PERFORMANCE OF FASTENERS IN WOOD FLOUR-THERMOPLASTIC COMPOSITE PANELS

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ABSTRACT

In the building community, there is a growing demand for high-performance, low-maintenance, and low-cost building products. To meet this demand, natural fiber-thermoplastic composites are being used to produce such products as decking, window and door elements, panels, roofing, and siding. In spite of the rapid growth in the use of these composites, little is known about their fastener performance. In this study, experimental fastener tests were performed on wood flour-thermoplastic composite panels. Results are presented for screw withdrawal, nail withdrawal, nail head pull-through, and lateral nail resistance tests. These results indicate that screw withdrawal, nail withdrawal, and nail head pull-through capacity are relatively unaffected by wood flour content. However, wood flour content affected lateral nail resistance. The use of pilot holes (predrilling) was found to have little effect on fastener capacity. The screw withdrawal capacity of the tested wood flour-thermoplastic composite panels was found to be equal to or greater than that of conventional wood panel products.

In today's home construction market, homeowners are demanding low-maintenance, high-performance building products. At the same time, builders are looking for low-cost, easy-to-install, labor-saving materials. Commodity building products made from natural fiber-recycled thermoplastic composites are meeting some of these demands. However, the only natural fiber-thermoplastic composite product that has been widely accepted by the construction industry is decking lumber. A lack of performance data and reluctance of builders to use undemonstrated products has hampered market development. To help fill this void of information, this study was undertaken to better understand the engineering performance of natural fiber-thermoplastic composites and determine how products manufactured from these composites compare with conventional wood building products. Specifically, the objectives of this study were to quantify the nail and screw resistance of wood flour-thermoplastic panels and to compare this resistance with the fastener performance of conventional wood panel products.

BACKGROUND

During the last few years, technical information on the performance of natural fiber-thermoplastic composites has become more available, including information on the effects of processing, mix design, additives, and fiber type on material properties (3,4,13-15). Also, many particle and fiber types have been investigated, including wood, wheat, kenaf, and jute (5,10-12). With the exception of ongoing research by Balma and Bender (2) on the performance of bolted connections, little technical information is available on the fastening of these composites.

This study was prompted by a natural fiber-thermoplastic composite producer who was interested in manufacturing panel products for use in the construction market. One of the first questions asked was "How does the fastener performance of these composites compare with conventional wood panel products?"

To date, no standards have been written for the testing of fasteners in panel products made from natural fibers and thermoplastics. However, ASTM Standard D 1037 (1) was developed to evaluate the engineering performance of traditional wood-based panels (such as

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TABLE 1. – *Fastener tests and specimen dimensions.*

Test	No. of specimens	Specimen dimension? (width by length by thickness)
Screw withdrawal	20	3 by 4 by 1.0 in.
Nail withdrawal	20	3 by 6 by 0.5 in.
Lateral nail resistance	20	3 by 6 by 0.5 in.
Nail head pull-through	20	3 by 6 by 0.5 in.

[a] 1 in. = 25.4 mm.

TABLE 2. – *Mean screw withdrawal resistance.*

Wood flour	Mean screw withdrawal	COV[a]
(%)	(lb./in. (N/cm))	(%)
20	870 (1,520)	7
30	905 (1,580)	7
40	905 (1,580)	8
50	855 (1,500)	10
60	855 (1,500)	7

[a] COV = coefficient of variation.

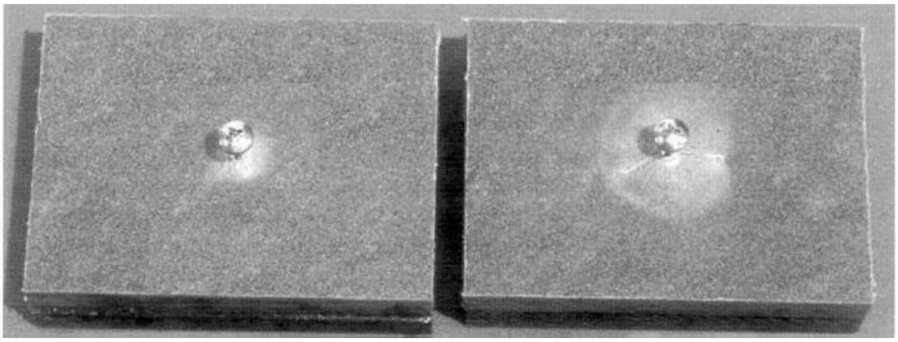

Figure 1. – Screw withdrawal failures.

