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Fastener withdrawal resistance of wood-based composite panel products

Steven M. Cook
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Fastener Withdrawal Resistance of Wood-Based Composite Panel Products

Steven M. Cook

**Thesis submitted to the
College of Agriculture and Forestry
at West Virginia University
in partial fulfillment of the requirements
for the degree of**

**Master of Science
in
Forest Resource Management**

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Division of Forestry

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2001**

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FASTENER WITHDRAWAL RESISTANCE OF WOOD-BASED COMPOSITE PANEL PRODUCTS

By
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Committee Chairman: Elemer M. Lang
Wood Industries

(ABSTRACT)

The purpose of this research project was to evaluate the performance of currently available wood-based panel products as sub-floor materials when used under quality oak strip flooring and exposed to cyclic EMC conditions. The critical evaluation criterion was the fastener holding capacity of various sub-floor materials. To accomplish this, investigation of the in-plane density variations of currently available panel products was performed, as was an investigation of the relationship between panel density and the fastener holding capacity of different panel materials. In addition, a comparison of the fastener holding capacity of six different panel products was investigated during and after a two and one-half year simulated moisture cycle. This allowed for a testing of the interaction between moisture content cycling, sub-floor materials, and fasteners on floor system performance. The results of this project were compared to results obtained in similar investigations done previously.

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LIST OF SYMBOLS AND ABBREVIATIONS

F_w	fastener withdrawal strength (lb)
SG	specific gravity
TS	thickness swell (%)
β	shrinkage/swelling coefficient (%/%MC)
MC	moisture content (%)
EMC	equilibrium moisture content (%)
HDD	horizontal density distribution
IB	internal bond
t	panel thickness (in)
h	panel height (in)
w	panel width (in)
M	mass (g)
M_o	oven-dry mass (g)
LE	linear expansion (%)
RH	relative humidity (%)
T	temperature (°F)
E	East Coast
W	West Coast
P	plywood
O or OSB	oriented strand board
3	3 / 4" thick panel
5	5/8" thick panel
S	1.5" staple fastener
N	1.5" nail fastener
N2	2" nail fastener
f	finished flooring
b_0, b_1, b_2	regression coefficients

INTRODUCTION

Hardwood flooring provides an aesthetically pleasing option for the homebuilder in search of a practical yet elegant floor surface. Its simple elegance and intrinsic beauty are unmatched by any other type of finished flooring. Cassens and Feist (1980) stated that the properties of wood make it a highly desirable flooring material in residential and public buildings. Hardwood floors are relatively easy to maintain and will provide years of trouble free service if they are installed and maintained correctly. Installation of these flooring systems must be designed to minimize the some of the negative physical and mechanical properties that are inherent with wood and wood products.

In a typical residential light frame construction, a flooring system is made up of several key components. These components include the floor joists, the sub-floor and/or underlayment, and the finished flooring surface, usually applied over construction felt paper or some other form of vapor barrier. Floor joists may be solid wood or a wood composite product varying in size, shape, and style. Advances in the forest products industry have caused the choice of sub-floor materials change from solid wood to wood-based panel products; specifically plywood and oriented strand-board (OSB).

Due to a steady increase in the population of the United States, there is an ever growing need for building materials, including wood and wood-based products. Therefore, more and more immature and sub-standard trees are being harvested. The harvesting of inferior trees often results in lumber and boards lacking in strength and performance qualities. The best way to utilize this inferior raw material is to break it down into pieces and bond these pieces together, making a finished product with

properties far surpassing those of the raw material. Also, solid wood is a substance that has very unpredictable properties. By breaking down the raw material and then reconstructing it, the industry can create a building material that is very homogeneous and in turn more predictable based on performance criteria. Youngquist (1999) stated that because wood properties are variable among species, within species and even within the same tree, solid wood cannot match processed wood-based products where mechanical and physical properties are concerned.

