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ABSTRACT

Web consolidation theories currently available are mainly based on indirect measurements and speculation. In this project, we use flash x-ray imaging in conjunction with image analysis techniques to directly measure the deformation during wet pressing of multilayer sheets. An image analyzer is used to obtain quantitative results on local sheet deformation and densification.

Wet pressing, impulse drying, or any other process which involves fluid flow in a deformable porous media share a common feature -- coupling between the fluid flow and the deformation of the medium. The technique we are using in this study allows direct measurement and analysis of this behavior. Detailed analysis of the relation between the sheet deformation (strain gradient in normal as well as lateral directions) and the fluid flow is the key to understanding and controlling the property development and dewatering behavior in web consolidation.

This paper reports the recent progress in development of a technique for local deformation studies in web consolidation.

INTRODUCTION

The coupling between the fiber deformation and the fluid flow through the layer in the press nip results in a density gradient normal to the sheet. The effects of this nonuniform density on the final sheet of paper are demonstrated by MacGregor [1] and others. To understand the physics of local web consolidation requires dynamic measurement of the sheet deformation. There have been a number of attempts to measure the dynamic sheet deformation in a press simulator [2-5]. The most reliable measurements to date are by Burns et al. [5] who have greatly improved the technique first developed by Burton [4]. These investigators use a proximity detector to measure the displacement of targets embedded in a handsheet formed for these experiments. These techniques, although quite useful and accurate, cannot easily be applied to roll press systems. In this paper we discuss a different technique based on flash x-ray imaging for direct measurement of the sheet deformation in a roll press nip. The objective of our study is to demonstrate the potential and limitations of our technique.

EXPERIMENTAL SETUP

When an inhomogeneous medium is exposed to x-ray radiation, components with different x-ray absorption coefficients will produce a contrast image. For example, a sheet of paper will absorb less radiation than a metallic object. The application of x-ray to assess sheet formation and quality is demonstrated by Farrington [6] who also discusses several other applications of this technique.

An experimental roll press has been designed and constructed for the flash x-ray studies. It consists of 6" diameter, 1" thick rolls with maximum operating speed of 300 ft/min. The value of the nip pressure is dependent on the thickness of the sheet and the felt. The relative positions of the x-ray unit with the rolls and the x-ray film cartridge are shown in Figures 1 and 2. The x-ray radiation source is a Hewlett-Packard Model 43733A flash x-ray unit.

By placing small solid x-ray tracers (particles, fibers, or continuous wires) in a sheet of paper, we are able to capture their displacement during the pressing process. An exaggerated example is shown in Figure 3, where spherical metallic particles are placed between several sheets. Because of reproduction of the image, the particles cannot be seen in Figure 3b; however, they are clearly visible in the original x-ray radiograph. A more realistic image is shown in Figure 4. Using the image analyzer, we then label each particle and measure its relative displacement in all directions. This information gives a direct measure of the local strain gradient tensor (i.e., local deformation in Z and machine directions). The local strain tensor can then be calculated. These results would be useful in understanding the dewatering mechanisms in wet pressing and web consolidation processes in general.

Currently, the impulse drying simulations are possible by using a commercial propane soldering torch to heat the upper roll to a maximum temperature of 550^{o}F. Either liquid silver nitrate could be applied directly on the surface of the sheet before it enters the nip or x-ray tracers (solid, liquid, or both) could be added to the sheet during forming.

For quantitative studies, we adopt the second approach, that is, x-ray tracers in the form of solid particles or fibers are carefully placed in the sheet. By recording their x-ray images before, during, and after the pressing process (be it wet pressing or impulse drying), we are, in principle, able to obtain direct quantitative results on local and directional sheet deformation. Our objective in this paper is to show that the scatter in the experimental data, at least for high basis weight and multilayer sheets, is small enough to resolve the actual deformation of the sample in the nip. The most critical issue for an actual measurement of the local sheet deformation is preparation of the sample.

In various experiments, we have placed small spherical solid particles (20 to 100 microns in diameter), continuous thin wires (~ 25 microns), and metallic fibers (~ 25 microns in diameter, 1 mm long) between multilayer sheets of paper. An image analyzer is used to enhance the contrast in the x-ray image and assist in measuring the local deformation of the sample. This process is demonstrated in Figures 4 and 5. The first figure is an x-ray image of tungsten particles in a sheet, and the second figure is the same picture when magnified and processed by the image analyzer.

The actual particles are smaller than their enhanced (in contrast) image in Figure 5. This is partly because of the relatively poor resolution of the x-ray film, which causes a blurring effect. In actual measurements, the image analyzer will be used to pinpoint the center of mass of each particle and to measure their relative distance from each other and from the rolls.

Figure 6 shows the enhanced x-ray image of three 50-micron tungsten wires embedded in multilayer sheets of paper (~ 30% solids). Here the wires are also much smaller than their enhanced image. Both continuous and discontinuous target fibers have been used in the measurements outlined in the next section. The layers are individual sheets free to move and separate from each other in the expansion side of the nip. The fibers can follow the top or the bottom sheet and, therefore, the measurements are not necessarily representative of the actual expansion of the layer. In actual measurements, fibers must be placed in a single sheet. This is not, however, a trivial task. The technique developed by Burns [5] could be a viable approach to meet this requirement. Since here we are only concerned with demonstrating the feasibility of the technique, we have used several layers of individual sheets.

DEFORMATION MEASUREMENTS OF INDIVIDUAL SHEETS IN WET PRESSING OF A MULTILAYER ARRANGEMENT

The purpose for this set of measurements is to show whether the current resolution of the system is sufficient for measuring local densification in a relatively heavy sheet. The main feature of the measurements to look for is the amount of scatter in the data and the regression coefficient. In general, the results show that the technique is capable of accurately measuring the local deformation if the basis weight is not small.

Figure 7 is a schematic plot of the test samples. Four layers of sheet, 150 g/m2 each with 28% solids, are arranged on top of a Nomex felt. Selection of the axes for analyzing the x-ray films and the thickness measurements with the image analyzer are also shown in this Figure. Discontinuous (Fig. 7a) and continuous (Fig. 7b) tungsten wires 50 microns in diameter are placed between the sheets.

Figures 8 to 11 are the measurements of sheet deformation along the nip. The vertical axis is the thickness in microns and the horizontal axis measures the length in the machine direction along the nip. The points are the actual measurements and the line is a 5th order regression fit. The samples in Figures 8 and 11 use discontinuous tungsten fibers where Figures 9 and 10 have a continuous target arrangement. Because of the nonsymmetric roll arrangement (see Fig. 1) and the use of stabilizer felts in the larger roll adjacent to the x-ray roll, the precise nip pressure cannot be obtained for these measurements. Therefore, we report the hydraulic pressure setting which is 50 (psi) in Figures 10 and 11, and 60 (psi) in Figures 8 and 9.

Considering the sample arrangements which essentially allow free movement of the individual sheets and targets, the compression and expansion behavior of the samples is consistent with the load (Fig. 8 shows the compression side of the nip only).

The amount of scatter in the measurements is much smaller than the variation in the thickness of individual sheets along the nip in all of the measurements. The regression coefficient is larger than .95 in all of the experiments. These measurements show that this technique can be used to measure local and instantaneous sheet densification in a roll press, at least for sheets with large basis weights.

With further development of the technique, and more accurate measurements of the samples prepared from single sheets, many interesting features of roll pressing previously unaccessible to the experimentalist can be obtained.

As stated before, the quantitative values of the current measurements cannot be related to single sheet pressing since the samples were prepared by stacking four individual sheets on a felt. With this arrangement, the sheets can separate from one another just before or after the nip, and targets are also free to follow each adjacent sheet. The next step in this study is to actually plant the targets inside a single sheet as it is being formed.

CONCLUSIONS

This study demonstrates the feasibility of using the flash x-ray technique to measure local sheet deformation in web consolidation processes. The advantage of this technique is the direct and relatively simple manner by which it images the sheet deformation in the nip. The main difficulty with this approach is sample preparation and placing the wire or the particles inside the sheet. The flash x-ray was able to resolve wires as thin as 50 micrometers. This prevents measurement of sheets with very low basis weight.