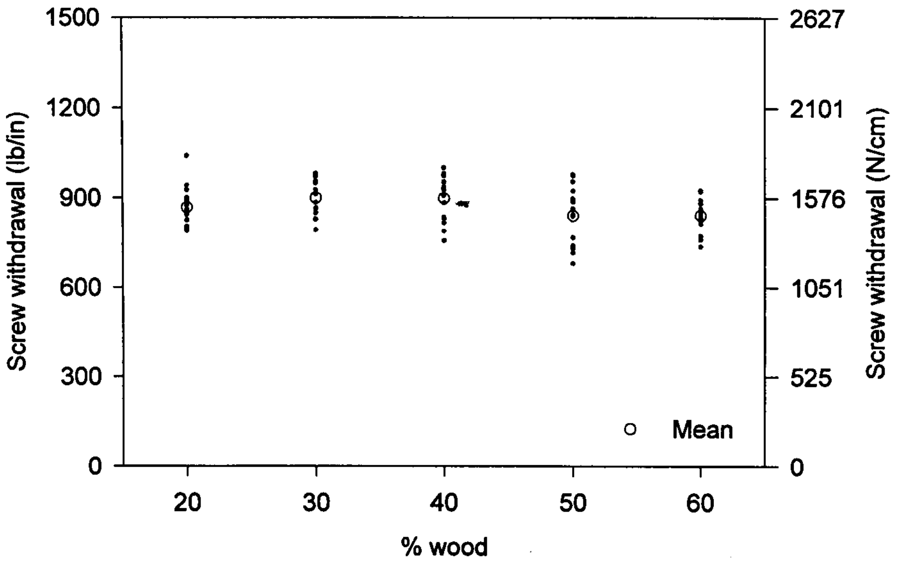

Figure 2. – Screw withdrawal test results.

hardboard, medium density fiberboard, and particleboard) and includes fastener tests. Although it was not developed for natural fiber-thermoplastic materials, we felt this standard offered the best *available* guidance to: 1) evaluate the fastener performance of panels made from this composite; and 2) provide a reasonable comparison to conventional wood panel products. Four fastener tests specified in ASTM D 1037 were performed: screw withdrawal, nail withdrawal, lateral nail resistance, and nail head pull-through.

MATERIALS AND MANUFACTURE OF PANELS AND SPECIMENS

The raw material used to manufacture the panels was a pelletized wood flour-thermoplastic feedstock produced with a twin screw extruder by North Wood Plastics of Sheboygan, Wis. Several pellet blends were provided and ranged from 20 to 60 percent wood flour by weight. The wood flour was 40 mesh pine. Only one polymer blend was used in this study, a copolymer of virgin low-density polyethylene (LDPE) and polypropylene (PP), 50/50 by weight. This is a standard blend manufactured by North Wood Plastics (9).

The panels were manufactured at the USDA Forest Service, Forest Products Laboratory (FPL) and were 20 by 20 by 0.5 inch (59 by 59 by 12 mm). The pellets were heated between platens of a 20- by 20-inch (59- by 59-mm) heated press using 0.5-inch (12-mm) stops. Heat and pressure were applied for about 20 minutes or until flashing squeezed out between the stops and the platen (indicating melting). The viscosity of the molten pellets increased as the percentage of wood flour increased, requiring additional pressure and pressing time to form the panels. In all cases, the press was heated to 200°C and cooled to approximately 60°C before the panel was removed from the press.

Test specimens were cut from the manufactured panels and ranged in size according to the requirements of each fastener test. The measured specific gravity of the specimens ranged from 0.99 to 1.06 (20% wood flour content to 60% wood flour content, respectively). **Table 1** shows the number and size of the specimens tested.