Flooring systems in general are fairly simple in design yet may become complex when the system must be based on performance criteria. Wood is a hygroscopic substance; readily gaining or losing moisture depending on the conditions surrounding it. Since the basic components of a flooring system are predominantly wood and wood-based materials, this hygroscopic property will influence the performance of wood products subjected to moisture patterns.

Hardwood flooring is generally installed in the final stages of building construction. This normally occurs after a structure is enclosed and the other floor system components are in place. However, sometimes a situation arises in which the sub-floor material has not yet reached its in service moisture content before flooring installation. As the sub-floor moves toward its in-service equilibrium moisture content and goes through subsequent seasonal environmental changes, the fastener holding capacity between the hardwood flooring and the sub-floor may be decreased. The sub-flooring and the flooring itself will experience dimensional changes in the form of shrinkage and swelling due to changes in environmental humidity and temperature. The problem arises when these changes do not occur at the same rate or in the same

magnitude. Over time, this may result in buckling, gaps, squeaks, floor migration or other forms of unacceptable flooring behavior.

With this in mind, it is evident that a process to test the performance of flooring systems is necessary in order to understand the interactions of the various floor system components and the role that these components play in the overall performance of the entire system. By understanding these components and how they interact with one another, we can combine them in a way that preserves the longevity of flooring in service. An accelerated environmental simulation allows us to test the efficacy of a flooring system during the first two and one-half years after installation. By comparing various combinations of fastener style and sub-floor panel type during an accelerated environmental simulation, conclusions may be drawn indicating which combination best supports acceptable in-service floor system performance.

Lang *et al* (1992) conducted a similar project at Virginia Tech approximately ten years ago. Results of that project aided the National Oak Flooring Manufacturers Association (NOFMA) in recommending fastener and sub-floor combinations that would offer the best performance when used in conjunction with oak strip flooring. The rate at which technological advancements in the composite panel industry have grown spawned a recent interest by NOFMA as to how these advancements may have changed the recommendations established after the previous project. This interest caused NOFMA to provide funding for this project to determine the performance status of currently available composite panel products as possible sub-floor materials under oak strip flooring.

OBJECTIVES

The overall objective of this project was to evaluate the performance of currently available wood-based panel products as sub-floor materials under quality oak strip flooring in cyclic equilibrium moisture content (EMC) conditions. In order to accomplish this, evaluation of the interactions between sub-floor panel type, fastener type, and moisture cycling was performed. Implementation of an accelerated environmental simulation provided information as to the performance of various sub-floor/fastener combinations and how they change over time. Specific objectives of this project were:

1. To investigate the in-plane density variations of currently available panel products for use as sub-flooring.
2. To relate the density to the fastener holding capacity of the different panels.
3. To compare the fastener holding capacity of six different wood-based composite panel products (two types of OSB and four types of plywood) during and after a simulated two and one-half year moisture cycle.
4. To investigate the interaction between moisture content cycling, sub-floor materials and fasteners on the performance of floor systems measured by the fastener holding capacity of the system.
5. To compare the experimental results with data obtained by a prior similar project.

This Masters thesis details the work done in order to fulfill these objectives. All relevant procedures and conclusions are contained in the following chapters:

- Chapter 2 provides a detailed literature review.
- Chapter 3 contains all relevant experimental methods.
- Chapter 4 details the project results and discussion.
- Chapter 5 provides a project summary and conclusions based on the research data along with recommendations for further research.

Literature Review

2.1 Floor System Performance

Several factors can influence the expected performance of a hardwood flooring system. Among these are the performance of the components that make up the system and the performance of the fasteners that hold the components together. Furthermore, the magnitude of the environmental changes that a flooring system undergoes will have a profound impact on the floor system performance. Wood in service undergoes constant changes in moisture content due to cyclic humidity changes. Due to the hygroscopic nature of wood and wood-based products, their moisture content is directly related to atmospheric conditions; relative humidity (RH) and temperature. Consequently, their performance characteristics are very much dependent on the environmental conditions surrounding them. It would stand to reason then, that in order to accurately gauge the performance of wood and wood based panel products, the products must be tested in cyclic environmental conditions, similar to what they would experience in service.