ACKNOWLEDGEMENTS

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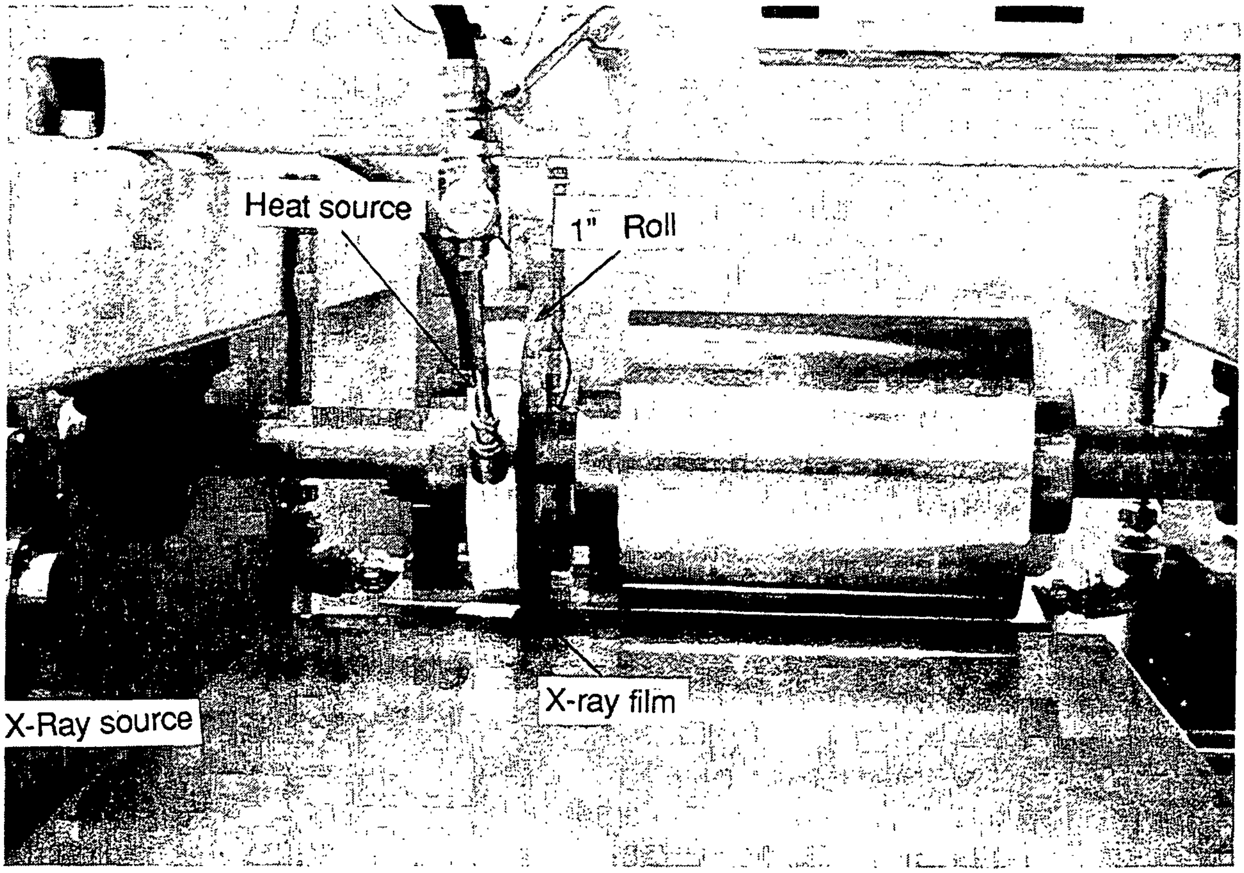
a)



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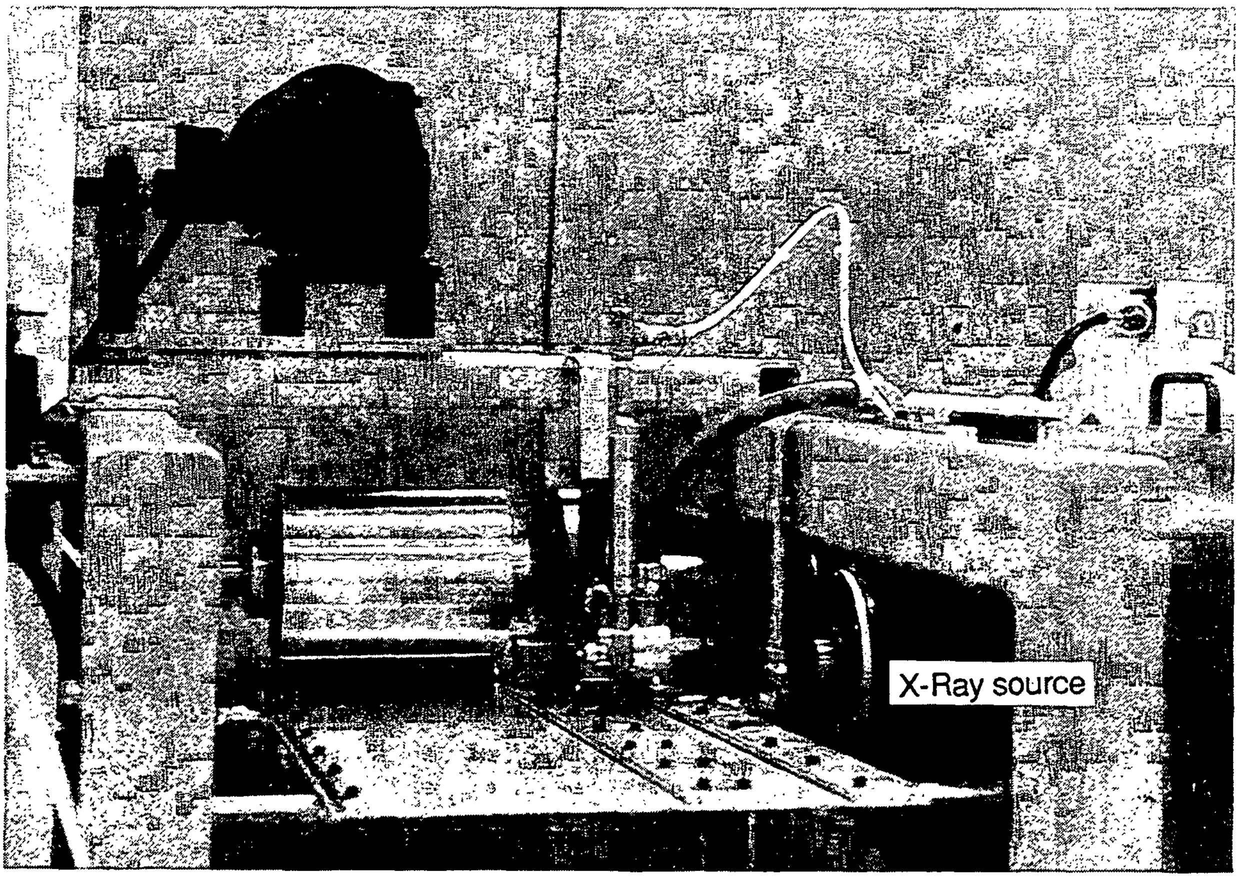