Tests performed

Screw withdrawal

The screw withdrawal test determines the load required to pull a standard size screw from the panel specimen. A No. 10 stainless steel sheet metal screw was hand-driven 0.67 inch (17 mm) into each specimen immediately before testing. A l/8-inch- (3-mm-) diameter pilot hole was drilled 0.5 inch (12 mm) into each specimen. A l-inch- (25-mm-) thick specimen is called for in the standard, but because of the difficulty in compression molding such a thick panel in the available press, we constructed the required specimen by gluing two 0.5-inch (12-mm) panels together.

Nail withdrawal

Similar to the screw withdrawal test, the objective of the nail withdrawal test is to measure the peak load required to pull a six-penny common nail (0.117-in. (3-mm) diameter) free from the 0.5-inch- (12-mm-) thick panel specimen. The nails used were common, plain shanked, and electrogalvanized. Nails were hand-driven immediately before testing such that the exposed length of the nail was equal on both sides of the specimen. Measured nail diameters were used to calculate the surface area in contact with the panel. Half of the nail withdrawal specimens were predrilled. For the predrilled specimens, a 3/32-inch (2.4-mm) pilot hole was used (equivalent to 80% of the nail diameter).

Lateral nail resistance

The lateral nail resistance test measures the peak load a nail can resist when pulled laterally through the plane of the panel. The nails were driven 0.5 inch (12 mm) from the edge of the specimen. Originally, we intended to predrill half of the specimens, but preliminary investigations indicated that the higher wood content panels cracked from driving the nail into the specimen if no pilot hole was used. Therefore, all remaining uncracked specimens were predrilled with a 3/32-inch- (2.4-mm-) diameter hole.

Nail head pull-through

A fourth fastener test investigated the force required to pull the nail head through the 0.5-inch (12-mm) panel specimen. The effect of predrilling was investigated for half of the specimens as described in the nail withdrawal test. The nails were driven immediately before the test was performed.

Results

To make it easier for the reader to calculate fastener resistance for composites of various thicknesses, results are presented in force per unit thickness. This unit was arrived at by dividing the fastener ultimate load by the embedded fastener length. For all results, a statistical two-tailed t-test was used to find the lowest significance level at which the means are considered to be equal (*p*-value).

Screw withdrawal

Figure 1 shows the predominant type of failure found in the screw withdrawal tests. For all specimens, the material tended to fail locally around the screw threads along the entire length of the screw. **Table 2** and **Figure 2** summarize the test results for the screw withdrawal tests.

As indicated in **Table 2,** the screw withdrawal capacity ranges from about 855 lb./in. (1,500 N/cm) to 905 lb./in. (1,580 N/cm). The variability in withdrawal resistance as measured by the coefficient of variation was rather low, ranging from about 7 to 10 percent. As shown in **Figure 2,** screw withdrawal resistance is relatively unaffected by wood flour content. This was verified using a statistical significance test on the data.

Nail withdrawal

The nail withdrawal tests were conducted to satisfy two objectives. As in the screw withdrawal test, the first objective was to find the withdrawal capacity of the fastener. The second was to explore the effects of predrilling on withdrawal resistance. **Tables 3** and **4**

TABLE 3. – Mean nail withdrawal resistance for specimens without predrilling.

Wood flour	*n*[a]	Mean nail withdrawal	COV[b]
(%)		(lb./in. (N/cm))	(%)
20	10	190 (330)	7
30	9[c]	190 (330)	7
40	10	200 (350)	8
50	10	185 (320)	6
60	10	170 (300)	5

[a] *n* = number of specimens used to calculate results.
[b] COV = coefficient of variation.
[c] Specimen number reduced by defect in material and/or nail.

TABLE 4. – Effects of predrilling on mean nail withdrawal.

	Predrilled			Not predrilled			
Wood flour	*n*[a]	Mean nail withdrawal	COV[b]	*n*	Mean nail withdrawal	COV	Change due to predrilling
(%)		(lb./in. (N/cm))	(%)		(lb./in. (N/cm))	(%)	(%)
20	10	200 (350)	8	10	190 (330)	7	+5.0
30	10	18.5 (320)	10	9[c]	190 (330)	7	-2.6
40	10	190 (330)	9	10	200 (350)	8	-5.0
50	10	180 (310)	8	10	185 (320)	6	-2.8
60	10	155 (270)	4	10	170 (300)	5	-8.8

[a] *n* = number of specimens used to calculate results.
[b] COV = coefficient of variation.
[c] Specimen number reduced by defect in material and/or nail.

