Know your fibers: Process and Properties

or

(A Material Science Approach
to
Designing Pulp Molded Products)

by

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Introduction

Cellulose fibers have unique qualities that allow them to be used for a variety of products from low-density cushioning to high-density structural products. Knowing the type of fibers and how to process the fibers for each product application requires special skill and is more an art than a science. There is much work being conducted in the paper industry to gather information on individual fiber properties, processing conditions, formation, online properties, and final paper mechanical and physical properties to move paper making toward more a science approach which can be modeled and used to predict performance characteristics. Much of this information is geared for paper making processes and papers having densities between 500 to 800 kg/m^3.

While pulp molding uses similar fibers as the paper industry, the forming processes, fiber forming characteristics, densities, and structural functionality are different than paper and requires gathering information specific for this industry. However, once this information is obtained, then some of the same techniques used in the paper industry can be used to move pulp molding toward a science approach for developing cushioning or other structural products. The goal being, to design and predict a product’s performance through computer modeling based on fundamental fiber characteristics and processing parameters.

The data presented is preliminary and was obtained from one panel per fiber type per pressing scheme. In the future, replicates will be run and statistical analysis will be conducted.

Objective

This long term research has four objectives:

1. To measure fiber characteristics and processing variations of different fiber types, virgin and recycled.
2. To measure the mechanical and physical properties of panels made from a variety of fiber types that have been pressed and dried using different processing schemes.
3. To correlate mechanical and physical properties with fiber type and processing conditions.
4. To develop a database of information that can be used to computer model and design a pulp molded structure based on performance needs and then specify the process conditions and fiber type or mixture necessary to achieve the performance.

Fiber Furnish

Several fiber types will be used to gather information on fiber characteristics and processing variations. The following are the fiber types used to obtain the data in this report. The paper stock was recycled using a small laboratory Valmet high-consistency (10%) hydropulper for 40 minutes in warm water. Furnish fiber length and ash content were measured. See figure 1 for fiber distribution for the furishes used for this study.

- ❑ BHwd = Virgin bleached Kraft: 80% hardwood + 20% softwood; ~1.5% ash
- ❑ Card w = Bristol with ink; ~2.5% ash
- ❑ LWCF wo = Light Weight Coated Free without ink; ~30% ash
- ❑ LWCF w = Light Weight Coated Free with ink; ~30% ash
- ❑ LWCG wo = Light Weight Coated Groundwood without ink; ~30% ash
- ❑ LWCG w = Light Weight Coated Groundwood with ink; ~30% ash
- ❑ OCC = Old Corrugated Containers; ~2.5% ash
- ❑ ONP wo = Old Newsprint without ink; ~2% ash
- ❑ ONP w = Old Newsprint with ink; ~3% ash
- ❑ OWP wo = Office Waste Paper without ink; ~12.5% ash
- ❑ OWP w = Office Waste Paper with ink; ~12.5% ash

Processing Methods

Panels were formed using a 50x50 cm (20x20 in) forming box. The sheet weight was 1000 g/m^2. A forming consistency of 0.4 to 0.5% was used for the initial series of tests. Six process schemes, listed below, were used to form, press, and dry the sheets. Forming characteristics and physical data for each fiber furnish were gathered, including drainage rates, wet mat thickness, moisture content, and final panel thickness; see figures 2, 3, 4, and 5 respectively. The six process schemes are:

- ❑ 0 Air = Wet formed only; Air dried
- ❑ 70 Air =70 kpa (10 psi) vacuum press; Air dried
- ❑ 380 Air =70 kpa vacuum press, 380 kpa (55 psi); Air dried
- ❑ 690 Air =70 kPa vacuum press, 690 kPa (100 psi); Air dried
- ❑ 380 Press =70 kPa vacuum pressure, 380 kPa (55 psi), hot press dried
- ❑ 690 Press =70 kPa vacuum pressure, 690 kPa (100 psi), hot press dried

Testing

Mechanical and physical properties will be measured on the dry panels in the full study. For this initial study only in-plane shrinkage and sonic MOE data were gathered, see figures 7 and 8, respectively. Sonic MOE correlates well with tensile MOE. The panels were conditioned at 22°C (72°F) - 50% relative humidity (RH) before measuring both properties. Panel thicknesses and weights were also measured after conditioning. Metriguard stress wave timer, Model 239A, was used to measure stress wave times across the diagonals of each panel. The sonic MOEs *(E)* were calculated using the formula:

$$E = (V^2)\,(d)\,(c)\left(\frac{1}{g}\right)$$

where: E = modulus of elasticity, GPa (psi); V = velocity, m/sec (in/see); d = density, kg/m^3 (lb/in^3); c = conversion factor, N/kg (1); and g = gravitational constant, m/sec (in/sec). This method is a quick and nondestructive test method that could be used with pulp molded structures. This same technology is used in the paper industry on the paper machine for online quality control of the process. The following list of mechanical and physical properties will be used to measure panel properties.

- In-plane shrinkage
- Sonic Modulus of Elasticity; In-plane and Out-of-plane
- In-plane Tensile/Compression Modulus and Strength
- Out-of-plane Tensile/Compression Modulus and Strength
- Linear Expansion (30 to 90% relative humidity) due to change in moisture
- Strength Retention in High Humidity Conditions (50% vs. 90% relative humidity)
- Poisson's ratio where possible

Correlation

Where possible, correlation's will be made between basic fiber properties and their effects on mechanical and physical properties. The following are possible correlation's, but are by no means exhaustive because there are many interrelationships. Statistical analysis will be used to help determine interrelationships. In the fill research study, we will try to model some of the relationships so that a structural part can be designed from basic fundamental properties.