Figure 1. X-Ray Roll Press a) exit side b) entering side

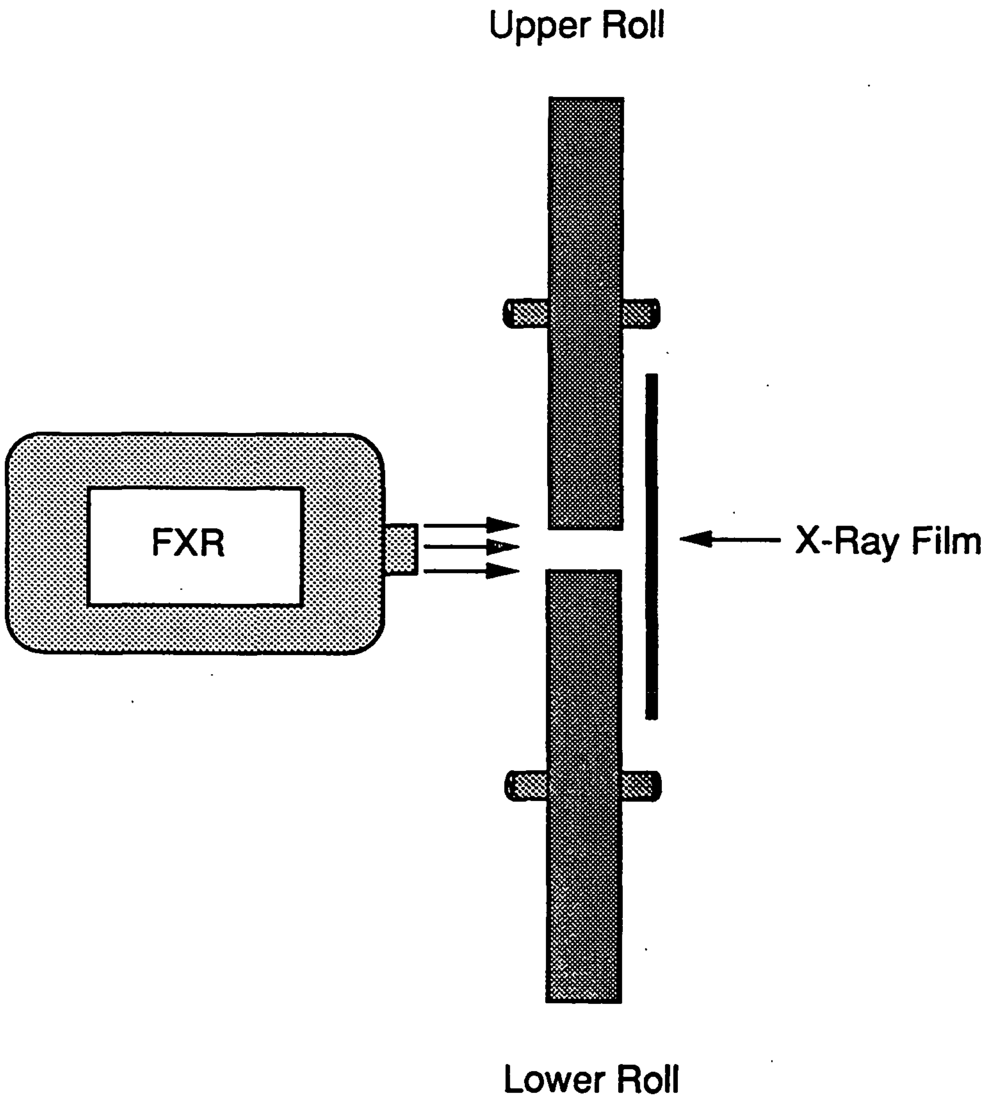


Figure 2. Schematic diagram of the relative position of the x-ray source, x-ray film, and the rolls.

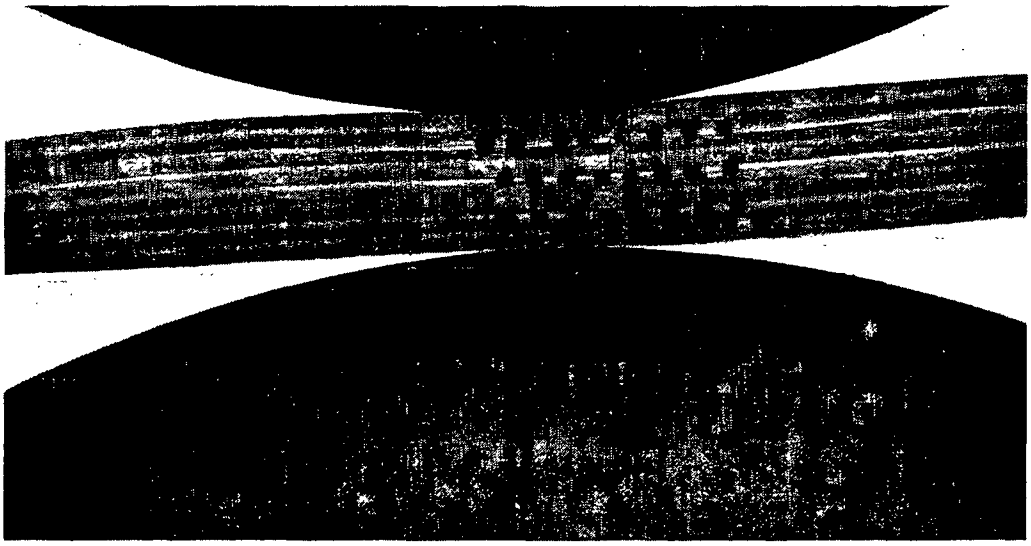


Figure 3a. Flash X-ray Rdiograph of Target Particles (zero load)

Figure 3b. Flash X-Ray Radiograph of Target Particles (compressed)

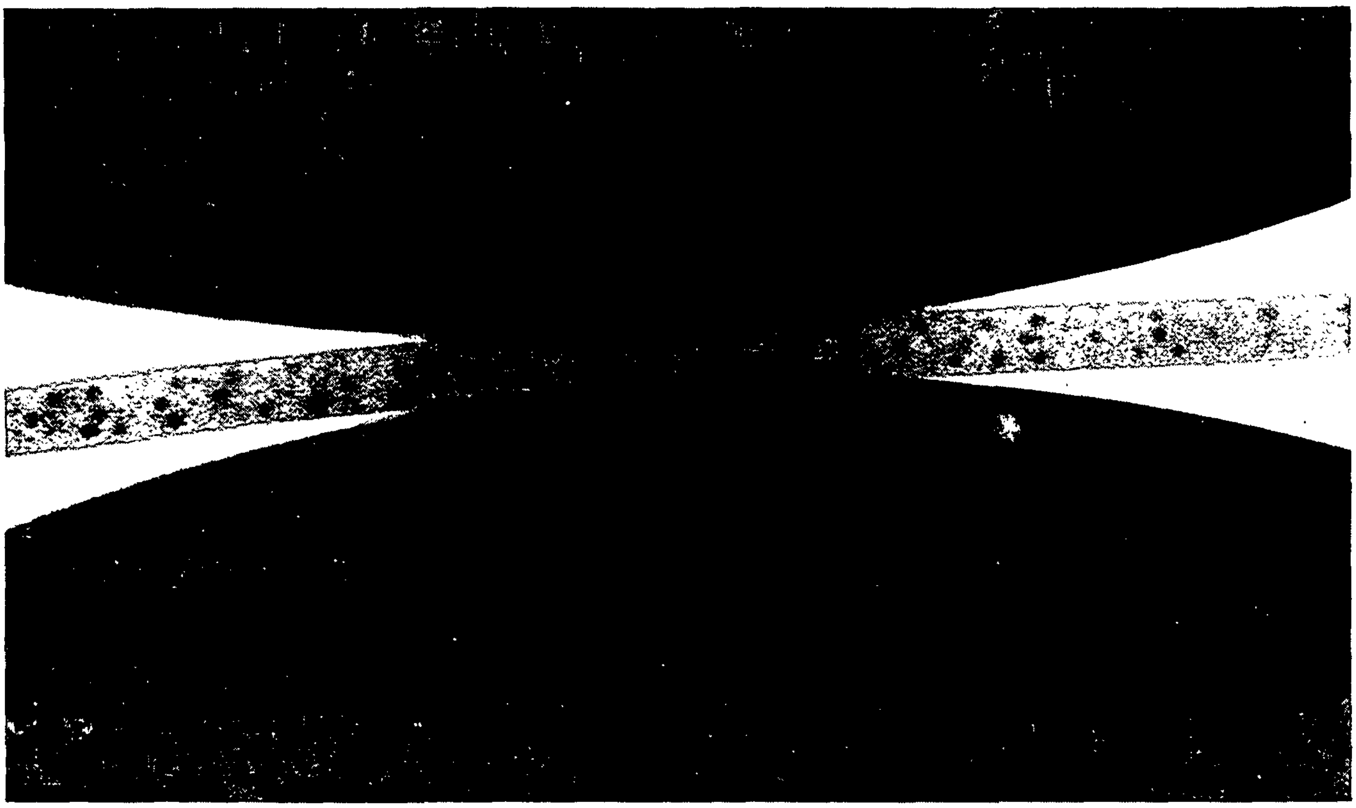


Figure 4. X-ray image of tracer particles in a deforming sheet.