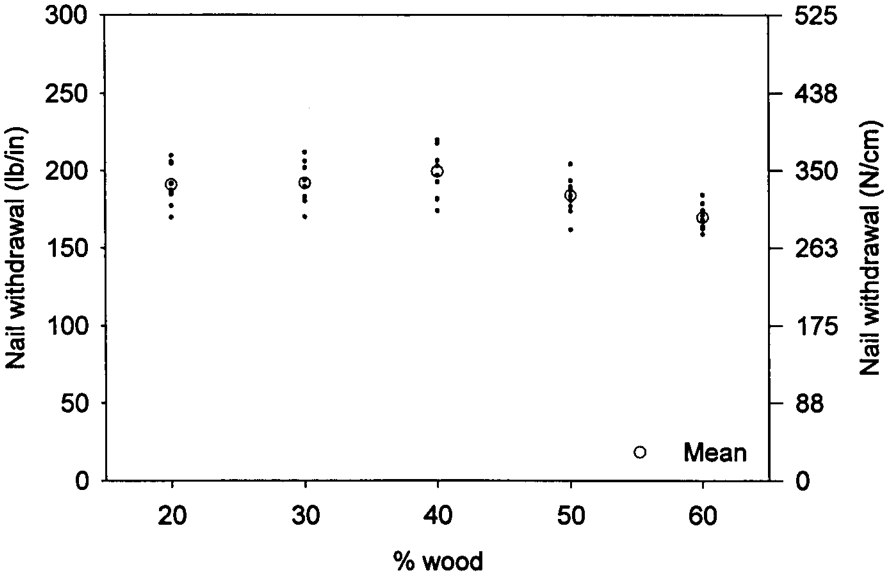

Figure 3. – Nail withdrawal test results.

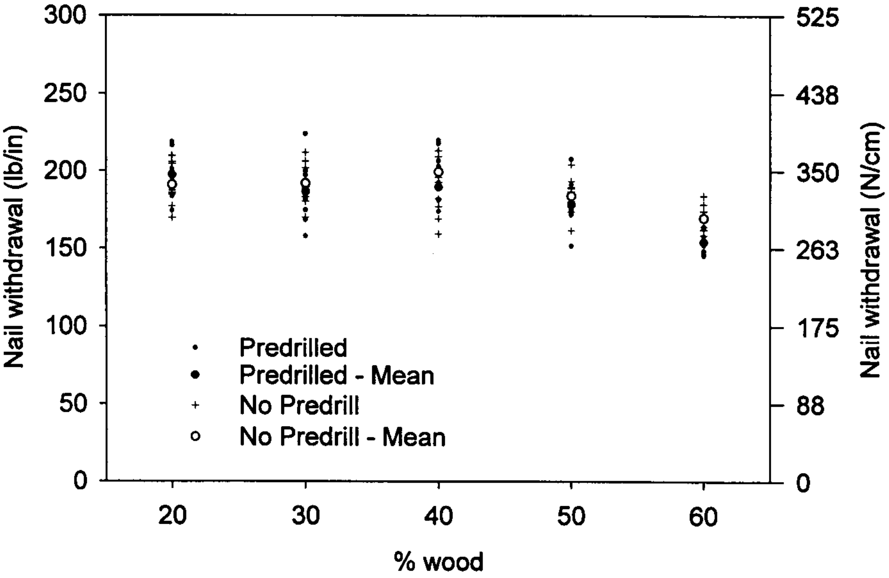

Figure 4. – Nail withdrawal test results showing effects of predrilling.

TABLE 5. – Summary of mean lateral nail resistance test results.