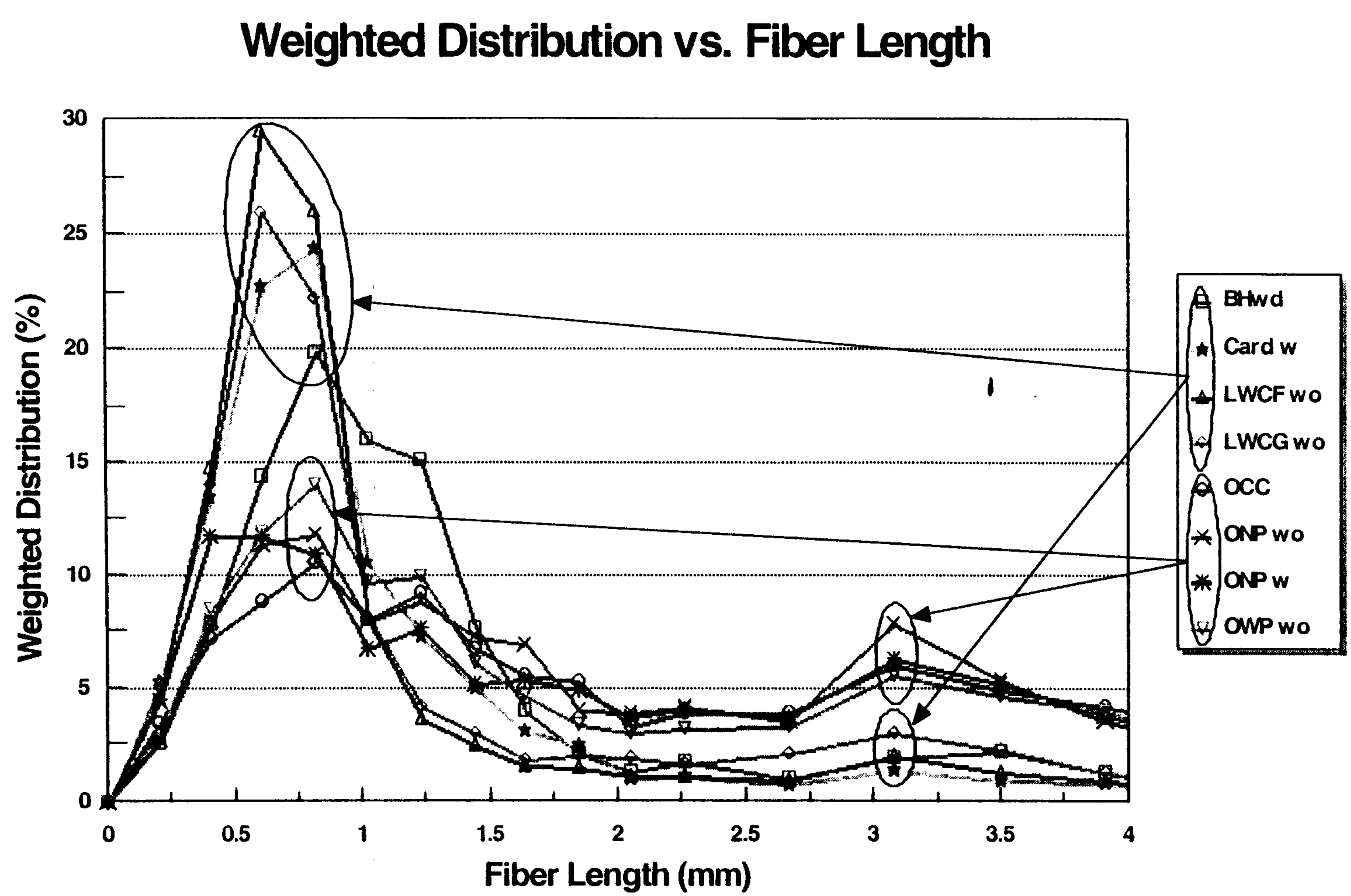
- In figure 1, fiber length distribution is shown. Fiber length distribution influences a number of properties and should be measured and incorporated into the model. For example, a short fiber length distribution will form a finer structure compared to a distribution with long fibers. Another example, for two furnishes at the same consistency, a short fiber length may allow fiber orientation to be predominantly parallel to the mold surface where a longer fiber length distribution the fiber orientation may have a significant out-of-plane orientation which will change the properties.
- In figure 2, drain rate will be included as a process/production issue that will need to be considered with modeling/designing a structure based on mechanical and physical properties. Drain rate correlates to press rate and time to dewater a fiber structure. For example, a "free" fiber furnish can accommodate a faster press rate and less dwell time than a slower draining furnish.
- In figure 3, mat thickness varies significantly with fiber furnish. Mat thickness on the mold has implications on mold design and pressing on the mold. Fiber length distribution, fiber/ash content, and processing parameters effects mat thickness.
- Mat thickness is reduced 3 to 47% with a small amount of uniform pressure. This has implications with single or multiple pressing on a three-dimensional mold on how steep a draw can be designed and mold detail.

- ❑ In figure 4, moisture content is reduced with simple pressing. This would have implications in the drying process by decreasing drying time and increasing production. Initial and pressed moisture contents are lower as ash content increases. An added advantage with pressing is “green” strength of the part is higher after pressing which relates to part removal from the molds. A simple preformed elastic film could be used to conform to the three-dimensional fiber part.
- ❑ In figure 5, final panel thickness is reduced with pressure. Furnishes with a fiber distribution having more long fibers show thicker panels. Furnishes with more ash content are thinner. OCC panels are thinner than ONP panels even if their fiber length distributions are similar, because OCC fibers have a significant portion of kraft fibers which are more flexible and conform to make a thinner panel. BHwd is thinner than OCC, because of a shorter fiber length distribution and lower-yield pulp.
- ❑ In figure 6, specific gravity of the panels increases with increasing pressure. For air dried panels, the greatest single increase is with 70 kPa (10 psi) vacuum applied pressure. The greatest effect on specific gravity is with continuous pressure in the hot press. Furnish also has a significant effect on panel specific gravity.
- ❑ In figure 7, furnish has significant effects on shrinkage. ONP which is a high-yield pulp has the lowest shrinkage, while BHwd which is a low-yield kraft pulp has the highest shrinkage. This has implications on calculating mold design to tit a specific product. High-yield fibers are generally stiffer and are less hydrophilic than low-yield pulps. The results are obvious, but they also quantify the difference. Applying pressure on the formed wet mat decreases shrinkage and continuous pressure in the hot press eliminates shrinkage for all fiber types. Other fiber characteristics may be measured to help quantify the fundamental differences for modeling purposes.
- ❑ In figure 8, panel specific gravity effects sonic MOE. For air dried panels, the data is closely grouped. For hot pressed panels, the data begins to differentiate furnish characteristics. Hot pressed BHwd virgin kraft fiber shows the highest sonic MOE compared with the recycled fibers. Other fiber characteristics may be measured to help quantify the fundamental differences for modeling purposes.
- ❑ In figure 9, all panel sonic MOE data is fitted to a squared regression line. This information could be used as a first approximation for modeling and designing a structure. A structure could be computer designed for specific performance based on sonic MOE, thickness, process variables, and other furnish characteristics. Further regression could be done for specific processing conditions such as for panels that were air dried only.

Summary

The following results are preliminary, but show some basic information that will be used in an attempt to model pulp molded structures so that by measuring several basic fundamental properties of a fiber furnish and specifying process conditions, a molded structure could be designed for a particular performance need.

This research is government supported and will be open to all as it becomes available.