Mohammad and Smith (1996) stated that environmental changes at the seasonal level might result in variations in single elements of a system, leading to degradation in the constituents and degradation in the ability of the fasteners to hold them together. Testing with the inclusion of the element of moisture cycling is important in establishing the behavior of hardwood flooring when used in conjunction with building materials commonly seen in construction (Lang *et al.* 1994). New information on the performance of fasteners in new sheathing and siding products is needed, especially when in a

weathered or aged condition, compared to conventional plywood sheathing (Chow *et al.* 1985).

2.2 Wood Moisture Relations

The performance of a floor system is based primarily on the response of each of three major system components to changes in moisture content (MC) throughout the system. These three major system components include floor joists, sub-flooring, and finished flooring.

2.2.1 Floor Joists

Floor joists in light frame residential construction are generally either nominal 2"x8" or 2"x10" southern yellow pine (syp) or spruce-pine-fir (s-p-f) lumber, or in a growing number of cases, engineered wood I-joists. Floor joists in residential light frame construction are designed to carry the load distributed by the sub-flooring and finished flooring. With this in mind, it may be said that stiffness, or a resistance to deformation, is a very important design parameter in terms of building serviceability (Chou and Polensek 1987).

In service, floor joists are subject to damping stresses and degradation or slip of nailed joints between the joists themselves and the sub-floor material covering them. Attempts were made to clarify these conditions (Atherton *et al.* 1980; Chou and Polensek 1987; Polensek and Bastendorff 1987; Feldborg 1989; Jang *et al.* 1993; Mohammad and Smith 1996) and how they affect the performance of framing to panel connections. As with all wood and wood based materials, floor joists are subject to seasonal changes in RH and temperature. These changes have an effect on the

mechano-sorptive behavior of wood, which is directly linked to the amount of deformation and strength exhibited by a structural member (Lu and Leichester 1997).

Unfortunately, wood is subject to a sorption hysteresis, where the adsorption (gaining moisture) equilibrium moisture content (EMC) of a given piece of wood is lower than the corresponding desorption (losing moisture) EMC. This would seem to complicate matters even more. However, it was determined (Peralta 1995) that due to the fact that the range of RH's experienced by wood in service is relatively narrow, the effect of hysteresis is minimal on the performance properties of wood. One of the best ways to minimize the effect of moisture cycling on the stiffness of nailed joints is to assemble the connection with the constituents as close to the in-service EMC as possible. By doing this it may be possible to eliminate or reduce the deformation due to conditioning which takes place in the material during initial adsorption (Humphries and Schniewind 1982; Mohammad and Smith 1996).

2.2.2 Sub-flooring

Either plywood or oriented strand board (OSB) generally represents materials suitable for use as sub-flooring. Performance criteria for plywood and OSB generally include mechanical properties such as modulus of elasticity (MOE) and modulus of rupture (MOR), and hygroscopic properties such as linear expansion (LE) and thickness swelling (TS). Another term important in the understanding of sheathing material performance is the horizontal density distribution (HDD) of a panel, which may be linked to the bearing strength of a panel (Suchsland and Xu 1989). One way to study HDD is to set up a simulation model in order to analyze the density variations that exist in panels. Measurement of HDD on OSB should be done with caution, however, as the

size of the specimens have an effect on whether density variations are attributed to non-uniformity in the mat, or simply voids in the panel (Xu and Steiner 1995).

These are all important in regards to floor system performance, especially when considering how they are effected by inevitable cyclic changes in RH and temperature. When comparing the performance of wood-based panels, it is important to understand that difference may occur, even with panels of a similar type. Some of this variation may be attributed to differences in the species that make up the panels. In other instances, panels manufactured utilizing the same species but at different mills may exhibit mechanical properties which differ as much as 33%, even though they fall within acceptable American Plywood Association (APA) guidelines (Biblis 1989).