Wood flour	n[a]	Mean lateral nail resistance	COV[b]
(%)		(lb./in. (N/cm))	(%)
20	19[c]	960 (1,680)	7
30	19[c]	895 (1,570)	9
40	19[c]	780 (1,370)	10
50	19[c]	640 (1,120)	6
60	19[c]	515 (900)	8

[a] n = number of specimens used to calculate results.
[b] COV = coefficient of variation.
[c] Specimen number reduced by material flaw.

and **Figures 3** and **4** summarize the nail withdrawal test results. As shown in **Table 3,** the nail withdrawal capacity ranges from about 170 lb./in. (300 N/cm) to 200 lb./in. (350 N/cm), showing a slightly lower capacity for the higher wood flour content specimens.

Table 4 and **Figure 4** show the effects of predrilling on nail withdrawal. Predrilling did not affect the nail withdrawal capacity.

LATERAL NAIL RESISTANCE

The maximum lateral load required to pull a fastener from the edge of the composite panels was also determined. **Table 5** and **Figure 5** show the test results. The material was very ductile for the lower wood content specimens; however, as the wood percentage increased, the material strain was considerably reduced. In most cases, the nail yielded before the material yielded, so the results given are conservative regarding the resistance capacity of the panel material. The results indicate that the lateral resistance of the nail decreased with increased wood flour content. A 46 percent decrease in lateral resistance was found between the 20 percent wood flour and 60 percent wood flour content specimens. This test subjects the material around the nail to tensile stresses. The results are consistent with previous work on wood flour-thermoplastic composites indicating decreasing tensile strength with increased wood flour content (18).

NAIL HEAD PULL-THROUGH

Similar to the nail withdrawal test, the effect of predrilling was explored in a nail head pull-through test. Typical failures, especially in the higher wood content specimens, exhibited cracking propagating from the nail. **Table 6** and **Figure 6** summarize the test data. The nail head resistance was affected by wood flour content, and the capacity of the 60 percent wood flour specimens was about 30 percent less than that of the 20 percent wood flour specimens.

As indicated in **Table 7** and **Figure 7,** predrilling had little effect on nail head pull-through capacity.

COMPARATIVE PERFORMANCE TO CONVENTIONAL WOOD PRODUCTS

The fastener performance of the tested panels was compared with the fastener performance of commonly available wood-based panel products:

plywood, oriented strandboard, particleboard, standard hardboard, and medium density fiberboard. The literature was searched for test data on the fastener performance of these panel products (6-8,16,17,19, Lewis 1967, unpublished data). In some cases, data were not available. In others, only industry-based performance specifications were available. Also, panel products are often manufactared to produce specific material performance (e.g., particleboard is manufactured with different densities that may affect fastener performance). For this reason, each material is shown as having a range of values denoted as minimum (Min) and maximum (Max). Where a range of data was not available, "Typical" values designate average values for the product. **Figures 8** and **9** summarize the comparison of the tested composite panels to the available data from the literature. Data could only be found for screw withdrawal and lateral nail resistance.

As indicated in **Figure 8,** the screw withdrawal resistance for the wood flour-thermoplastic composites is equal to or higher than that of the conventional wood panel products. The higher capacity of the screws in the wood flour-thermoplastic composites is probably due to the ability of the thermoplastic to conform around the thread of the screw, allowing load transfer continuously along the thread.

Figure 9 indicates that the lateral resistance of the composites with a lower percentage of wood flour was comparable to particleboard; however, the composites with a higher percentage wood flour were considerably lower in resistance.

CONCLUSIONS

The following conclusions were found from the fastener testing of the wood flour-thermoplastic composite panels.

- Screw withdrawal capacity and nail withdrawal resistance were relatively unaffected by wood flour content.
- Predrilling did not greatly affect nail withdrawal resistance.
- Lateral nail resistance was affected by wood flour content. As wood flour content increased, the lateral nail resistance decreased up to about 46 percent (from 20% wood flour to 60% wood flour content).
- Nail head pull-through resistance was unaffected by wood flour content up