1. Kajaani FS 100 weighted distribution of fiber lengths for various fiber types used in the study. (Preliminary data)

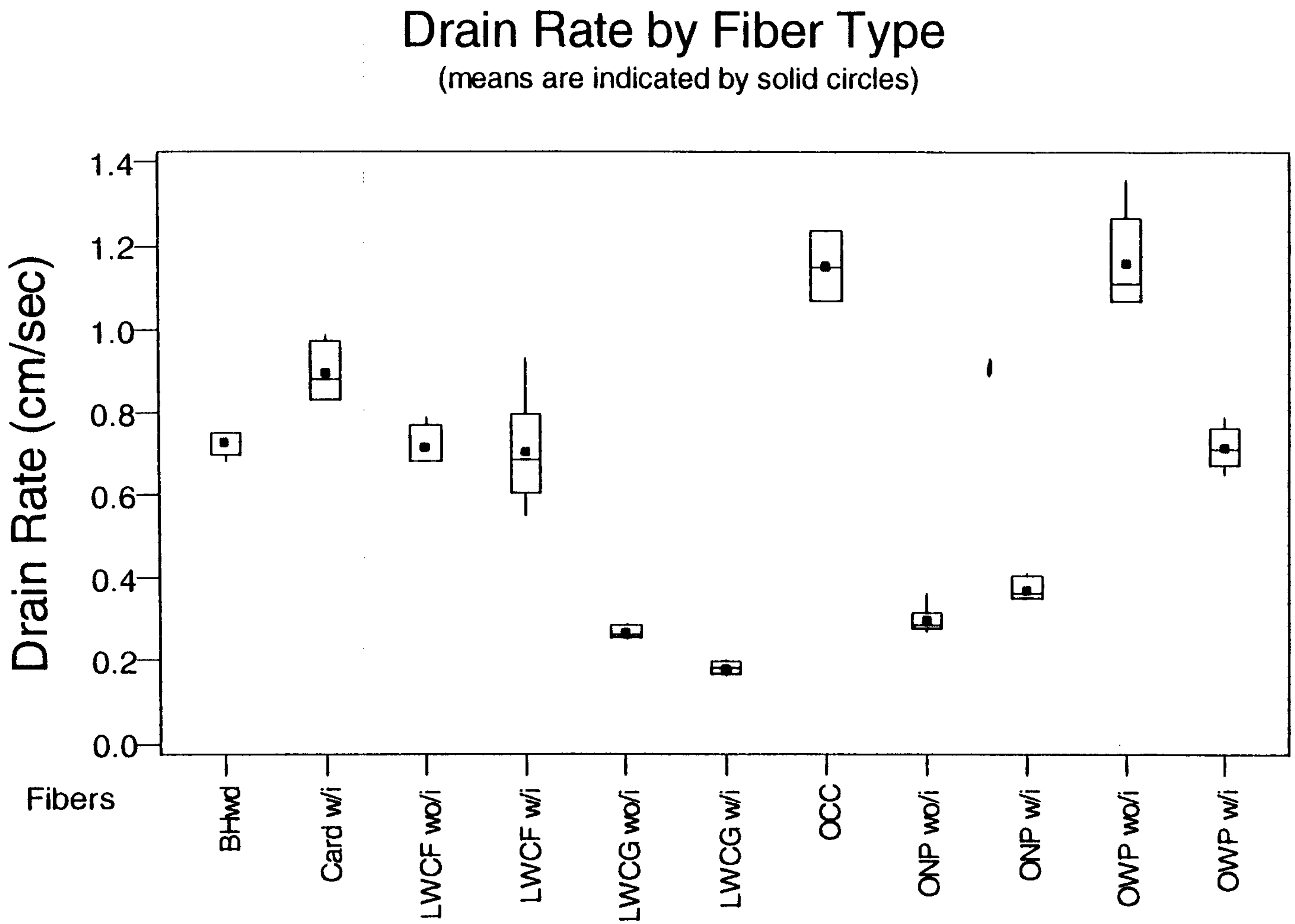


Figure 2.(a) Drainage rate vs. fiber type. (Preliminary data)

