

The Effect of Dehydration and Pyrolysis on Cedar Elm Tree Specimens

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Introduction

On average, about 5 million acres burn every year in the U.S., resulting in millions of dollars in damage and leaving countless people homeless. Wildfires are particularly dangerous because of their ability to spread quickly and self-propagate. After the ignition point, a wildfire can spread as fast as 14.29 miles per hour and sustain itself with brush and trees. The wildfire can further spread by throwing embers miles away, spawning new, smaller fires [1]. Models have been developed to predict the behavior of wildfires in order to provide recommendations for evacuations and firefighting efforts. Although models for plume lofting and wind propagation stages have been developed [2-4], limited work has been done to model the creation of embers from the parent fuel package [5]. The focus of the following report is to provide additional research in this topic by testing the density and corresponding flexural strength of tree limbs after they have interacted with the fire plume.

Background

Brand lofting plays an integral role in how wildfires spread. The process of brand lofting and deposition is composed of three stages. The first stage consists of the parent fuel element generating embers by the process of aerodynamic shearing of elements that have had their structural integrity compromised. In the second stage, the embers are moved to a higher elevation within the fire plume. The third stage consists of wind carrying embers outside of the plume and depositing them in a new location. As a given ember is transported, it loses mass. Depending on its dimensions and composition upon landing in a new location, an ember will do one of two things: it will either burn out in the air, or have enough mass and thermal energy to serve as a new ignition point [5]. The interest of this work is to determine the required stress to cause an ember to break off from the parent fuel element relative to the ember's density after interacting with the plume.

Experimental Procedure

Experiments were performed to determine the affect of drying and pyrolysis on Cedar Elm tree specimens' solid density and flexural strength. The variety of the tree used for experimentation was determined by using information pertaining to the bark, shape of leaf, and arrangement of leaves for the tree that was selected (Figure 1).



Figure 1. Bark (left), Leaf (middle), and Cluster of Leaves (right) Used to Determine Tree Variety

Samples of branches with small (2-4 mm), medium (4-6 mm), and large (6-9 mm) diameters were collected from a limb of the Cedar Elm tree (Figure 2).



Figure 2. The Cedar Elm Tree Limb Used for Specimen Collection

The diameter ranges were selected by computing the average and standard deviation of the samples' diameters. The medium range was approximately equal to the average diameter, the small range was approximately one standard deviation less than average, and the large range was approximately one standard deviation greater than average (Figure 3).



Figure 3. Freshly Cut Twigs Grouped by Diameter

The samples were collected at ambient conditions of 55 °F and 43% relative humidity. These samples were then divided into two test groups with an approximately equal number of branches of each diameter range for each group. The first group was tested after heating in an oven at 100 °C for two hours. The second group was tested after heating in an oven at 250 °C for two hours (Figures 4 and 5).



Figure 4. Specimens of Small (bottom), Medium (right), and Large (left) Diameter Heated to 250 °C for Two Hours



Figure 5. Specimens of Small (bottom), Medium (right), and Large (left) Diameter Heated to 100 °C for Two Hours

The mass loss in the low temperature group was due to evaporation of moisture only. The mass loss in the high temperature group was due to both evaporation and pyrolysis [5]. The low temperature specimens appeared visually similar to unheated specimens while the high temperature specimens showed charring (Figures 4 and 5). Three-point bending tests were performed on each of the samples. The span of the bending tests varied from sample to sample. The load for fracture was measured with a load cell by loading each of the samples in the center of the span. The load cell was read by taking video of the three-point bending test and pausing the video at the moment of fracture so that the fracture load could be accurately determined (Figure 6). The fracture stress was calculated from Equation 1.

$$\sigma_F = \frac{8F_F L}{\pi d^3} \quad (1)$$



Figure 6. Example of Three-Point Bending Test

Next, the mass of each sample was measured with a digital scale. The volume of each sample was measured by submerging each sample in water and measuring the volume of water displaced. This method is considered more accurate than approximating the samples as cylinders of diameter, d , and length, L (Figure 7) [6]. The solid density of each sample was then computed as shown in Equation 2.