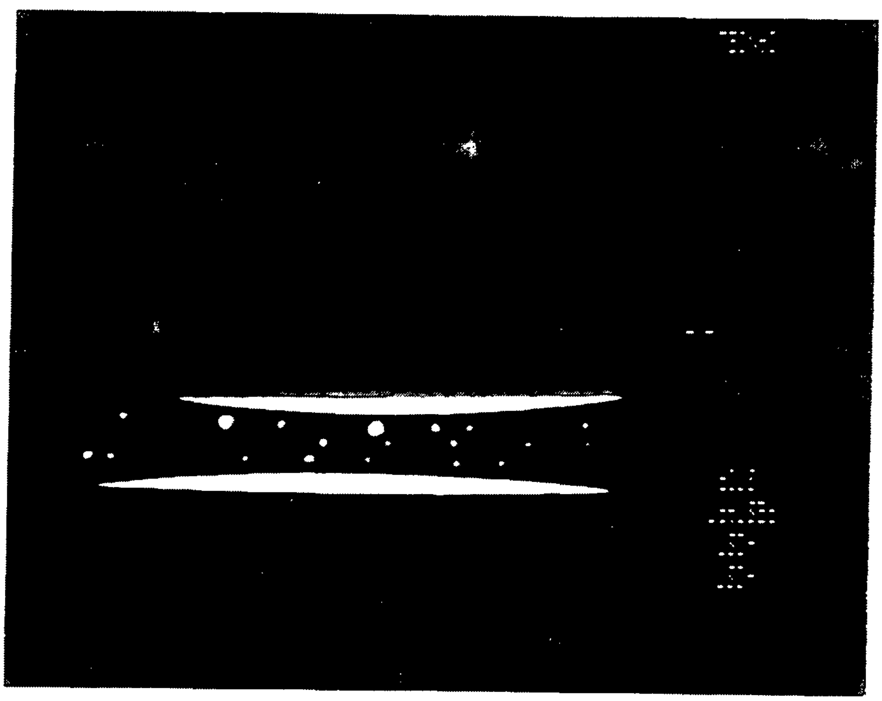


Figure 5. X-ray image of solid particle tracers in a sheet inside the nip of a roll press.

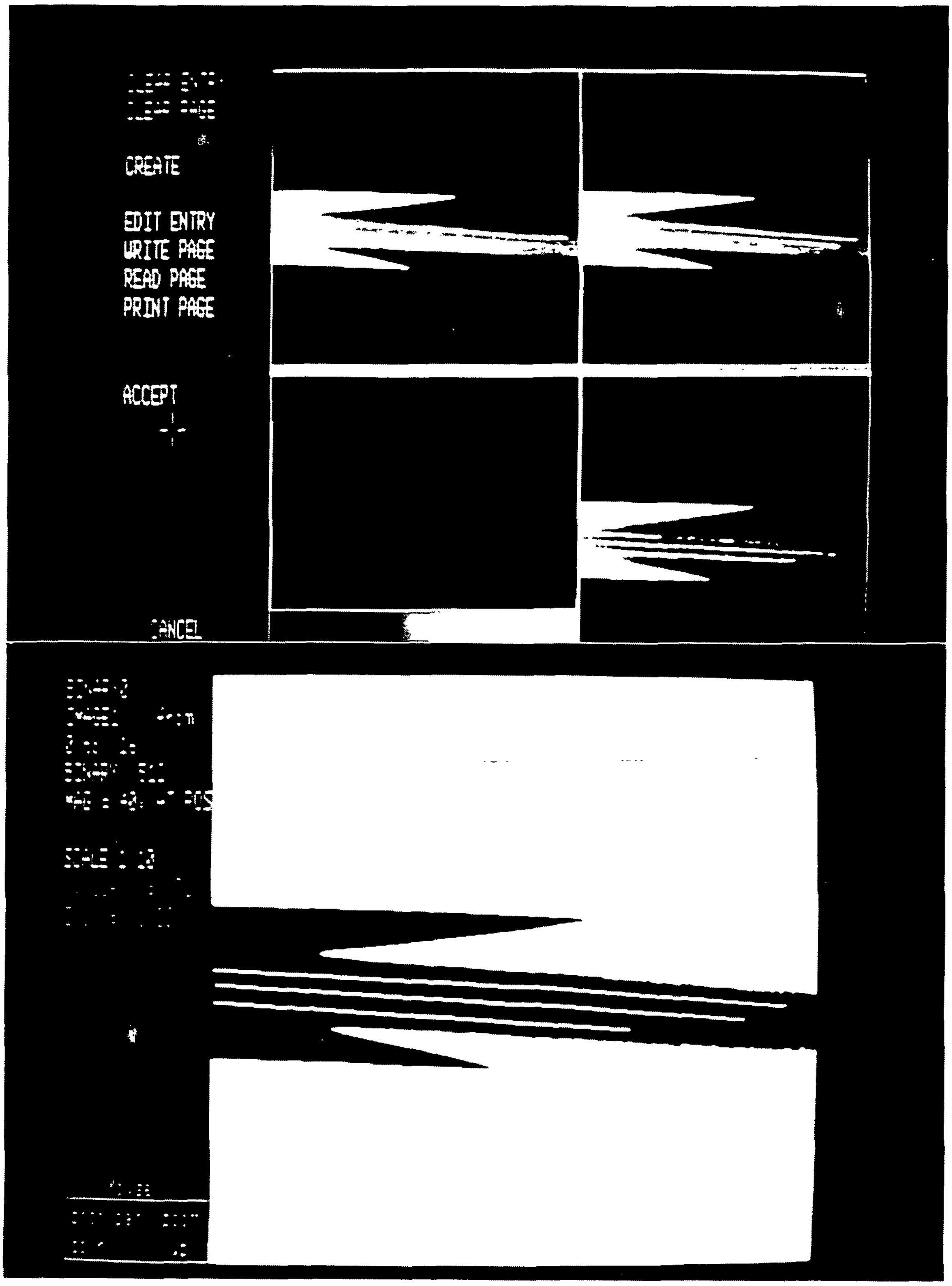


Figure 6. Enhanced x-ray image of three 50-micron tungsten wires embedded in multilayer sheets of paper.