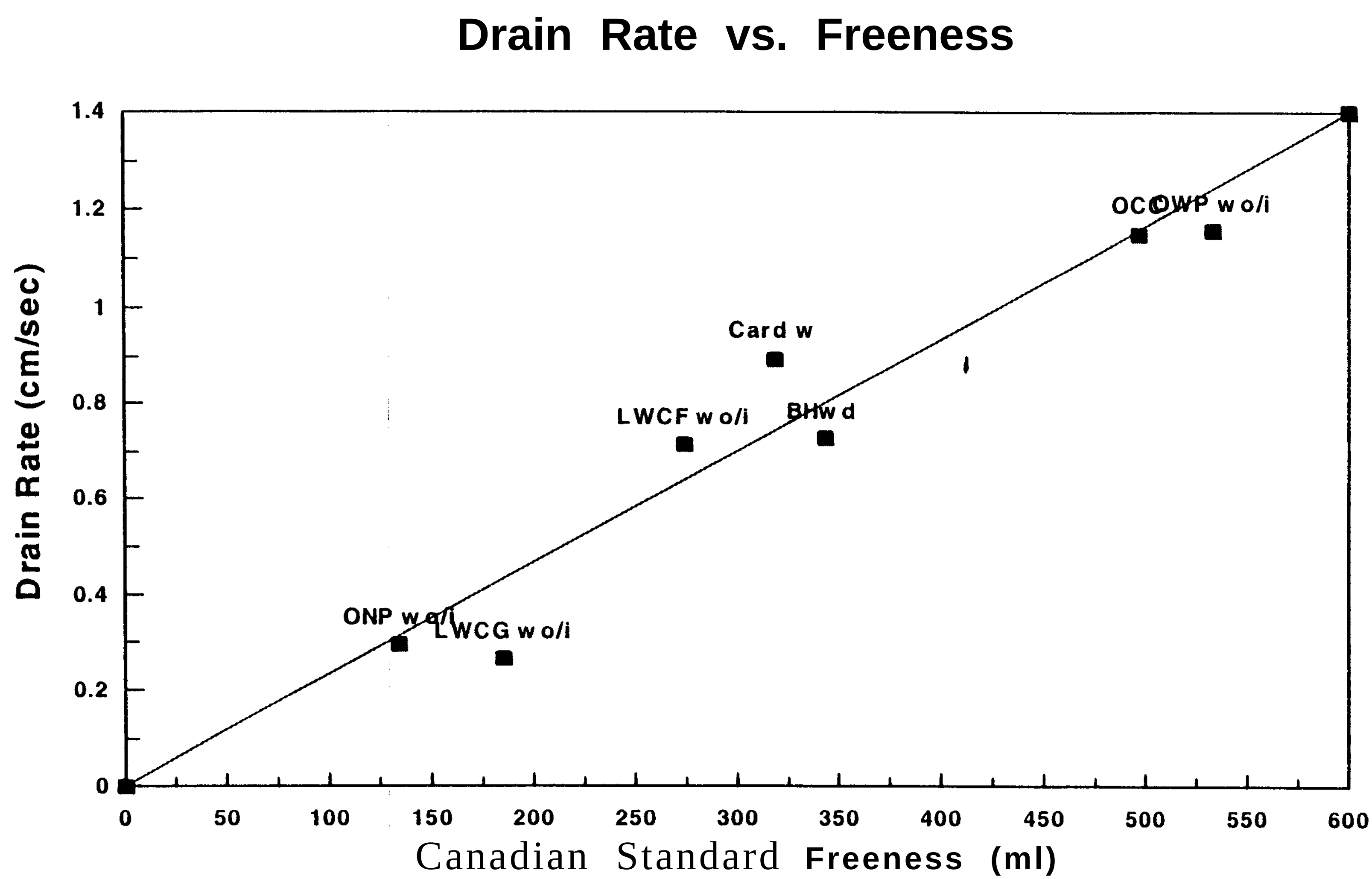


Figure 2.(b) Drainage rate vs. Canadian Standard Freeness. (Preliminary data)

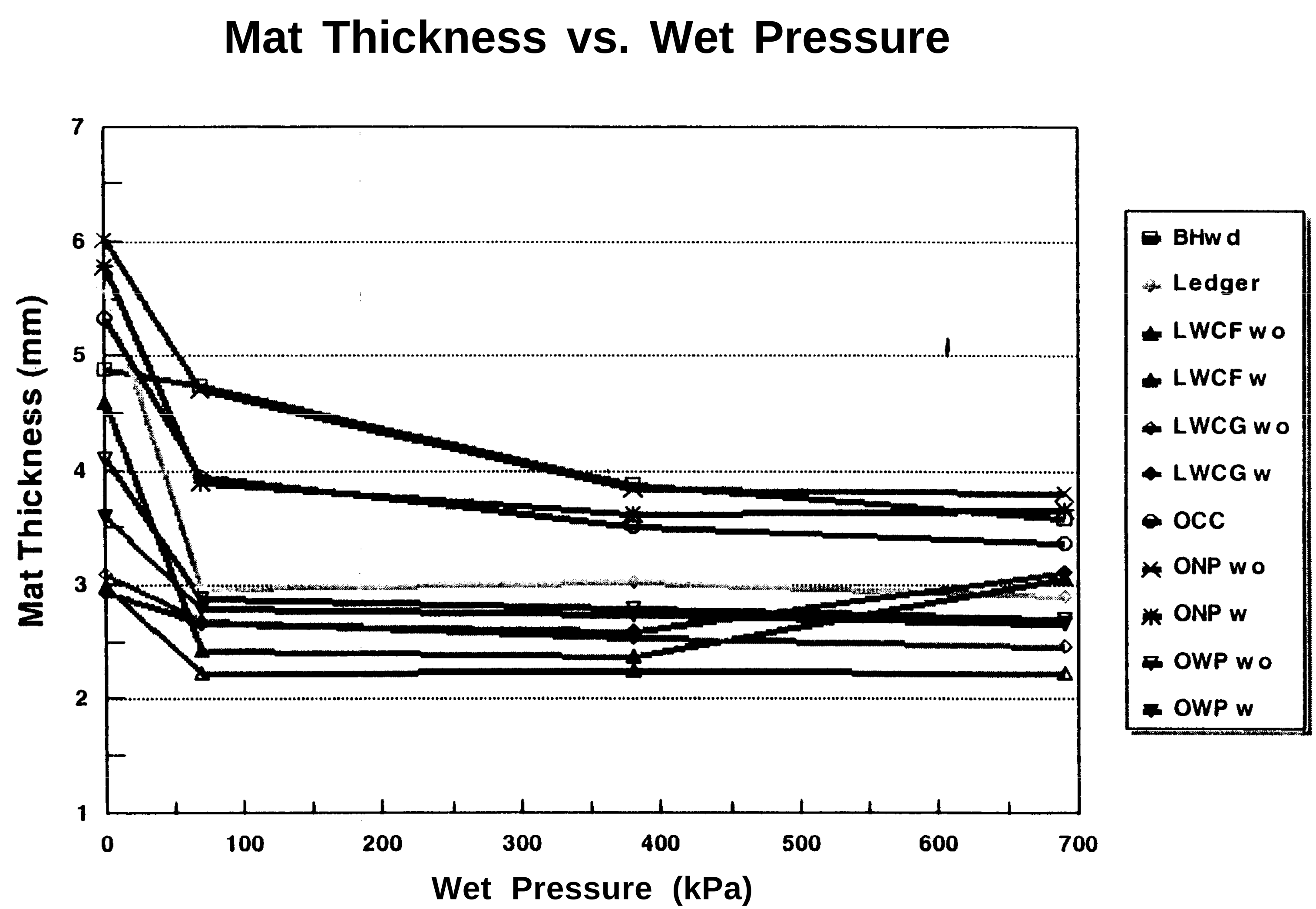


Figure 3. Mat thickness after wet pressing. (Preliminary data)