It would be expected that changes in MC would effectively decrease the mechanical properties of plywood. In the case of Douglas-fir plywood, however, it was determined that over the range of MC's expected in service, 6.8-15.2%, this did not prove true (Palka 1977). The hardness of both Douglas-fir and southern yellow pine (syp) plywood did indeed decrease with an increase in MC (Chow 1976). Use of plywood as a sheathing material (as opposed to OSB) should be considered, although lightly, based on the fact that the deflection in plywood during RH cycling was found to be less than the deflection of OSB during identical cycling (Price 1985).

Results pertaining to the effect that moisture content changes have on the mechanical properties of OSB ranges from minimal to appreciable (Lehmann 1978; Wu and Suchland 1997). Reasons for this could be species difference, variations in testing methods and variations in panel formation.

Aside from affecting the mechanical properties of OSB, processing parameters, specifically flake distribution and orientation, may have an impact on hygroscopic factors including LE and TS (Wu 1999). Unfortunately for the contractor or homeowner, the greatest LE of OSB panels occurred throughout a range of moisture contents most likely to occur in service (Wu and Suchland 1996). With all the currently available deformation data that exists for OSB, theoretical models, such as the one developed by Lang *et al.* (1995) can predict the free hygroscopic deformation of wood composite panels with very acceptable accuracy.

In an attempt to discover new ways to improve the performance of OSB, wood scientists are constantly trying new methods of manufacture. One such method is species substitution. A study conducted by Kuklewski *et al.* (1985) showed that red maple flakeboard either equaled or exceeded the performance of aspen flakeboard with respect to static bending, internal bond (IB), and nail withdrawal.

2.2.3 Finished Flooring

As with other components of a flooring system, hardwood flooring is subject to stresses and performance flaws which occur during seasonal moisture cycling. Hardwood flooring is generally installed at an MC that is correct for a particular season. As the wood dries, shrinkage occurs and cracks tend to develop in the joints of the flooring. A more serious problem arises when the wood picks up moisture and swells. This results in buckling of the flooring strips. At this point, some of the wood cells are crushed and this results in a “compression set” situation from which the wood never fully recovers (Cassens and Feist 1980). In order to combat this, hardwood flooring must be

properly assembled and finished as quickly as possible. The finish may act to retard or inhibit the gaining of atmospheric moisture, at least to some degree.

2.3 Fasteners

The factor in a flooring system, which may well be the weakest link, is the fastener that holds the major components together. Sub-flooring is fastened to the floor joists, usually with nails or screws. Furthermore, the finished flooring itself is in turn nailed to the sub-floor by some means; usually nails or staples.

Nail and staple connections generally experience two types of loading scenarios in service: axial withdrawal and lateral withdrawal. Four factors exist which contribute to the degradation of nailed joints in a lateral direction. These are nail bending strength (nail ductility), bearing strength of sheathing and framing material and the friction which exists between the framing and the sheathing material (Jang *et al.* 1993).

Fastener performance tests generally involve testing fasteners, whether they be nails, screws, staples, etc., in either axial withdrawal or lateral resistance. Axial withdrawal describes a nail or fastener that is removed directly perpendicular to the face of the substrate to which it is attached. Lateral resistance, important in determining the stiffness of a connection, indicates a fastener's ability to minimize the movement or slip of two fastened substrates in a parallel direction.

Nails and staples used to fasten hardwood flooring to sub-flooring are generally driven through the tongue of the flooring at an angle of 45°. Therefore they are subjected to withdrawal forces which are neither exclusively axial nor exclusively lateral,

but a combination of both. A good deal of work has been done studying the lateral and axial nail resistance of both solid wood and wood-based panel products.

The lateral nail resistance is especially important in flooring systems, as it has direct impact on floor joist-to-sub-floor connections. Gromala (1985) tested the lateral nail resistance for ten common sheathing materials that could possibly serve as sub-floor materials. These included plywood, flakeboard, hardboard and gypsum board. Several equations exist (McLain 1997) which predict the withdrawal strength of plain-shank common wire nails by relating it to ultimate shank withdrawal, wood specific gravity, and nominal fastener diameter.

