A Combined Stress Experiment Using A Hacksaw

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Abstract:

An analytical and experimental study of the combined axial and bending stresses that occur in a typical hand-held hacksaw is described. A commercially available handsaw is loaded statically by tension in the saw blade. The tensile load on the hacksaw blade results in both bending and axial compressive stresses in the backbone of the hacksaw. This study demonstrates the experimental technique of using strain gages to validate an analytical solution, as well as the concept of creating and calibrating a load transducer to measure the applied load. This paper presents details on the analysis, experimental approach, and the results.

Introduction:

Figure 1 illustrates a typically-constructed hand-held hacksaw.

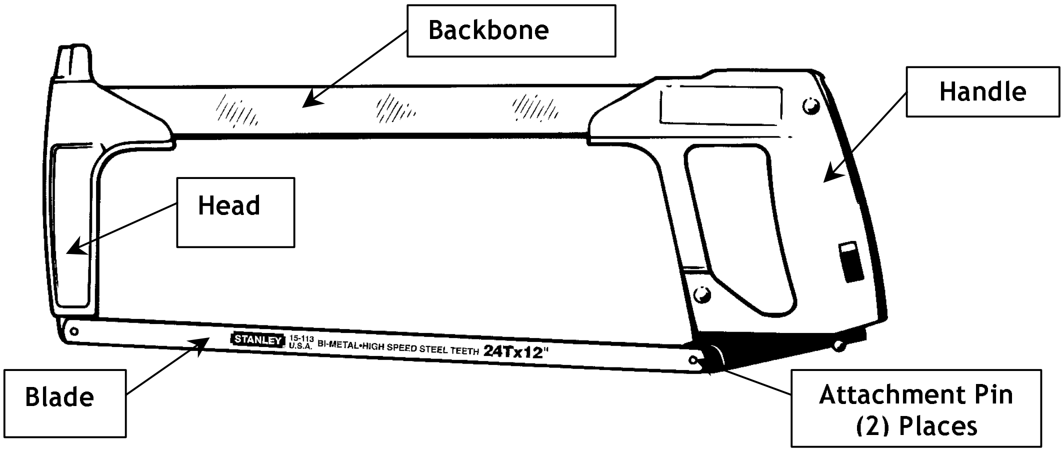

Figure 1: Typical Hacksaw.

The head, handle, and backbone make up the frame of the hacksaw. The rigidity of the frame places the blade in tension in order to prevent buckling due to the slenderness of the blade. When a tensile force is applied to the blade, the head and handle portions of the saw see a resulting tension. These forces produce both axial compressive forces and bending forces in the backbone

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of the saw. A Stanley Contractor Grade high-tension saw was chosen for this experiment, due to the following characteristics:

- It has a quick blade tightener/release mechanism that facilitates a rapid and easily repeatable loading and unloading of the blade.
- The blade tension is adjustable up to 340 lb.
- The backbone consists of rectangular, chrome-plated steel tubing that allows for the effective application of strain gages.
- The distance between the centerline of the saw blade and the backbone varies linearly, with the smaller distance occurring at the head. This causes the bending moment to vary along the length of the saw and makes for a more interesting analysis.

Theory:

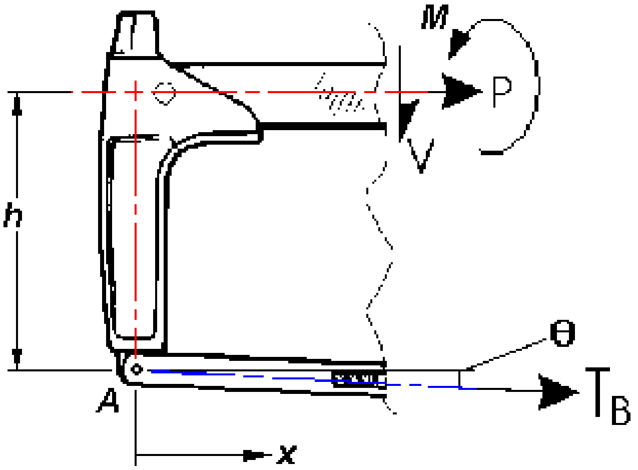

Figure 2: Free body diagram of saw head and backbone.