$$\rho_s = \frac{m}{v} \quad (2)$$

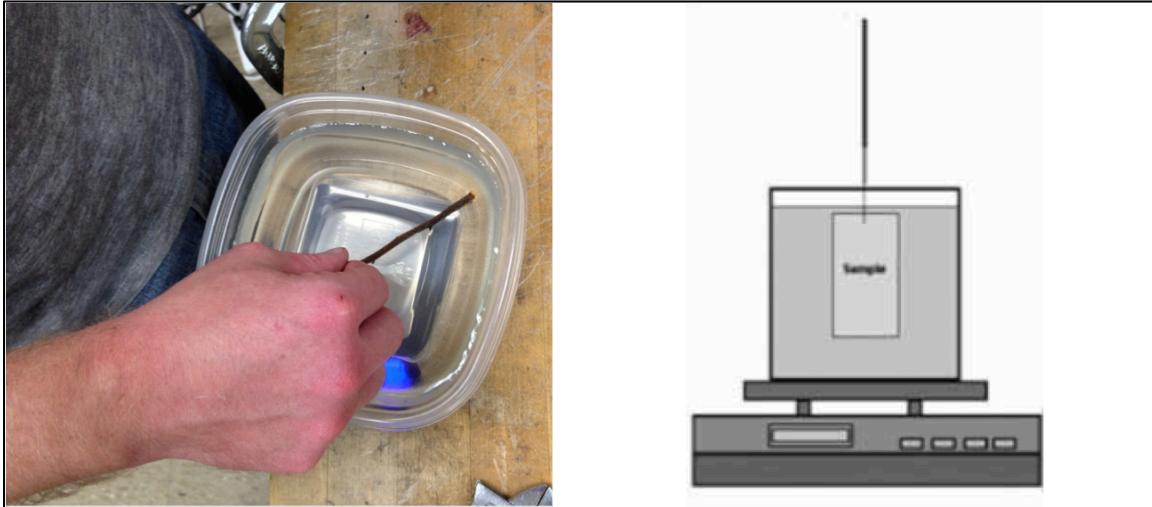


Figure 7. Volume Measurement Setup (left) and Diagram [6] (right)

Results

After the experimental procedure was executed, the data was compiled and compared for specimens heated to 100 °C and 250 °C (Figure 8).