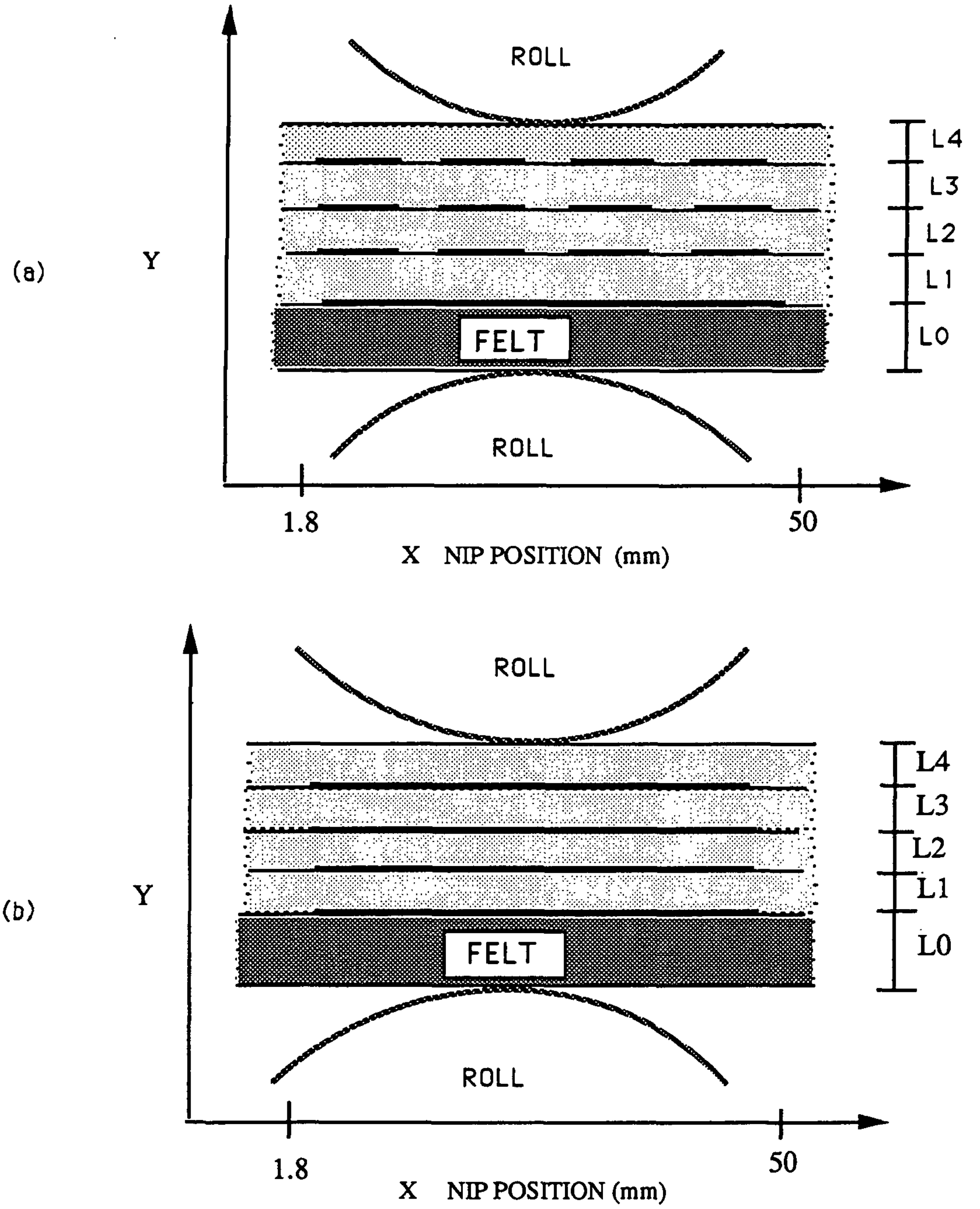


Figure 7. Schematic of the test samples.
4 layers of paper, L1 through L4, each with 150 g/m2 basis weight, 28% solids.
X-Ray shuts are at two different pressures, 50 and 60 psi. Roll press speed is at 17 ft/min.
Selection of axes for analyzing the x-ray films and the thickness measurements with the image analyzer are also shown. Targets : 50 microns, tungsten wires (99.95%) are located between the sheets in two different arrangements : (a) Discontinuous wires 5 mm long and 2 mm apart, and (b) Continuous wires 4 " long. Also a continuous wire is placed between the sheet and the felt in both sets.

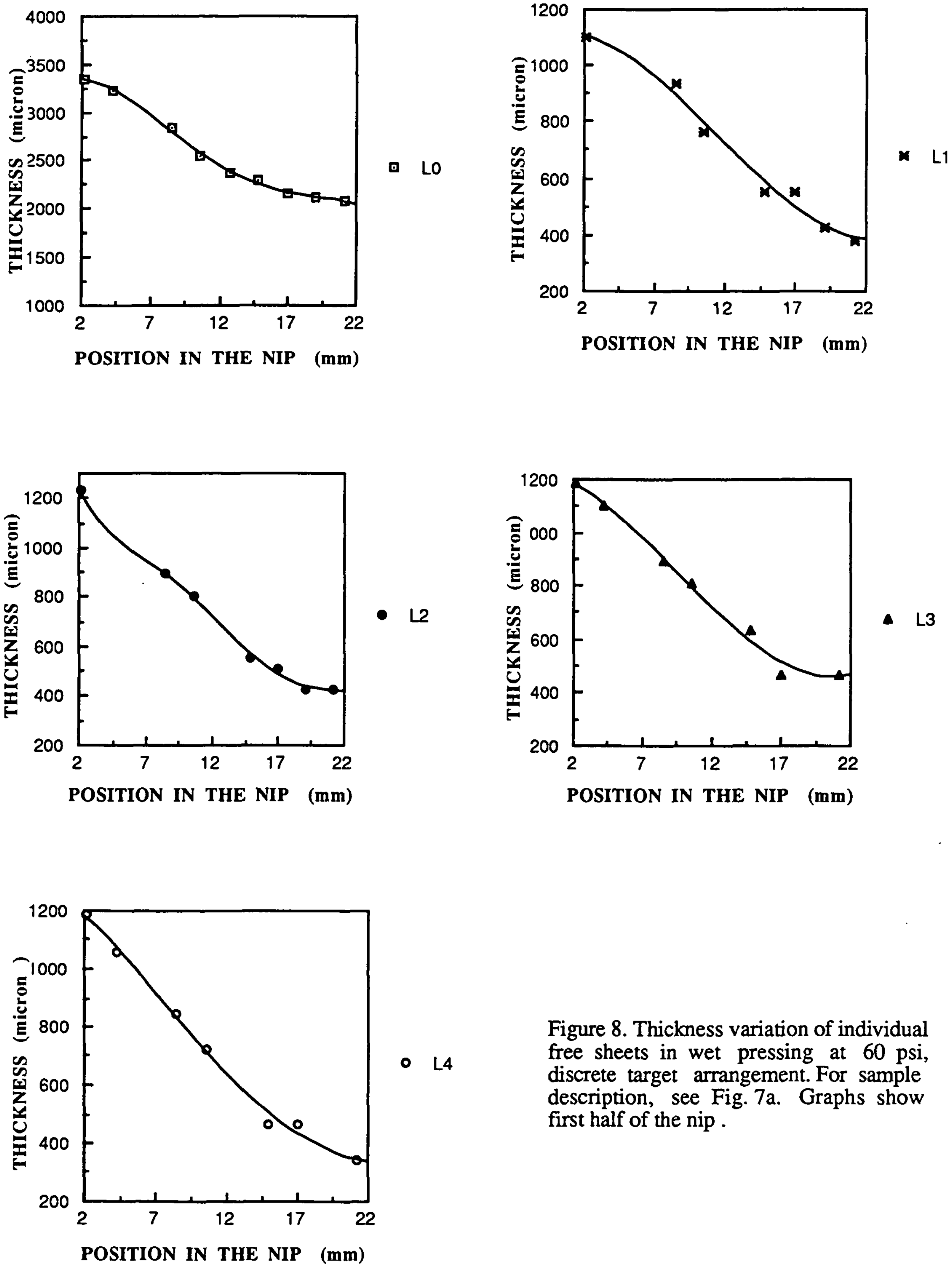
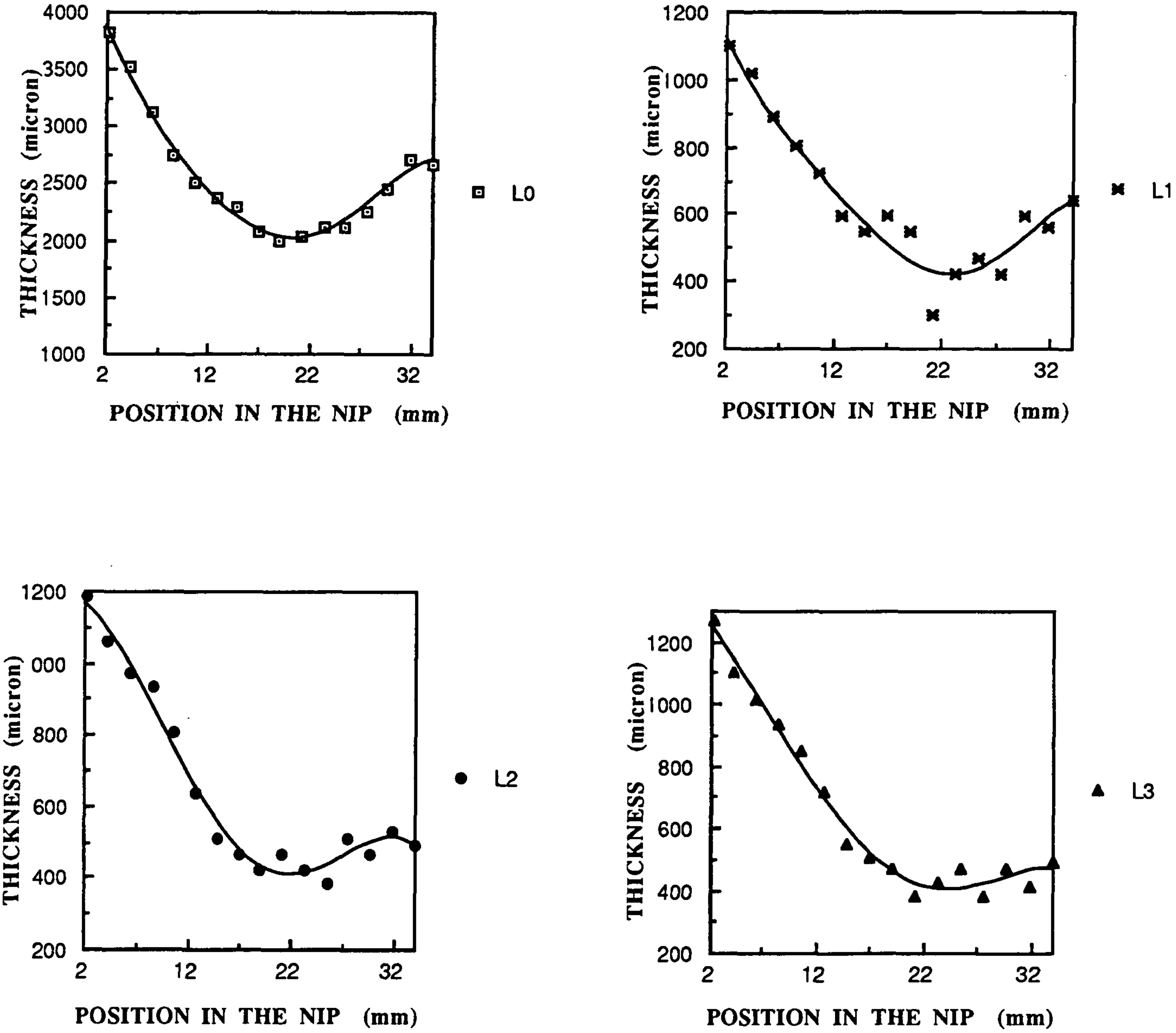