6d common nails were tested in direct withdrawal by Elias (1982) in both 3/8" and 1/2" plywood in an attempt to establish minimum acceptable values. Information from such a test can be used to predict the performance expected by composite panels in relation to flooring fastener retention.

Finite-element models may be very useful for predicting load-withdrawal relationships (Groom and Leichti 1993). A setup with which to test different loading scenarios would prove very beneficial to the wood scientist. Not only does such a setup and method exist for testing axial and lateral loads, it may even test wood joints under a combination of both axial withdrawal and lateral resistance (DeBonis and Bodig 1975). Parameters of the tests varied by wood species, nail penetration depth, and load application angle.

It seems as though no matter what is discussed with respect to flooring systems, RH and moisture seem to be factors. The performance of nails and fasteners is no exception. A fair amount of work has been done in an attempt to relate changes in MC

to the performance of mechanical fasteners. In the majority of instances, it could be concluded that an increase in MC significantly deteriorated the performance of fasteners due to degradation in the materials which were fastened together (Barnes and Lyon 1978; Chow *et al.* 1985,1988; Feldborg 1989, Rammer and Winistorfer 2001).

It is apparent based on the literature that the status of the wood-based composite products industry has changed over the past decade. Due to the fact that the need for raw materials is increasing and the quality of the constituents in plywood and OSB seems to be decreasing, an attempt to re-evaluate the fastener holding capacity of currently available panel products in relation to hardwood flooring systems seems to be in order. By following certain procedures done at Virginia Tech by Lang *et al.* (1994) in which the fastener holding capacity of sub-floor materials under cyclic environmental conditions was investigated, conclusions may be drawn as to the type of panel which will give the best performance in service.

Experimental Methods

3.1 Introduction

In order to fulfill the previously stated project objectives, plywood and OSB products were received from four plants covering two geographic regions of the United States. East Coast panel products were procured from Hickory, NC and Richmond, VA. West Coast panel products originated in San Francisco, CA and Seattle, WA. These panels were used for all project tests: as sub-floor materials for fastener withdrawal tests, in standard ASTM nail withdrawal tests, in the horizontal density distribution investigation, and in a moisture meter calibration investigation. A code was developed describing the various panel type/fastener/floor combinations:

“E” or “W” – designates panel origin; East Coast or West Coast

“O” or “P” – designates panel type; OSB or plywood

“5” or “3” – designates panel thickness; 5/8” or 3/4”

“N”, “N2”, or “S” – designates fastener type; 1.5” nail, 2” nail, or 1.5” staple

“f” – denotes finished flooring;

Therefore, a test floor coded **EP5Sf** would indicate finished flooring installed on East Coast, 5/8” thick plywood fastened with a staple.

East Coast plywood was comprised exclusively of southern yellow pine while West Coast plywood was found to be either Douglas-fir or ponderosa pine. East Coast OSB was a mixture of hardwoods and softwoods, with the principle hardwoods being yellow-poplar and maple along with smaller amounts of various other hardwoods such

as walnut and cherry. The primary softwood found in the East Coast OSB was southern yellow pine. West Coast OSB was comprised of a mixture of soft hardwoods, with aspen as the predominant species.

Unfinished hardwood flooring was shipped from a manufacturer in Memphis, Tennessee and the pre-finished flooring was purchased at a local home improvement warehouse. All flooring fasteners and tools necessary for their installation were provided by NOFMA. NOFMA personnel were responsible for laying out the nailing patterns of the hardwood floor systems and for performing the actual floor installation.

3.2 Horizontal Density Distribution

The horizontal density distribution was investigated for each of the six panel types by calculating panel specific gravity on a dry volume basis. This was performed in an attempt to gain an understanding as to the density variations among panel types and between geographic locations. These included $\frac{3}{4}$ " OSB, $\frac{3}{4}$ " plywood, and $\frac{5}{8}$ " plywood from both East Coast and West Coast points of origin. Originally, 35 2" by 2" specimens were cut from each panel type. In order to obtain a better distribution of data, additional panel specimens (taken from fastener withdrawal tests during the coupon phase) were added. All measurements were done before any treatment cycling took place. Horizontal density distribution measurements were found following ASTM Standard D 2395-93, Standard Test Methods for Specific Gravity of Wood and Wood-Base Materials, Method A-Volume by Measurement. Probability/density functions of the various distributions were found using ExperFit computer software.