Figure 2 is a Free Body Diagram (FBD) of an arbitrary section taken through the saw. The shear force (*V*), bending moment (*M*) and axial force (*P*) are all shown as being in the positive direction for the standard beam convention. The blade is a two-force member that produces a point load applied at point *A*. Since the blade sits in the frame at a slight angle (θ), the resultant force will have *X* and *Y* components. The tensile force in the blade (T_B) is counteracted by both an axial compressive force (*P*) and a shear force (*V*) in the backbone. This axial compressive force serves to balance the horizontal component of the tensile force (T_B) while the shear force (*V*) balances the vertical component.

$$\Sigma F_x = 0 \tag{1}$$

$$P + T_B * \cos(\theta) = 0$$

$$P = -T_B * \cos(\theta)$$

$$\Sigma F_y = 0 \tag{2}$$

$$-V - T_B * \sin(\theta) = 0$$

$$V = -T_B * \sin(\theta)$$

Because both the horizontal and vertical components of T_B being applied at point *A* are eccentric to the axis of the backbone a bending moment (*M*) is produced. It is calculated as follows:

$$\Sigma M_A = 0 \tag{3}$$

$$M - P * h - V * x = 0$$

$$M = P * h + V * x$$

$$M = -T_B * \cos(\theta) * h - T_B * \sin(\theta) * x$$

where *h* is the vertical distance from point *A* to the neutral axis of the backbone and *x* is the horizontal distance from point *A* to the location of the section. Figure 3 shows the cross-section of the backbone. The axial stress (σ_A) in the backbone is calculated by dividing the resultant compressive force (*P*) by the cross sectional area of the backbone (*A*):

$$\sigma_A = P / A \tag{4}$$

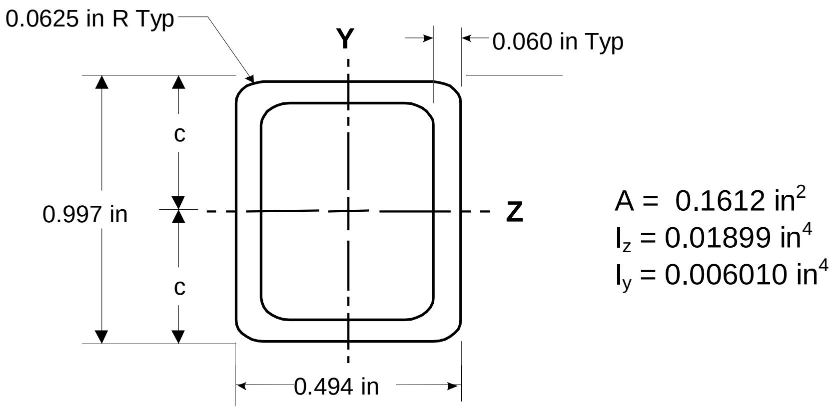

Figure 3: Cross-sectional drawing of the backbone.

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The bending moment produces a bending stress (σ_B), which is tensile on the top and compressive on the bottom surfaces of the saw's backbone. We can now use the flexure formula to calculate the bending stresses:

$$\sigma_B = \pm M * c / I_z \tag{5}$$

where c is the distance from the neutral axis to the outer surfaces of the backbone as illustrated in Figure 3 and I_Z is the moment of inertia about the Z-axis.

The strains on the top (ε_{top}) and the bottom (ε_{bottom}) of the backbone are calculated by dividing the combined stresses by the modulus of elasticity (E = 29.0 E^6 psi for steel):

$$\varepsilon_{top} = (\sigma_{B\text{-}top} + \sigma_A) / E \tag{6}$$

$$\varepsilon_{bottom} = (\sigma_{B\text{-}bottom} + \sigma_A) / E \tag{7}$$

Experiment Verification:

I. Instrumentation:

The Stanley High-Tension Hacksaw was instrumented with eight Measurements Group, Inc. EA-06-240LZ-120 Student Gages. The strain gage locations are shown in Figure 4 and listed in Table 1.