Figure 8. Thickness variation of individual free sheets in wet pressing at 60 psi, discrete target arrangement. For sample description, see Fig. 7a. Graphs show first half of the nip .



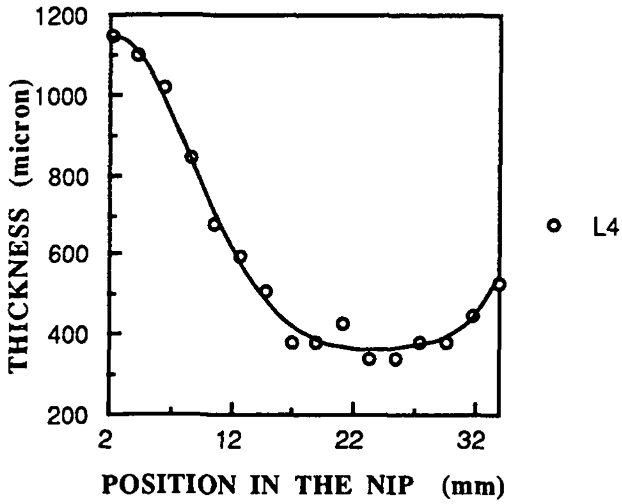
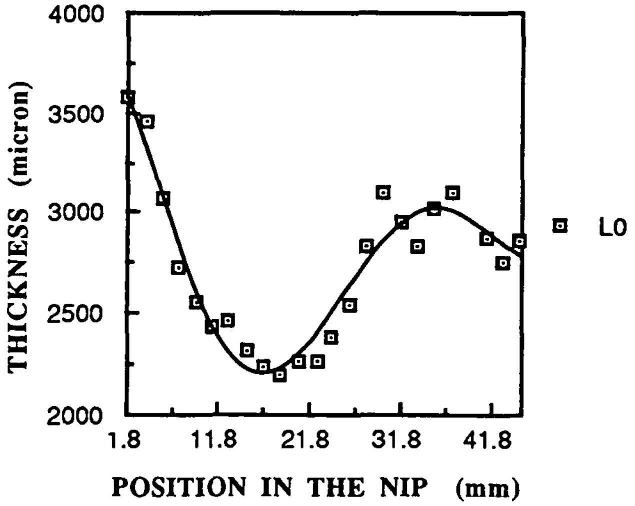
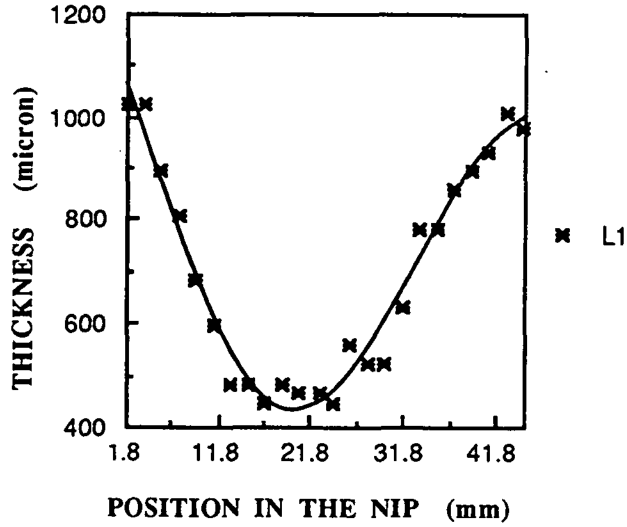
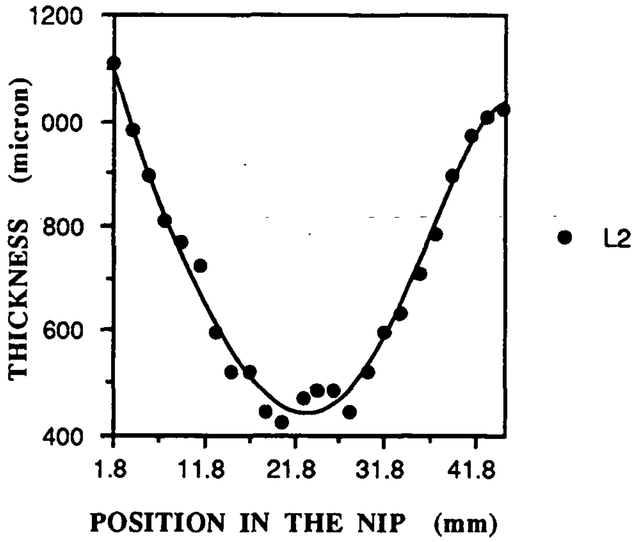
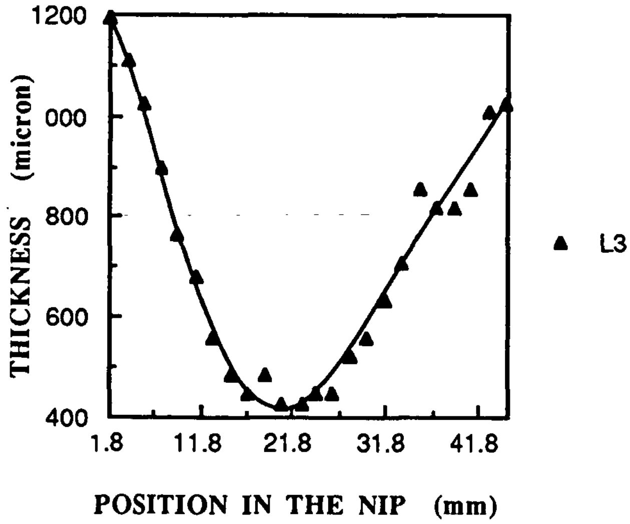


Figure 9. Thickness variation of individual free sheets in wet pressing at 60 psi, continuous target arrangement. For sample description, see Fig. 7b.