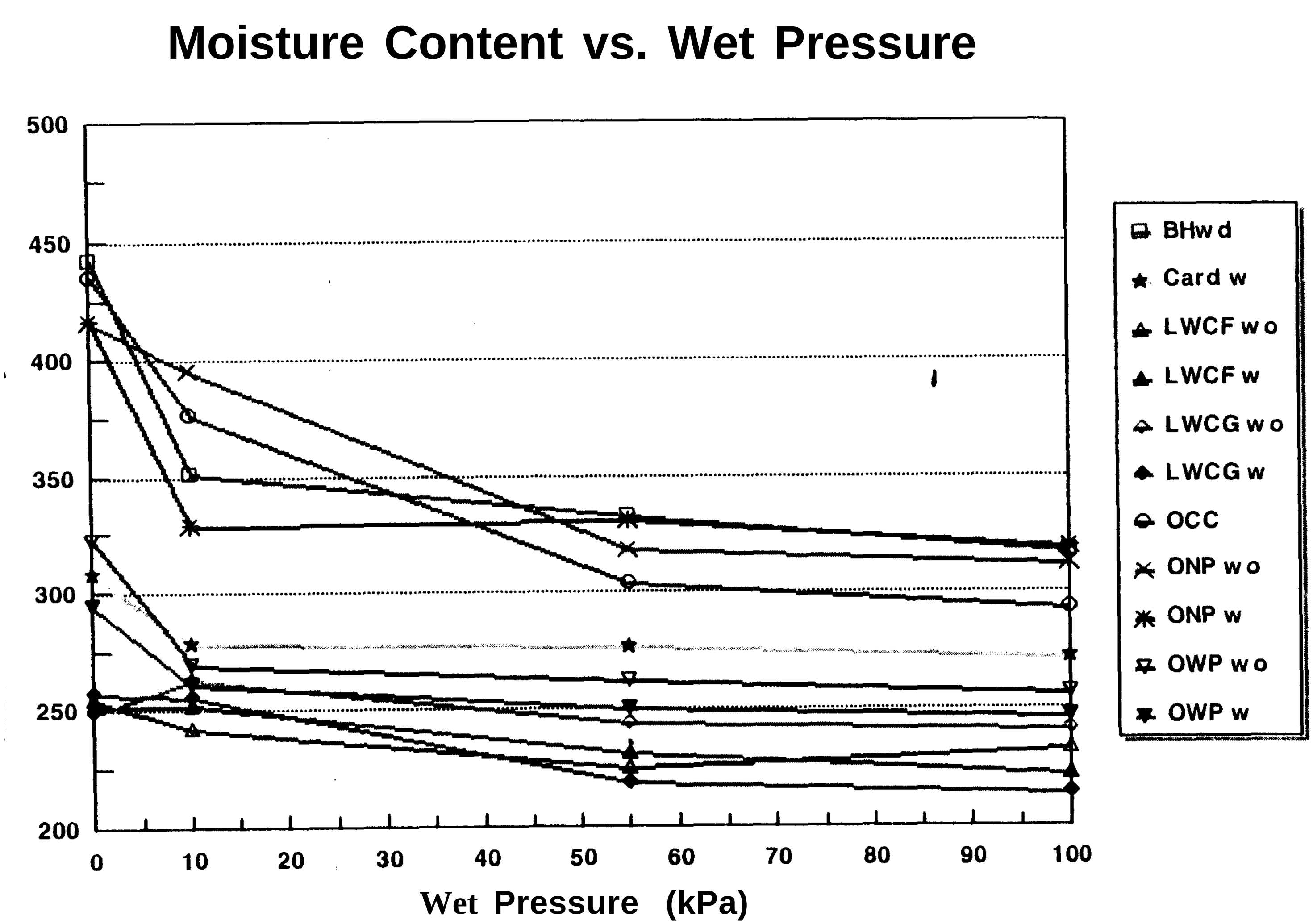


Figure 4. Moisture content (dry basis) vs. wet pressing pressure. (Moisture content (%) = total weight/dry weight) (Preliminary data)

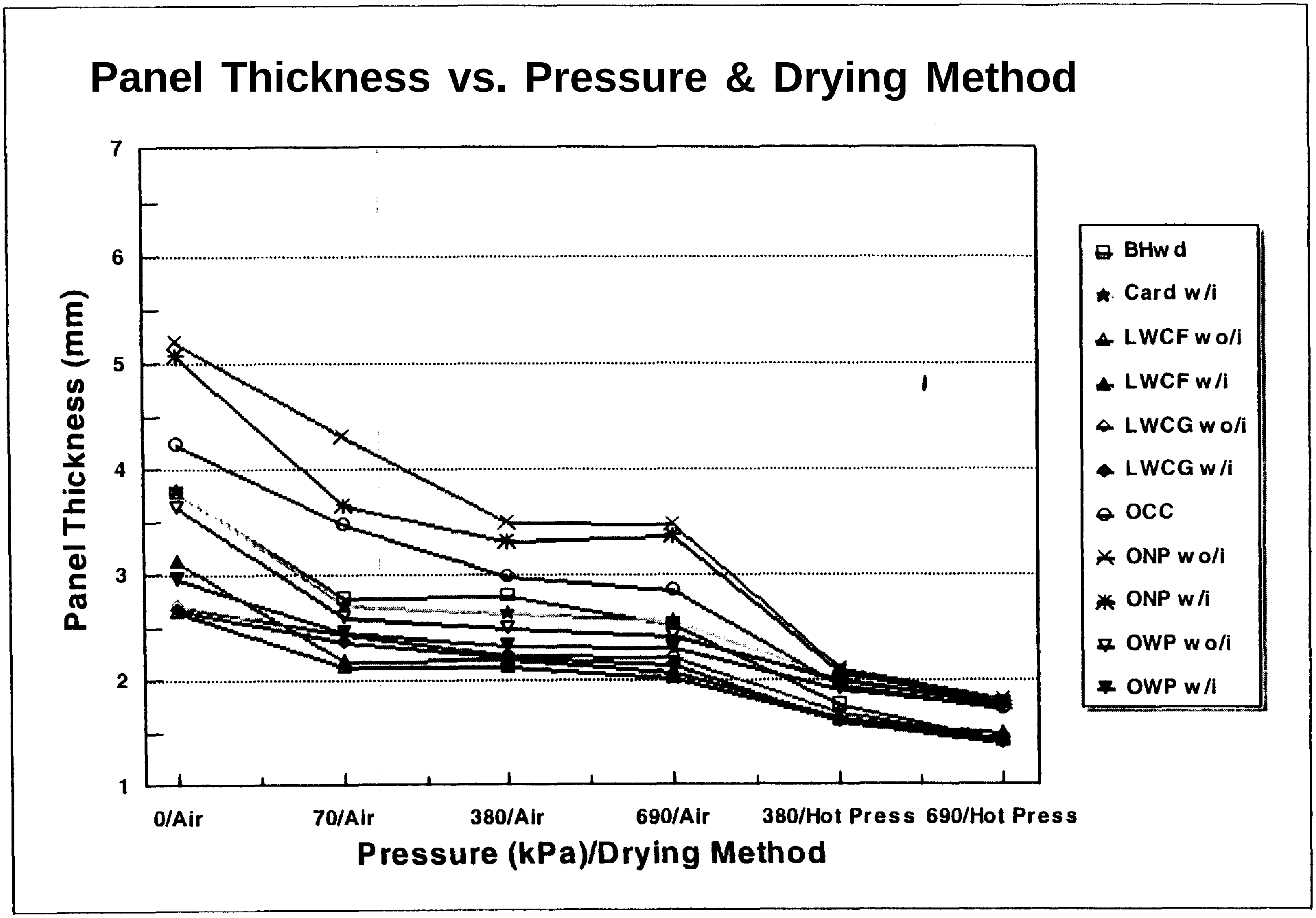


Figure 5.(a) Panel thickness for all processing schemes. (Preliminary data)