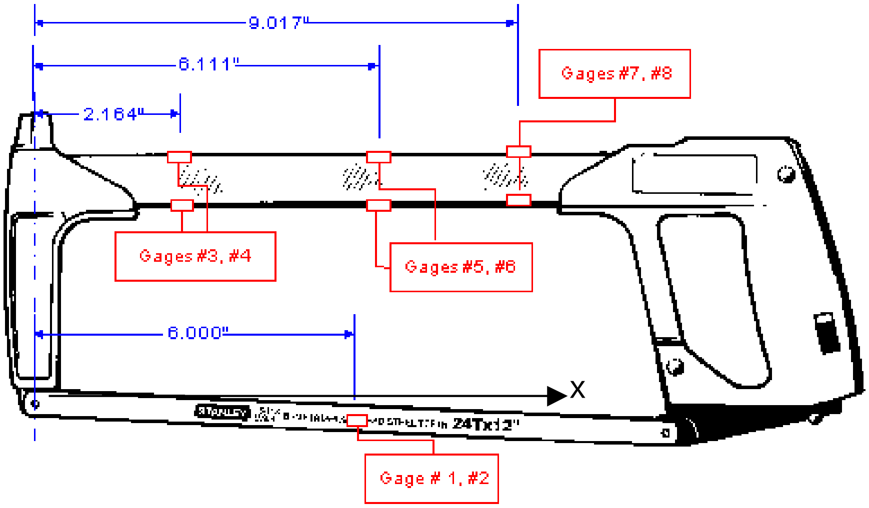

Figure 4: Mounting locations of strain gages

Table 1: Gage Locations

Gage No.	X (in)	Description
1	6	Front of Saw blade
2	6	Back of Saw Blade
3	2.164	Top of Backbone
4	2.164	Bottom of Backbone
5	6.111	Top of Backbone
6	6.111	Bottom of Backbone
7	9.017	Top of Backbone
8	9.017	Bottom of Backbone

The backbone is instrumented with six strain gages, three along the top surface and three along the bottom surface of the backbone. Two strain gages are also located on the saw blade, since it is used as a load transducer. The strain gages on the saw blade were placed back-to-back on the front and backsides of the Saw Blade in order to average out any effects due to bending in the saw blade. The gages were bonded to the hacksaw with a Measurements Group, Inc. M-Bond 200 cyanoacrylate adhesive system. Strain gage readings were taken using Measurements Group, Inc. P-3500 Portable Strain Indicator with a SB-10 Switch and Balance Unit.

II. Load Transducer Calibration:

Calibration of the load transducer was accomplished by acquiring strain gage readings for various tensile loads. The instrumented saw blade was placed in a test frame shown in Figure 5 and instrumented with a 0-5,000 kg dynamometer. The transducer was loaded from 0 to 551 lb in 55.1 lb increments and strain gage readings were taken at each increment. A linear regression analysis was performed on the calibration data. Figure 6 presents the results from the load transducer calibration showing a plot of the load versus strain. It can be seen from the plot that the behavior of the load transducer is linear.

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Figure 5: Photograph of test frame set-up.

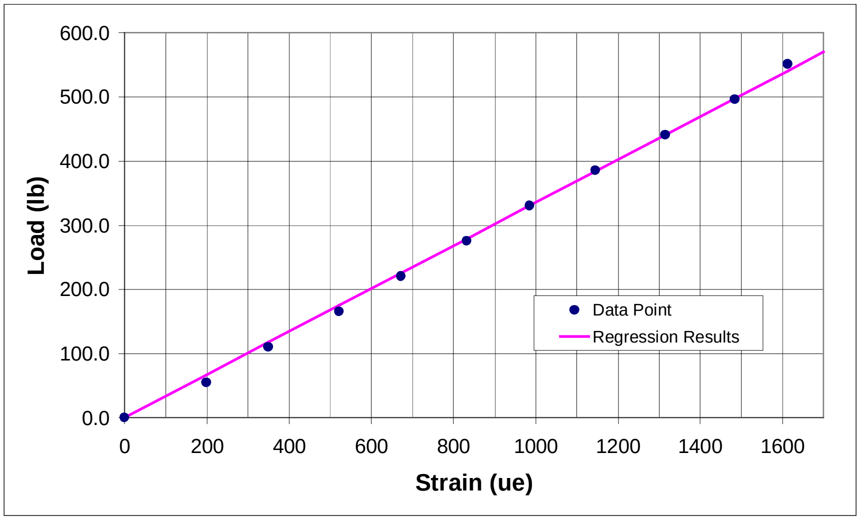

Figure 6: Load Transducer Behavior.