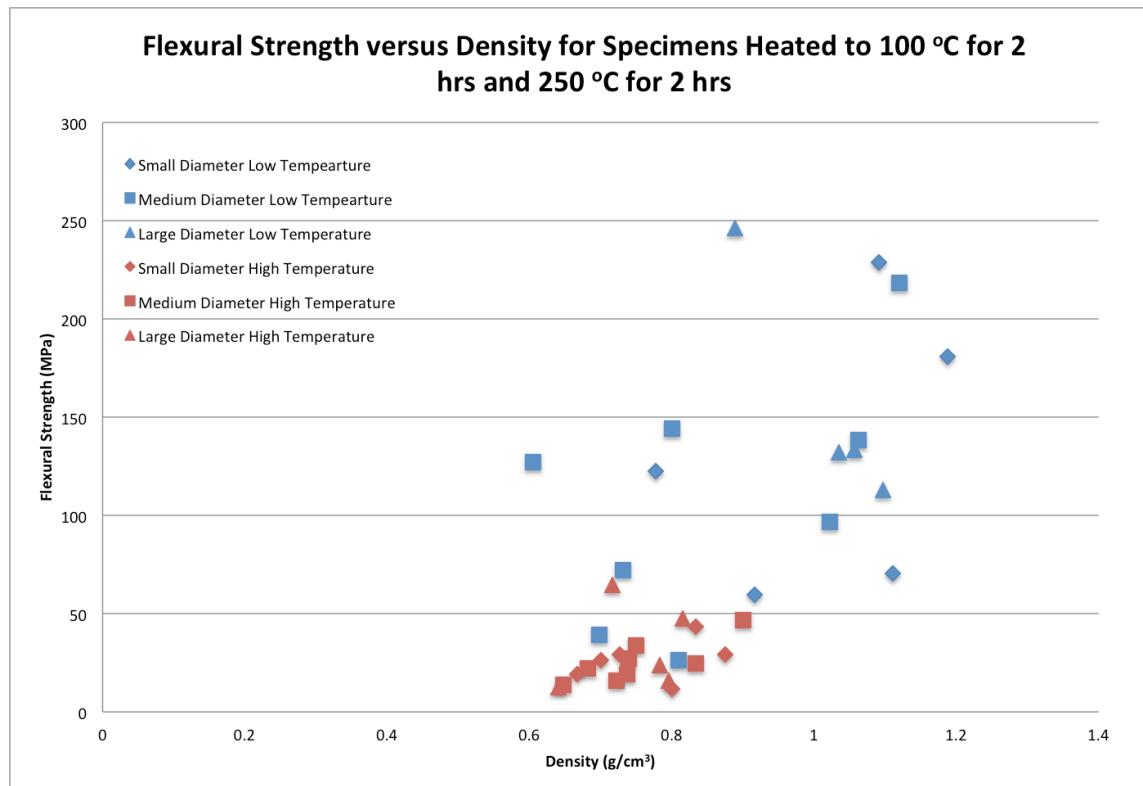


Figure 8. Flexural Strength Results from Specimens Heated to Two Temperatures

As one can see from the figure, there exists a considerable amount of scatter in the data. However, the overall trend suggests that greater values for density result in greater flexural strength for the specimens of small and medium diameter. This trend correlates with the results of similar work [5], however one should note that specimens of large diameter exhibited a decrease in flexural strength with increasing values for density. Due to the fact that the specimens are organic, they innately have imperfections. It is suspected that such imperfections weaken the specimen at particular points, and since specimens of large diameter support subsequent branches, large specimens should have more defects. Therefore, although a specimen may have a greater density, if the load was applied at the defect, the specimen may break at a lower value for stress when compared to a specimen not loaded in proximity to a defect. An example of such a defect has been presented in Figure 9. One should also note that the magnitude of the flexural strength for the specimens agrees with previous work performed on wooden dowels [5]. Additionally, as one can see from Figure 8, the specimens heated to 250 °C illustrated a decrease in flexural strength when compared to the specimens heated to 100 °C. Again, these results correlate with the general trend exhibited by wooden dowels heated to the same conditions [5].



Figure 9. Example of Defect

To better illustrate the results, the data from Figure 8 has been reproduced into two separate graphs (Figures 10 and 11). As one can see from Figure 10, the values for density range between approximately 0.6 and 1.2 g/cm³ for specimens heated to 100 °C, while the values for flexural strength vary from approximately 25 to 250 MPa. Alternatively, Figure 11 illustrates that the specimens heated to 250 °C produced values for density and flexural strength that are closer together. Specifically, the density ranged between 0.65 and 0.9 g/cm³ while the flexural strength ranged from approximately 10 to 65 MPa. It can be concluded from the data that the pyrolysis process caused all the specimens to achieve a similar composition, resulting in relatively similar properties for density and flexural strength when compared to the dehydrated specimens.

