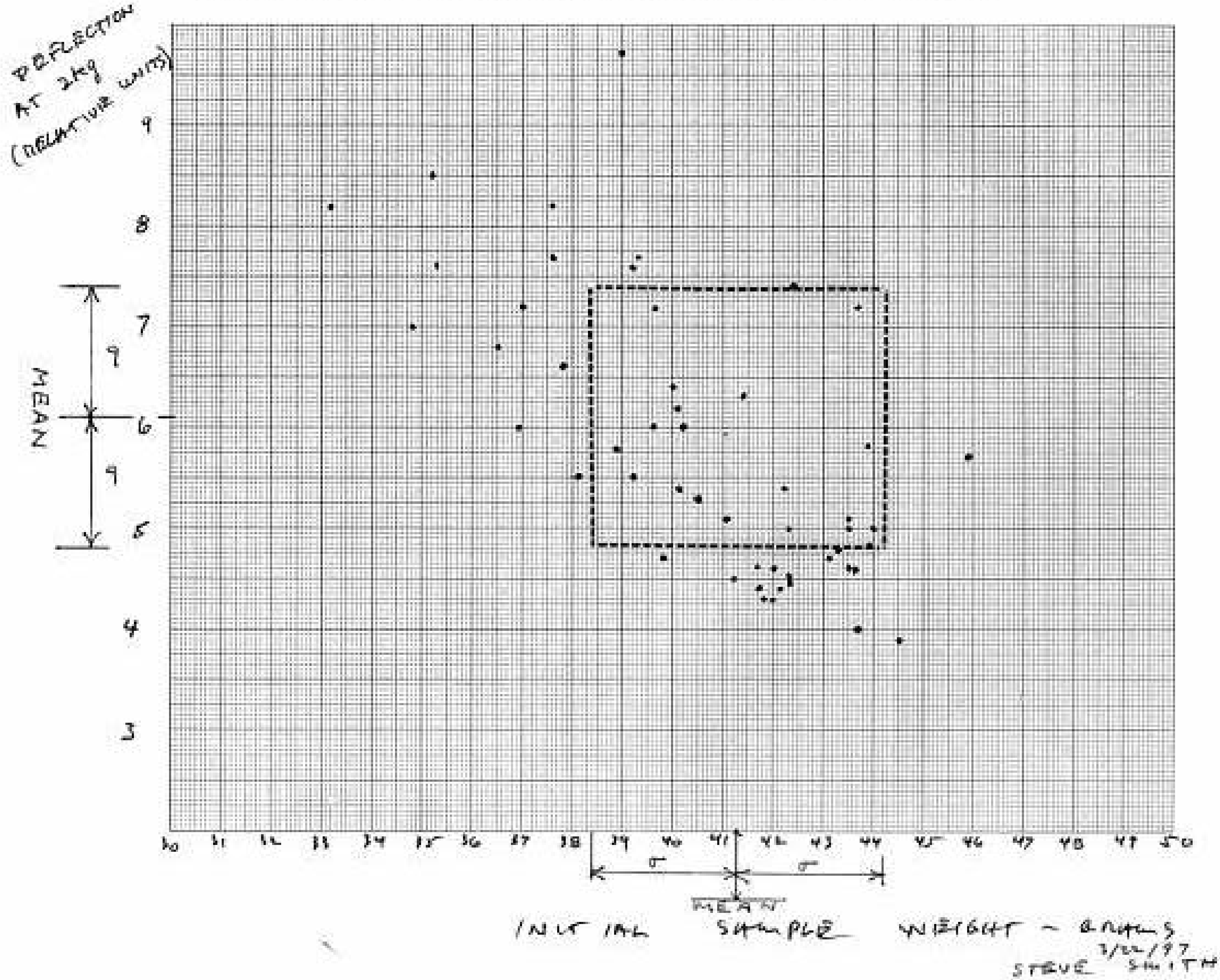


PROPTERTIES OF IMPREGNATED WOOD SPECIMENS



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