

## CHAPTER 4

### Effect of Densification on the Cellular Structure of Wood

#### 4.1 INTRODUCTION

During densification, the cellular structure of wood is permanently changed, which results in a material with new properties. One of the major factors influencing mechanical and physical behavior of densified wood is the amount and type of cellular collapse. Another important factor is the influence of the environment.

The purpose of this work was to evaluate the effect of densification treatments on the changes in the structure of two wood species, yellow-poplar and loblolly pine, and correlate it with the changes in tensile strength and stiffness. The cellular structure of wood undergoes significant changes during compression at high temperature and steam pressure. It is believed that strength and dimensional stability of a compressed sample will be highly influenced by structural modifications of the cell wall resulting from applied compressive strains. Cellular collapse occurs by either elastic buckling, plastic yielding, or brittle crushing, depending on the test conditions and the nature of the cell wall material (Wolcott 1989). Changes in the cellular structure of wood can be observed with SEM or light microscopy and quantified using image analysis techniques.

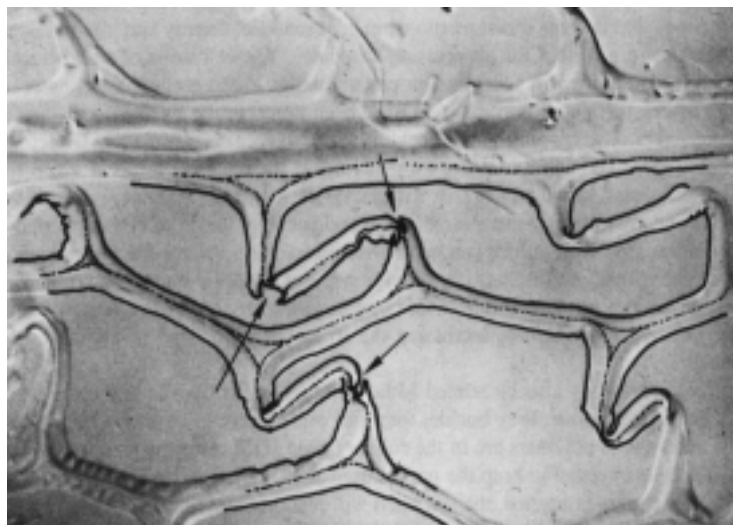
#### 4.2 BACKGROUND

In the past, many studies have been done on the characterization and location of failure when solid wood is subjected to various stresses (Bodig 1965; Keith and Cote 1968; Dinwoodie 1968; Kunesh 1968; Kennedi and Chan 1970; Inoue 1996). Kunesh (1968) noticed that in radial compression of solid wood a failure first starts from buckling of rays in an earlywood layer and results in progressive failure by buckling of the rays throughout the specimen. Others have attributed failure to crushing of tracheids of earlywood, usually at the border of an annual ring. Bodig (1965) also found that initial failure occurs in the earlywood layer. Geimer et al. (1985) analyzed damage to the flakes of Douglas-fir flakeboard caused by hot-pressing. He observed the fractures and plastic hinges in the buckled cell walls of some flakes, as well as pure elastic buckling in others (Figure 4.1).

Very little research has been published on the microstructure of wood compressed in the transverse direction under extreme environmental conditions, such as high humidity, temperature and steam pressure. Inoue et al. (1996) investigated the effect of pre-steaming on the fixation of

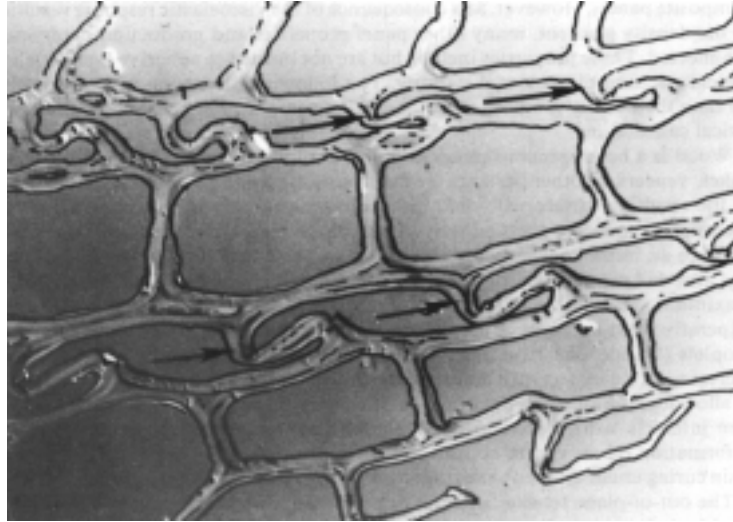
compressed solid wood. Based on SEM observations, he found that cell walls were usually deformed elastically; however, some cell wall fractures (cracks, snaps, and disconnections of the cell walls) were observed, especially in the samples steamed above 180°C. The brittle fractures were attributed to steaming.