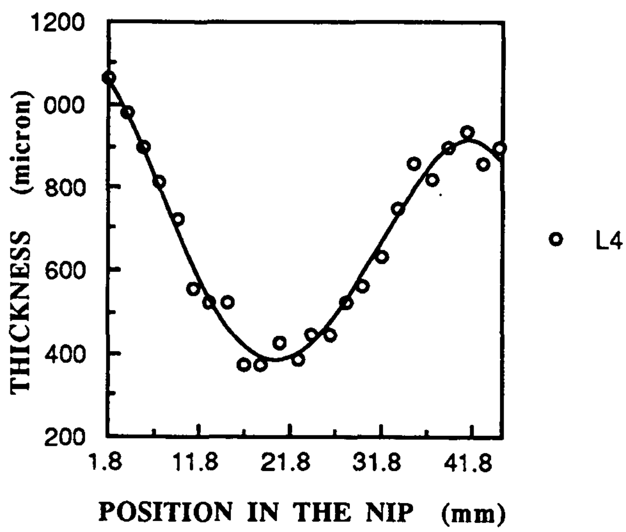
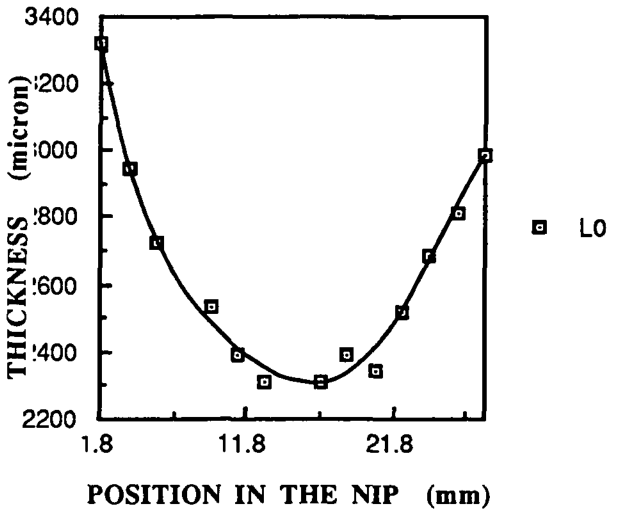
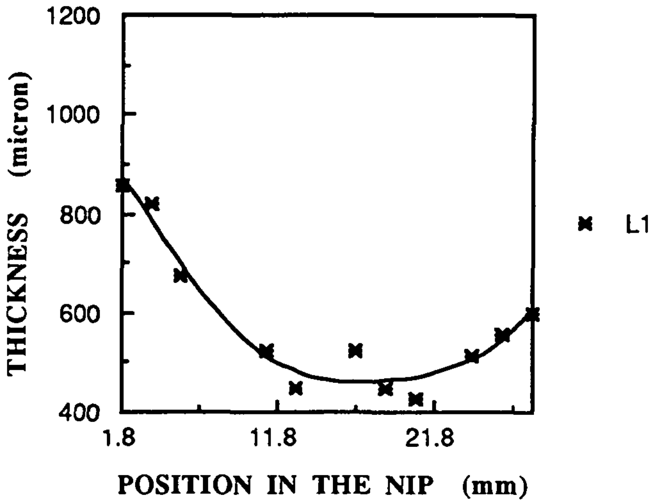
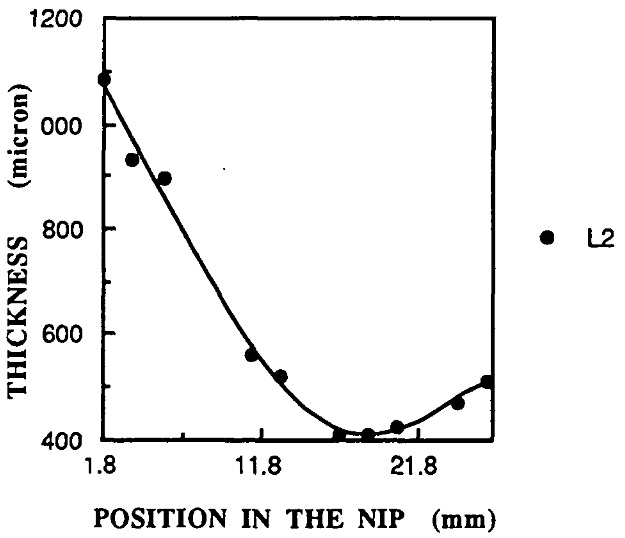
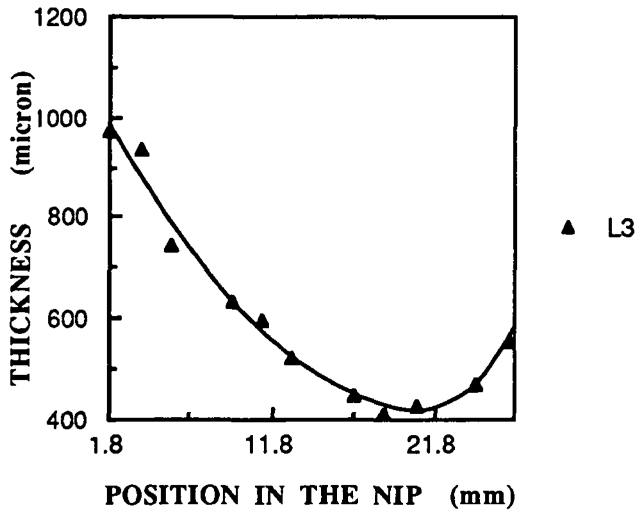


Figure 10. Thickness variation of individual free sheets in wet pressing at 50 psi continuous target arrangement. For sample description, see Fig. 7b.









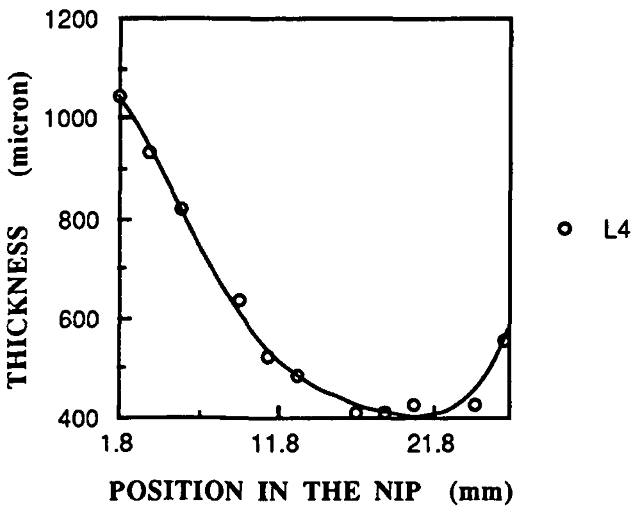


Figure 11. Thickness variation of individual free sheets in wet pressing at 50 psi, discrete target arrangement. For sample description, see Fig. 7a. Graphs show first half of the nip .

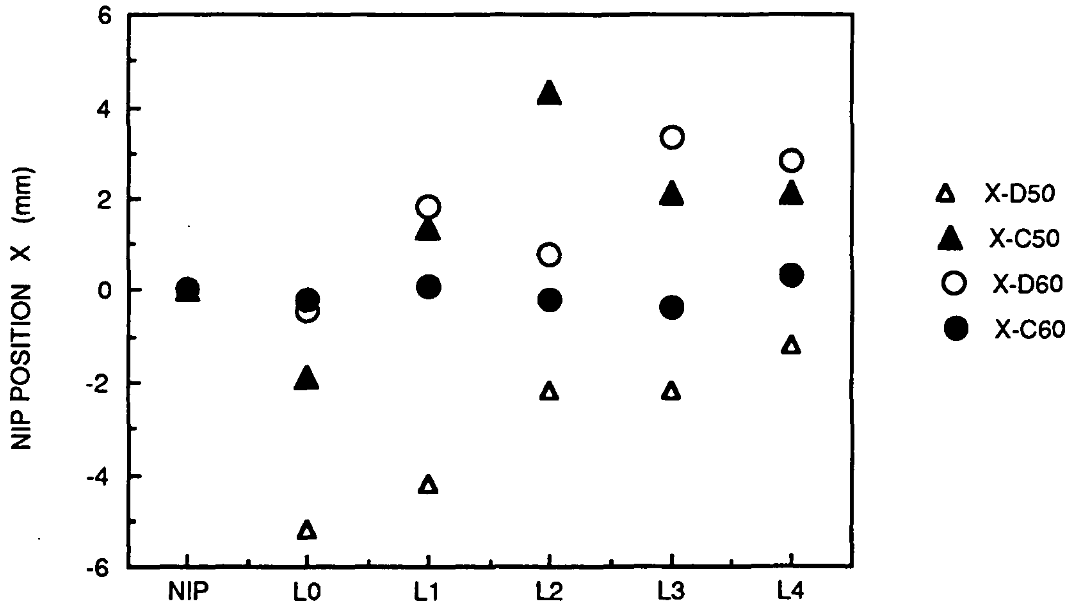


Figure 12. Location of the minimum sheet thickness relative to the mid-nip at 0.