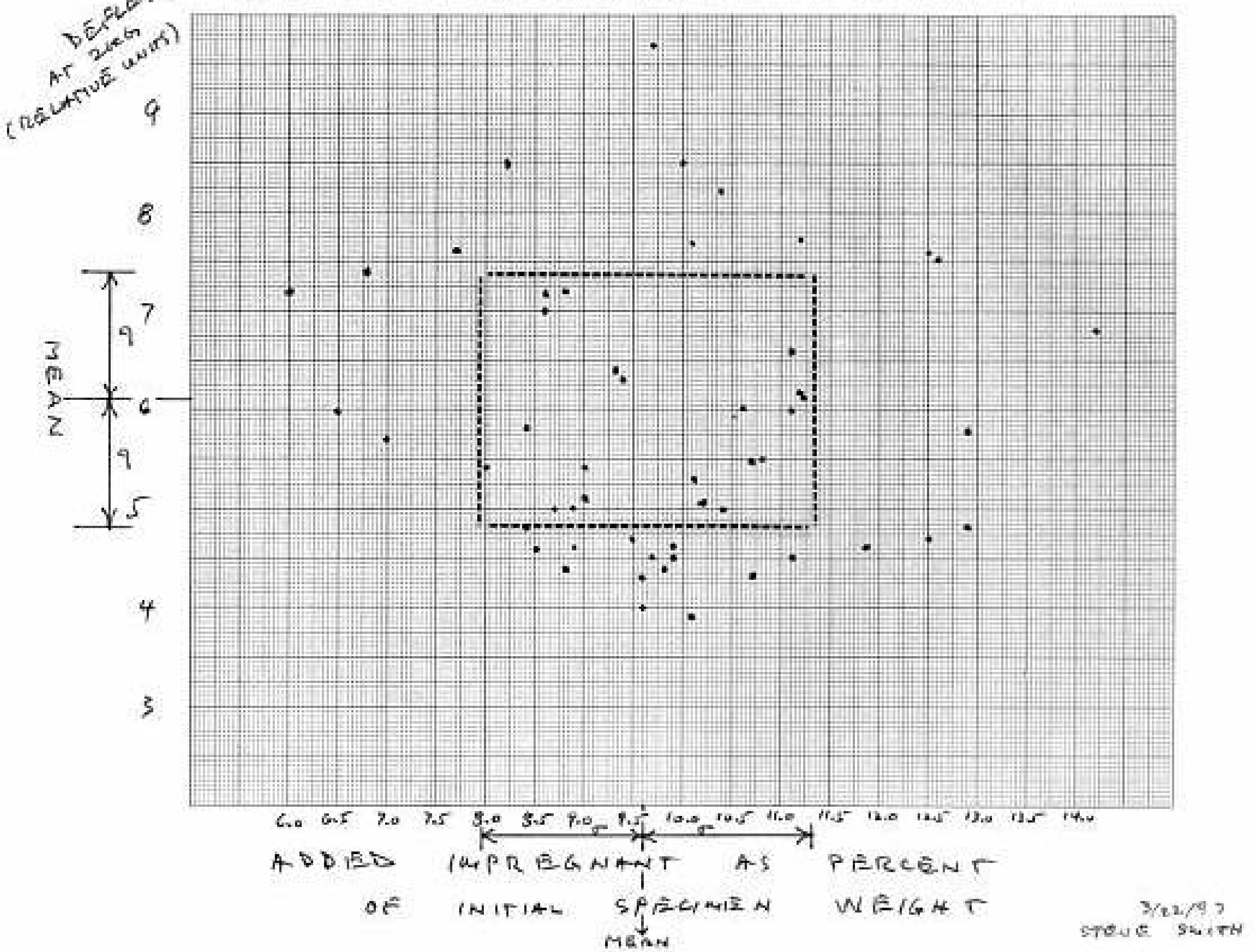

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