III. Experimental Procedure:

The saw blade (load transducer) was positioned on the hacksaw attachment pins, which were located on the head and handle of the saw as illistrated in Figure 1. The strain gage balance unit was used to zero all the strain gage readings. Tension was then applied to the saw blade by using the saws' tensioning mechanism. The strain gage readings from the loaded hacksaw were recorded, at which point the tension was removed from the blade. Strain gage readings were taken after the load was removed to determine instrumentation drift, which was found to be a maximum of 6 με. This test procedure was replicated four times.

Discussion of Results:

There was good agreement between the experimental and the analytical results for all four experimental replications. The applied load varied from 304.5 to 306.7 lb among the replications, which produced slightly different analytical and experimental results. The difference between the analytical and experimental results was consistent between the four replications. It varied less than 0.90 % for each location between replications, therefore only the results from one replication are presented. The analytical and experimental results from one of the experiments are tabulated in Table 2 and graphically shown in Figure 7.

Table 2: Analytical and Experimental Results

Gage No.	Analytical Results				Experimental Strain	Difference (Analytical/ Experimental)
	Bending Stress (psi)	**Axial Stress (psi)**	**Combined Stress (psi)**	**Strain**		
3	35,408	-1,893	33,514	1,156	1,179	-1.98 %
4	-35,408	-1,893	-37,301	-1,286	-1,256	-2.41 %
5	36,971	-1,893	35,078	1,210	1,217	-0.61 %
6	-36,971	-1,893	-38,864	-1,340	-1,353	0.95 %
7	38,122	-1,893	36,229	1,249	1,247	0.18 %
8	-38,122	-1,893	-40,015	-1,380	-1,374	-0.43 %

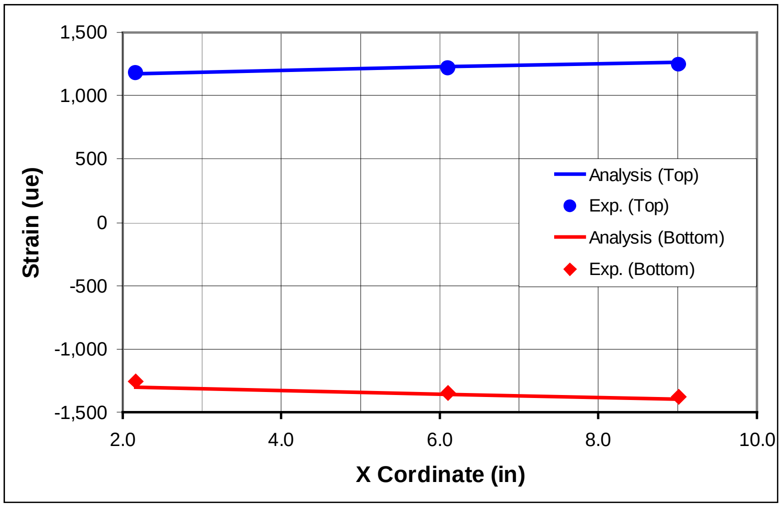

Figure 7: Analytical and Experimental Results

The results presented in Table 2 and Figure 7 come from a test having a test load (T_B) of 305.5 lb. Results show there is good agreement between the analytical and experimental results. The greatest difference was –2.41 %, which occurred at gage #4. The difference between the analytical and experimental results is due to gage location measurements that were taken. Errors in measurement *h* shown in Figure 2 will affect the analytical solution the most.

Summary:

A simple hand-held hacksaw that most people are probably familiar with was used to demonstrate the concepts of axial, bending, and combined stresses and strains. The paper outlined an analytical procedure for calculating the stresses and strains in the backbone of a conventional hacksaw. The analytical results were then verified experimentally. The paper gives details on the experimental procedure using strain gages to validate the analytical solution. Finally, analytical and experimental results are presented showing that there is good agreement between the two.

Acknowledgement:
The inspiration for this paper came from an article titled, “Of Clamps & Spring & Things”, contained in the December 1995 Issue 26, of Experimental Stress Analysis Notebook. (Measurements Group, Inc. publication) This article can be found at the following web address: http://www.measurementsgroup.com/guide/notebook/e22/e22.htm.

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