Generally, the best conditions for fractures occur when hemicelluloses and lignin are in the glassy phase and the polymers are brittle. On the other hand, when the wood temperature is above the  $T_g$  of both amorphous polymers, then large deformation can occur without fractures (Wolcott et al. 1990).



a)

**Figure 4.1**



b)

**Figure 4.1** Cross sections of compressed Douglas-fir flakes. (a) Elastic collapse (160x), (b) Fractures in cell walls caused by extreme buckling (250x) (Geimer et al. 1985).

### 4.3 EXPERIMENTAL

#### 4.3.1 Materials

##### Specimen preparation

Two specimens were randomly selected from each group of the specimens tested in tension, except for the 3mm, mature, yellow-poplar control specimens, because there was no difference between the 3 and 4 mm control specimens. (Table 3.2). Smaller specimens were cut from selected specimens for SEM observation (54 specimens total). The densified, undensified and control specimens were placed in a beaker filled with water and placed in a desiccator. Vacuum was applied for about one hour to replace air in the lumens. The specimens were allowed to soak for about 24 hours until they were completely saturated with water. Sections of 20 to 60  $\mu\text{m}$  were sliced off from the cross-section of each specimen using a sliding microtome with a sharp knife until a smooth, clear surface was obtained. Specimens were allowed to dry at the room temperature for several days. Dry specimens were mounted on the stage using electrically conducting silver paint and coated with gold/palladium (60/40%) in a vacuum evaporator.

### **4.3.2 Methods**

#### ***Observation***

An AMRAY 1810 scanning electron microscope was used for observations of the wood structure. The working distance (distance between the surface of the specimen and the front surface of the objective lens) was 12mm. Preliminary observation had shown that wood cells were not damaged when observed with a voltage lower than 10 kV. Therefore a voltage of 10 kV was selected for SEM observation of the samples. The image analysis system also included a personal computer with image processing and analysis software (Image-Pro Plus 3.0, Media Cybernetics). Images from the SEM were transmitted to the computer and enhanced. Several images at different magnifications were randomly obtained from each of the specimens.

### **4.4 RESULTS AND DISCUSSION**

Selected SEM micrographs of the observed samples are presented in Appendix C. These images are representative of the general condition of each specimen. Only qualitative observations are presented.

No difference was noted between control samples and uncompressed samples from the treatments 1, 2 and 3. This means that the temperature alone did not affect the wood structure. However, variation in the strain level, treatment, and species did affect the degree of damage. A big difference was noted between the specimens from different treatments. Specimens subjected to treatment 1 showed the greatest degree of structural damage (Figures C8, C24, C25, C26, C30, C33, C58, C59, C81, C82, C83, C84, Appendix C). The type of fracture was mostly brittle with many fractures in the cell walls. Earlywood areas in these samples were crushed the most. Samples from treatment 2 showed less or no damage to the cell walls. Although there were some brittle fractures present in the cell walls (Figures C90, C91) and also some separation between cells (Figures C39, C66), the most common mode of failure was elastic collapse. Treatment 3 caused the least amount of damage to the cell walls. The cellular collapse occurred mostly by elastic buckling and plastic yielding (Figures C16, C18, C70, C98) with little or now fractures in the cell walls. However, a few fractures to the cell walls took place (Figure C53).

A difference was noted in the type of failure between southern pine and yellow-poplar. Southern pine specimens seemed to be damaged to the higher extent. Moreover, the way the failure occurred in these two species was different. In southern pine, the difference in resistance to compression of earlywood and latewood, combined with the abrupt transition in density

between these two zones, resulted in considerable stresses in earlywood tracheids at the border (Figure C81). Presence of resin canals in southern pine also contributed to the higher extent of damage. Failure in some cases might have started from the resin canal (due to the stress concentration around the resin canal) and progressed further in the radial direction (Figure C78). Moreover, there were some initial drying cracks present in the southern pine specimens prior to densification (Figure C75, C76). In yellow-poplar, distribution of the stress throughout the specimen was more uniform, although earlywood cells showed more structural damage than latewood (Figure C57).

No noticeable difference was found between the specimens compressed at the 25 and 50 % of strain.

Some difference was noticed between extent of damage in juvenile and mature yellow-poplar. Generally, juvenile wood showed more structural damage, than mature wood. It can be attributed to the thinner cell walls in juvenile wood and also probably to the higher microfibril angle of juvenile wood.

As can be seen from all the pictures of Appendix C, some recovery of the deformation is present due to the method of specimen preparation for SEM (soaking in water). Figure C102 was included as an example and shows how the densified wood usually looks like when comes out of the press.

#### **4.5 CONCLUSIONS**

Densification treatments had the greatest effect on the degree of damage to the cell walls. In treatments 2 and 3 cell walls deformed elastically on the whole, however, a few cracks, and disconnections of the cell walls were observed. The type of cellular collapse was different in southern pine and yellow-poplar specimens. The southern pine was more susceptible to cell wall fractures.

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