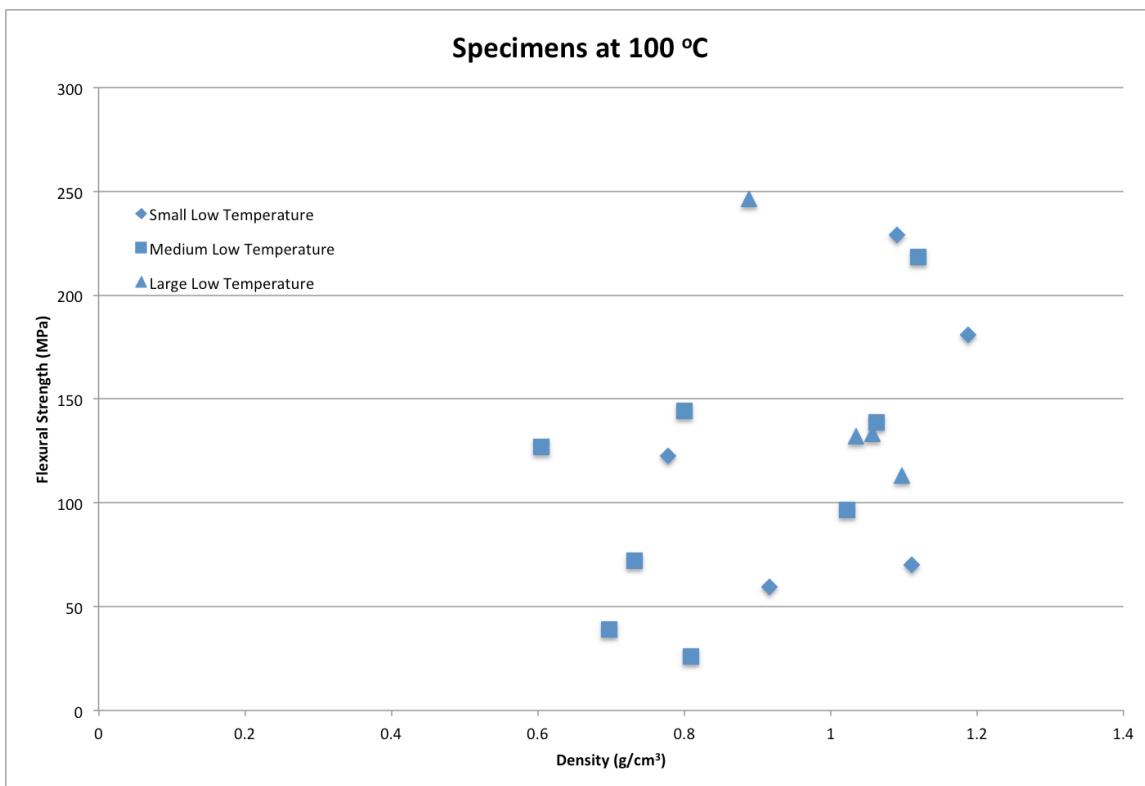


Figure 10. Flexural Strength Results from Specimens Heated to 100 °C for Two Hours