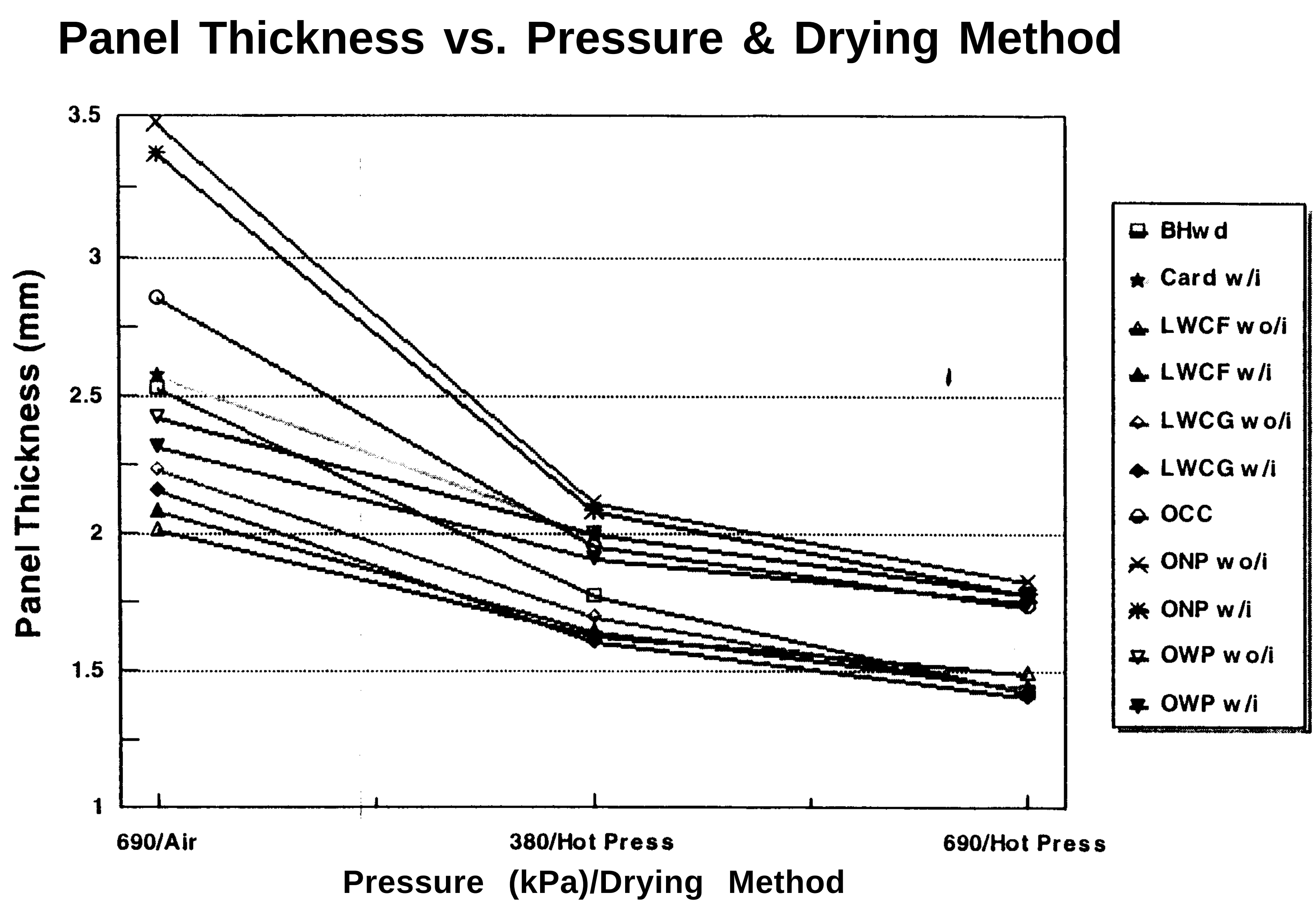


Figure 5.(b) Panel thickness for three of the processing schemes. (Preliminary data)