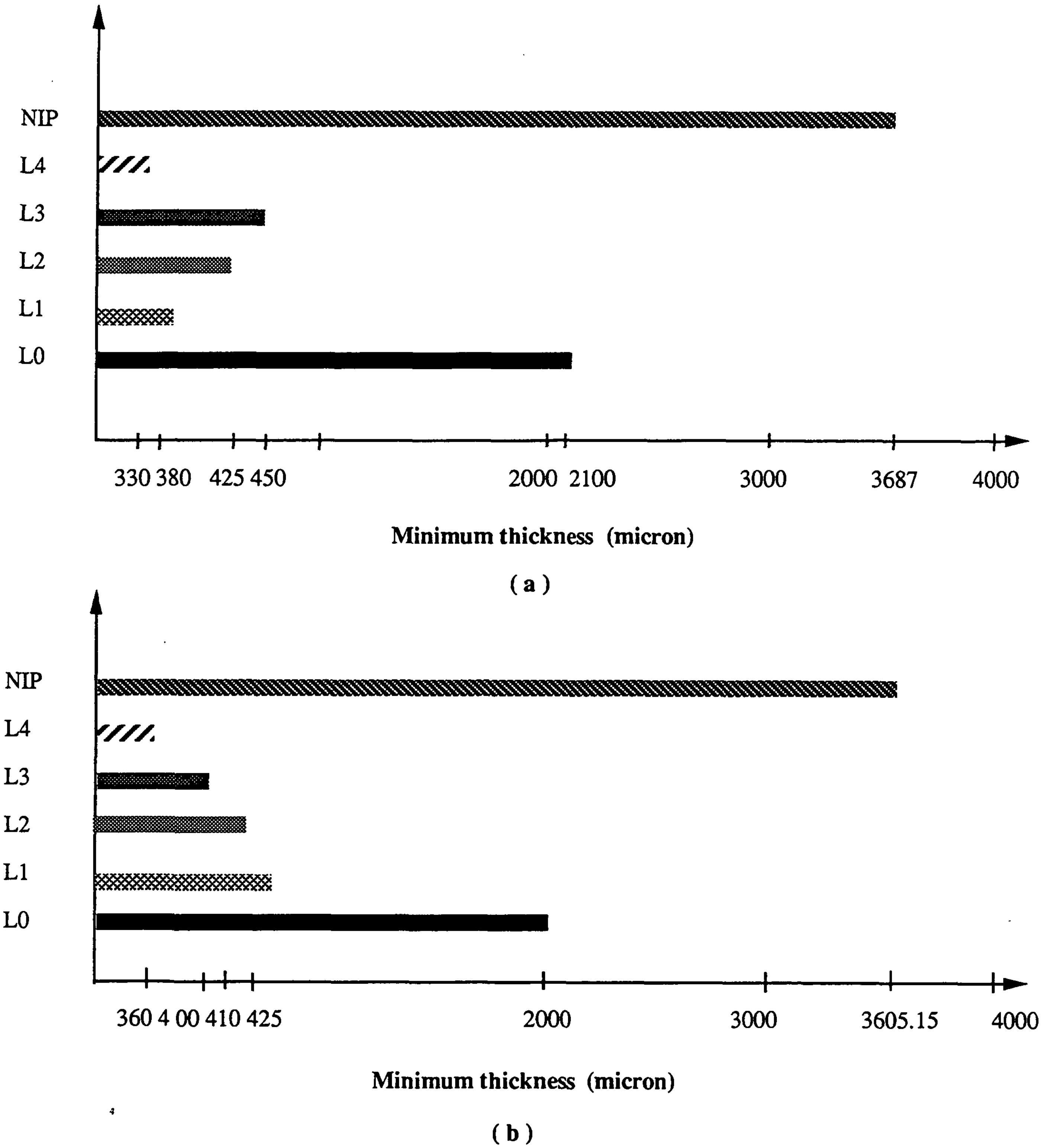


Figure 13. Minimum thickness of each individual sheet.
(a) Discontinuous wires at 60 psi and (b) Continuous wires at 60 psi.

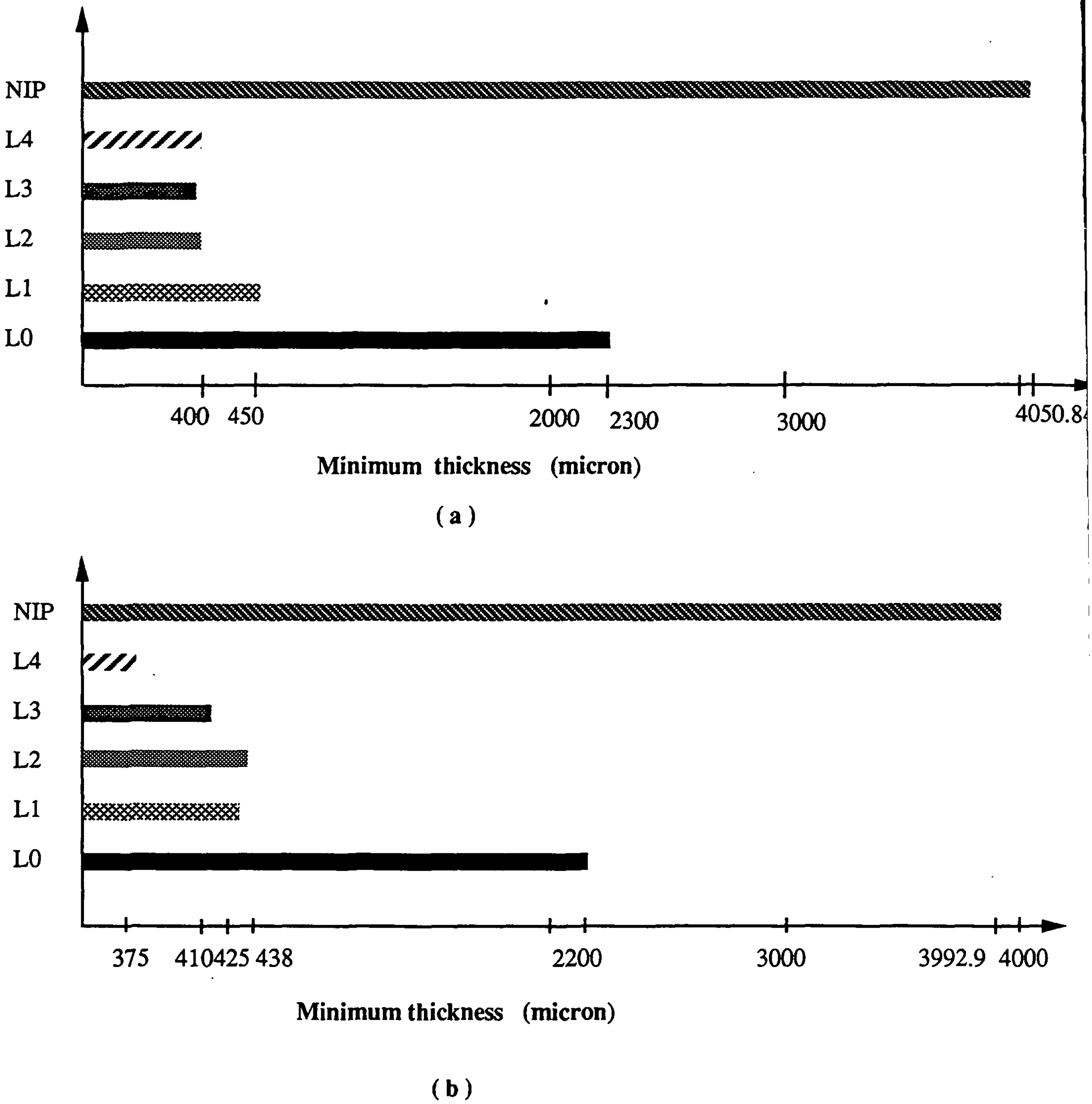


Figure 14. Minimum thickness of each individual sheet.
(a) Discontinuous wires at 50 psi and (b) Continuous wires at 50 psi.