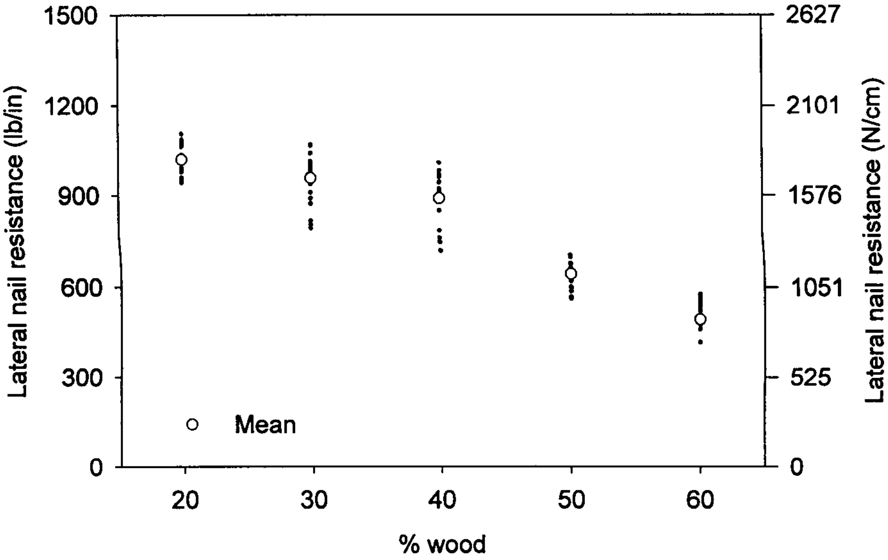

Figure 5. – Lateral nail resistance test results.

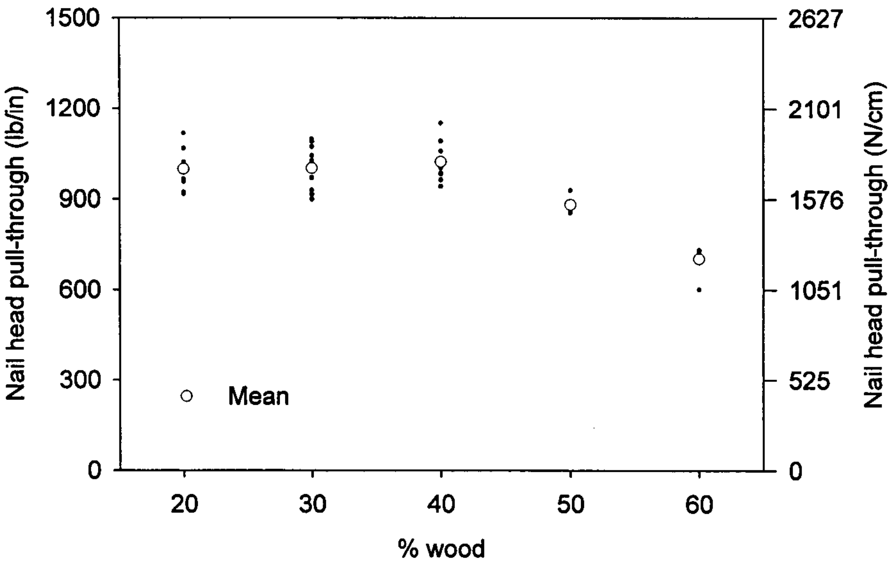

Figure 6. – Nail head pull-through.

TABLE 6. – Nail head pull-through test results with predrilling.

Wood flour	n[a]	Mean pull-through resistance	COV[b]
(%)		(lb./in. (N/cm))	(%)
20	10	1,000 (1,750)	6
30	10	1,005 (1,760)	7
40	10	1,020 (1,790)	6
50	8[c]	885 (1,550)	3
60	10	700 (1,230)	6

[a] *n* = number of specimens used to calculate results.
[b] COV = coefficient of variation.
[c] Specimen number reduced by material flaw.

TABLE 7. – Summary of nail head pull-through for specimens with no predrilling.

Wood flour	n[a]	Mean pull-through resistance	COV[b]
(%)		(lb./in. (N/cm))	(%)
20	10	1,040 (1,820)	4
30	9[c]	970 (1,700)	7
40	10	1,010 (1,770)	5
50	7[c]	900 (1,580)	4
60	10	730 (1,280)	4

[a] n = number of specimens used to calculate results.
[b] COV = coefficient of variation.
[c] Specimen number reduced by material flaw.