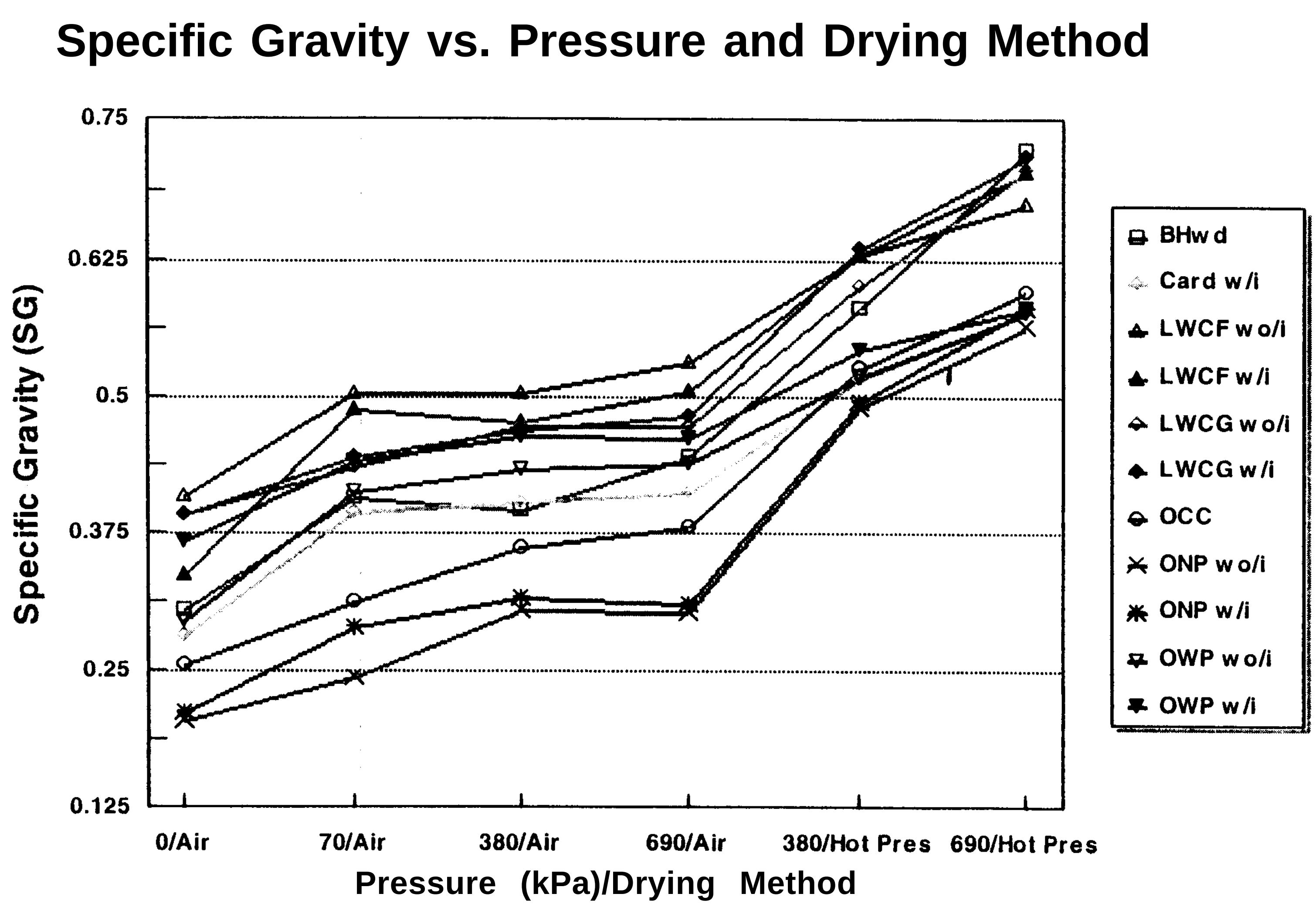


Figure 6. Specific gravity vs. processing scheme for the fiber types. (Preliminary data)

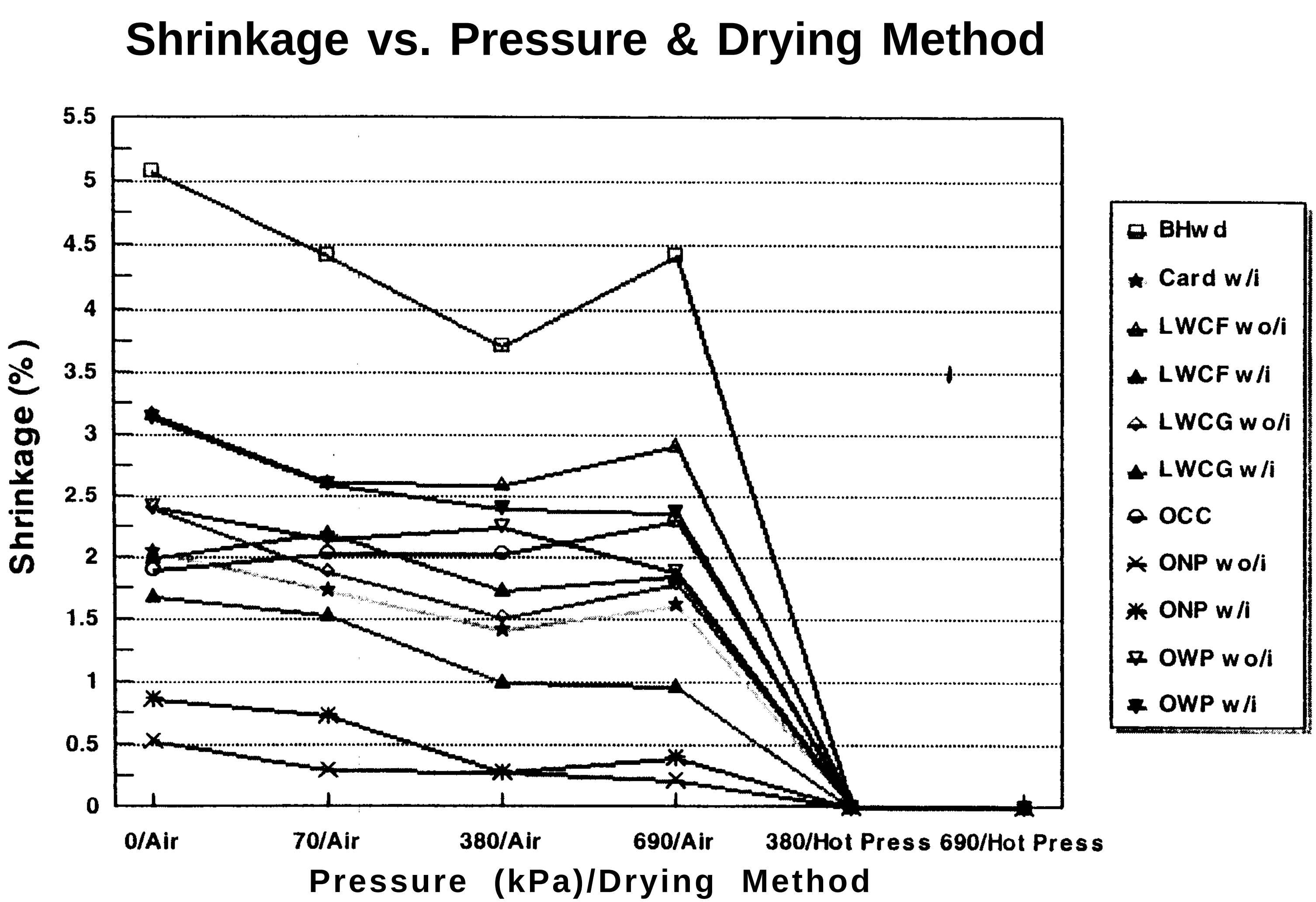


Figure 7. In-plane shrinkage vs. processing scheme for the fiber types. (Preliminary data)