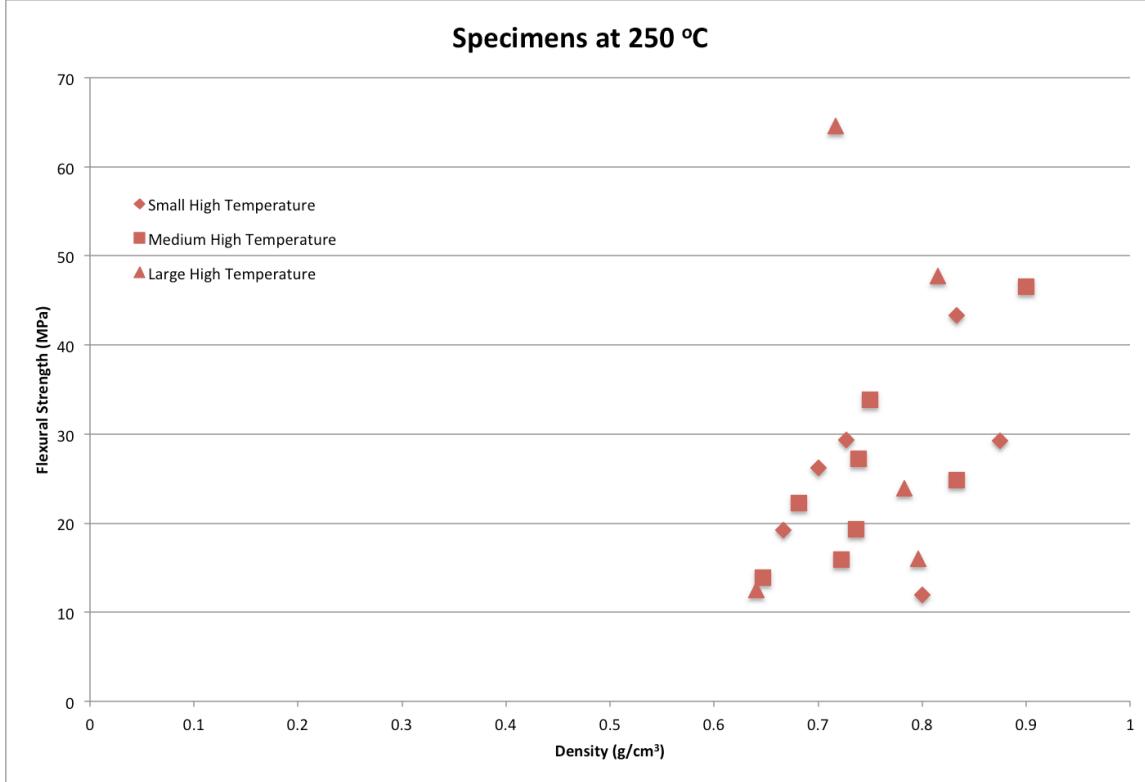


Figure 11. Flexural Strength Results from Specimens Heated to 250 °C for Two Hours

Uncertainty Analysis

Uncertainty analysis was performed on the experimental data in order to characterize the primary sources of error in the experiment. Uncertainty in solid density was due to uncertainty in mass measurements (0.05 g) and uncertainty in volume measurements (0.05 cm³). Equations 3-5 were used to calculate the uncertainties in solid density.

$$\delta\rho_m = \frac{\delta m}{v} \quad (3)$$

$$\delta\rho_v = \frac{m}{v^2} \delta V \quad (4)$$

$$\delta\rho = \sqrt{\delta\rho_m^2 + \delta\rho_v^2} \quad (5)$$

The uncertainty in mass and volume measurements contributed roughly equally to the overall uncertainty in solid density. The average contribution due to both mass and volume was approximately 0.03 g/cm³. The average overall uncertainty in solid density was 0.04 g/cm³.

Uncertainty in fracture stress was due to uncertainty in span length (0.5 mm), uncertainty in diameter (0.005 mm), and uncertainty in force measurement (1.22625 N). Equations 6-9 were used to calculate the uncertainties in fracture stress.

$$\delta\sigma_L = \frac{8F\delta L}{\pi d^3} \quad (6)$$

$$\delta\sigma_d = \frac{24FL\delta d}{\pi d^4} \quad (7)$$

$$\delta\sigma_F = \frac{8L\delta F}{\pi d^3} \quad (8)$$

$$\delta\sigma = \sqrt{\delta\sigma_L^2 + \delta\sigma_d^2 + \delta\sigma_F^2} \quad (9)$$

The uncertainty in fracture stress was dominated by the uncertainty in force measurement. The average contribution to the overall uncertainty by the uncertainty in force measurement was 5.6 MPa versus approximately 0.2 MPa for the contributions due to both uncertainty in span length and diameter. This is an important result because it suggests that in future experiments of this nature it may be a worthwhile investment to use a more sophisticated device for measurement of fracture force.

Conclusion

The results for this work suggest that there is value in further studying the effect of the fire plume on the density and flexural strength of tree branches. All in all, the results corresponded to the results of similar work in terms of magnitude and general trend [5]. As expected, the specimens that underwent pyrolysis were weaker, in general, than the dehydrated specimens. However, the data showed a considerable amount of scatter. By nature, the tree specimens have imperfections, which may account for the large amount of scatter in the data. Furthermore, the uncertainty analysis illustrated that using a more precise instrument for the force measurement would decrease the uncertainty in the flexural strength results. Moreover, a more precise method for applying the load to the exact center of the span would most likely yield better results for the flexural strength. The issue encountered in precisely placing the load at the center was that irregularities, such as bumps and curves, dictated that the applied load sometimes shift very slightly to the left or right of the center. This work provides justification for continued research into the affect of heating on tree branches' mechanical properties.

References

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