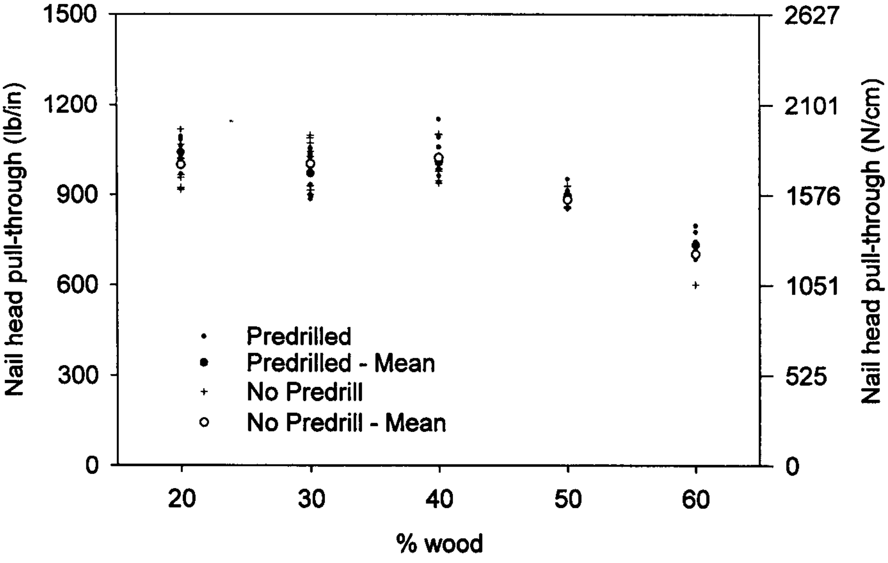

Figure 7. – Effect of predrilling on nail head pull-through.

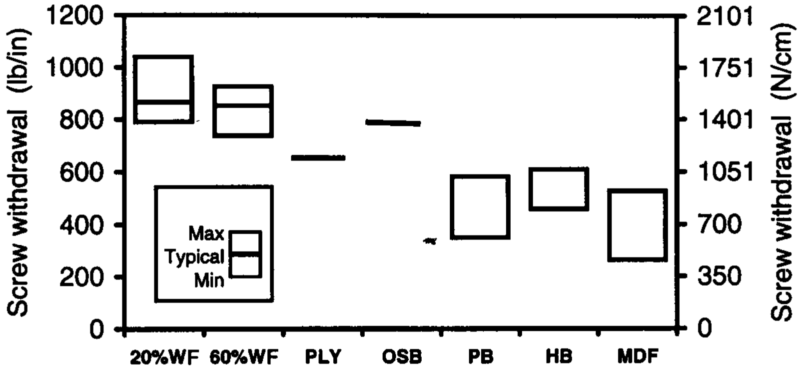

Figure 8. – Comparison of screw withdrawal resistance for wood-plastic composites and conventional wood panel products; WF = wood flour content by weight; PLY = plywood; OSB = oriented strandboard; PB = particleboard; HB = hardboard; MDF = medium density fiberboard.

to about 40 percent wood flour content. Above that percentage, resistance decreased linearly with increased wood flour content.

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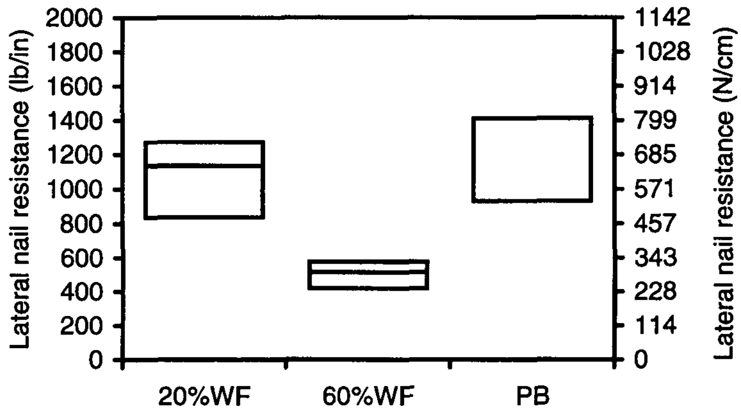

Figure 9. – Lateral nail resistance for wood-plastic composite panel and particleboard: WP = wood-polypropylene; PB = particleboard.