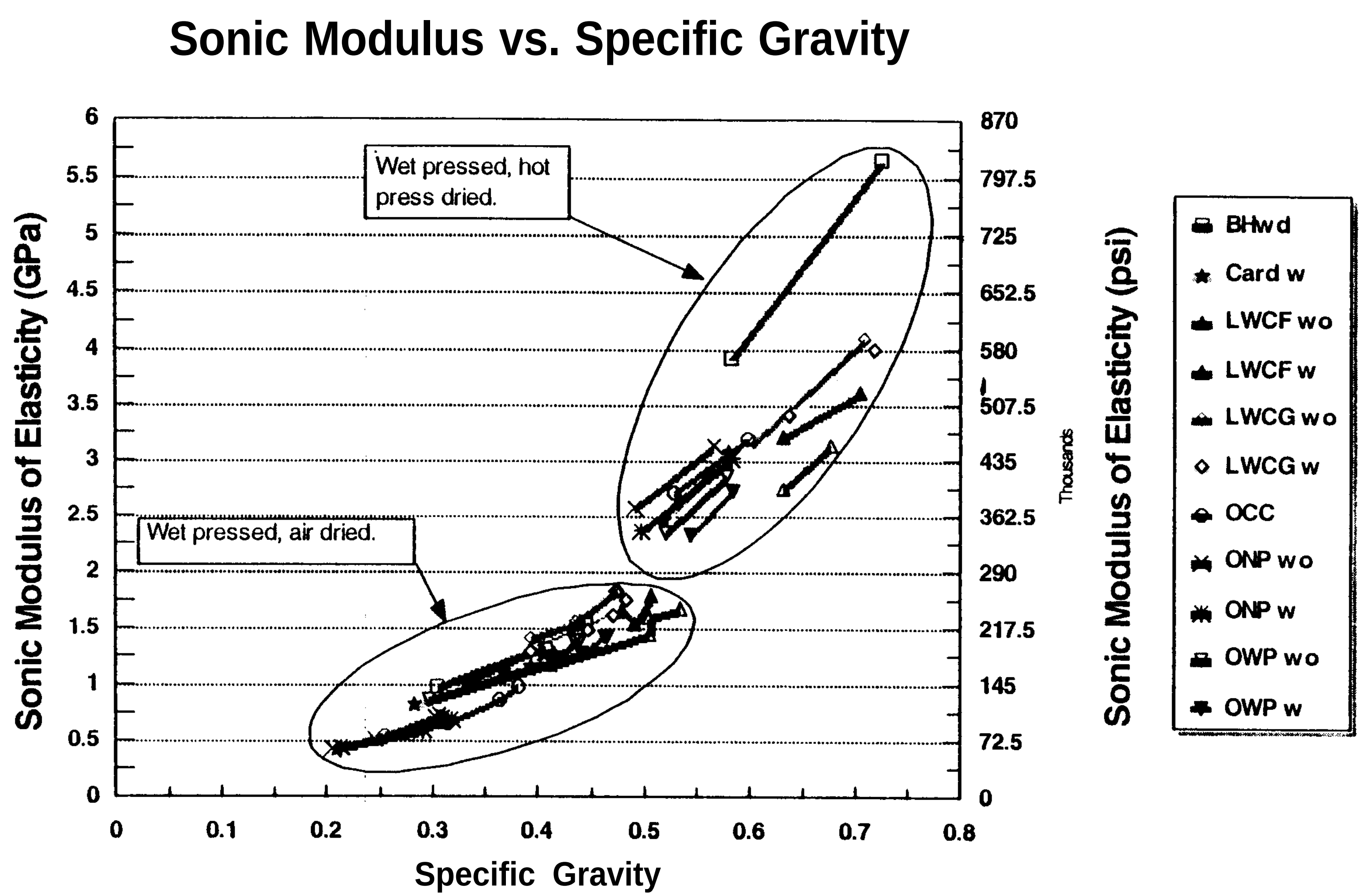


Figure 8. Sonic MOE vs. specific gravity for the fiber types as affected by pressing and drying methods. (Preliminary data)

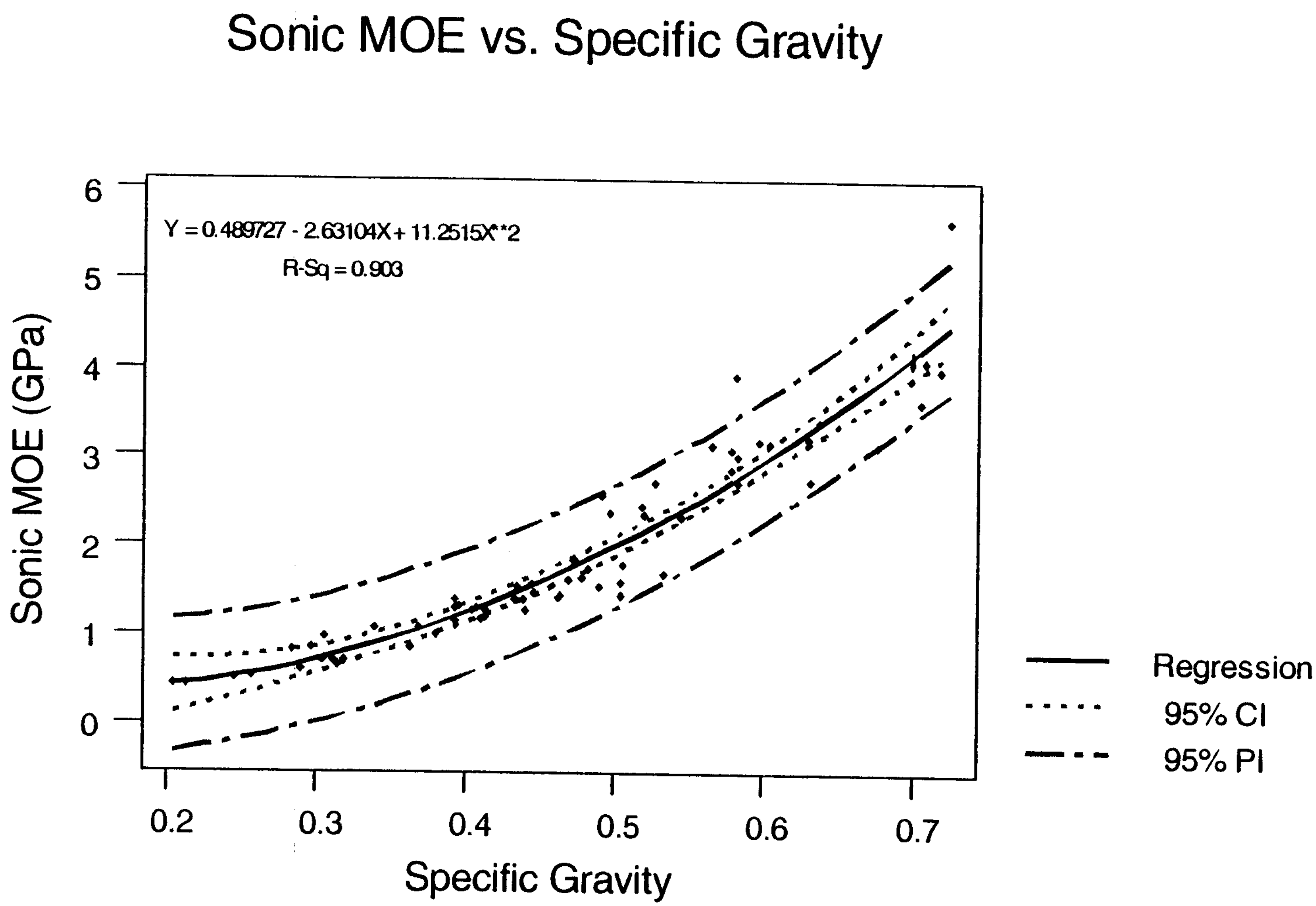


Figure 9. Regression fitted line for Sonic MOE as a function of specific gravity for all data points. (Preliminary data)

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