3.3 Floor Construction

A total of 68 floor systems were built using nominal 2x4 No. 2 KD19 s-p-f as floor joists (Figure 3.1a). The joists were spaced according to the span rating of the various sub-floor sheathing. All sheathing was APA Rated and was designated Exposure 1 (Figure 3.1b). Three panel types, P3, O3, and P5 were used from the two geographic locations, East Coast and West Coast, for a total of six panel combinations. All P3 panels consisted of five or seven plies, while the P5 panels were either four or five ply. All O3 was 3-layer with the face strands parallel to the length of the panel. The use of panels from two separate geographic locations allowed us to determine whether or not panels comprised of a certain species had an effect on the overall results of the treatment cycle.

All test floors were 24.75" in width with the joists running perpendicular to the length of the flooring system (Figure 3.2). Rimboards, joists, and panels were precut and stacked prior to system assembly. Templates were fabricated prior to the assembly of the sub-floor systems according to the span rating of each panel (Figure 3.3a). Cardboard nailing patterns were constructed for P3, O3, and P5. The patterns were simply laid on top of the panels and the nailing points were marked (Figure 3b). All panels were attached to the joists with 8d common nails using a pneumatic nail gun, spaced according to APA specifications (APA 1998). Edge joists required five evenly spaced nails and all internal joists were connected using three nails. The number of floor joists were dependent on the span rating of a particular panel. Accordingly, P5 required a span of 16" and had a finished length of 49.5". P3 sub-floors had a span of 24" OC and the length of a finished system was also 49.5". O3 sub-floors required a

a.

b.

Figure 3.1 Sixty-eight constructed floor systems (a); example of a typical APA grade stamp (b).

Figure 3.2 Test floor assemblies. **a.** 5/8" plywood, span rating 16" OC; **b.** 3/4" plywood, span rating 24" OC; **c.** 3/4" OSB, span rating 19" OC.

a.

b.

Figure 3.3 Floor joist template for OSB floor system (a); APA specified nailing pattern for OSB (b).

span of 19" OC and was 39.5" in length. Nominal 2"x4" sills or rimboards were fastened to the ends of the joists along the length of each system to prevent any distortion or buckling of the panels during treatment.

After the assembly of the sub-floors was complete, but before any flooring was installed, the sub-floor systems were placed into the environmental chamber and conditioned until they reached a 16% MC. The purpose of this treatment was to simulate a mild construction site exposure that may exist after the sub-flooring is installed but before the building is enclosed. When the panels reached the targeted 16% MC, the drying process began and the oak strip flooring was installed when the sub-floor panels reached an MC of 10%.

The oak floor shipment consisted of unfinished, non-sanded, tongue and groove, oak strip flooring, $\frac{3}{4}$ " thick and 2 $\frac{1}{4}$ " wide in random lengths. Pre-finished flooring manufactured by Bruce Hardwoods and purchased locally was used as a means for comparison. This product was tested during the final phase of the project. NOFMA professionals performed the installation of the flooring according to NOFMA standards. Each floor system was comprised of eleven strips of flooring with 15-lb felt construction paper between the sub-floor and the flooring itself. The felt provided a vapor barrier between the two components of the floor as would be done in a real life situation. The first strip in the sequence was face using a pneumatic nail gun. Each subsequent strip was then fastened with either 1.5" barbed cleats, using a mechanically driven nail gun, or 15 gauge 1.5" staples with a $\frac{1}{2}$ " crown using a pneumatically driven staple gun (Figure 3.4a). The approximate angle of penetration for both the cleats and the staples was 45° (Figure 3.4b). Both cleats and nails were used for

a.

b.

Figure 3.4 Various fasteners used in floor system construction (a); cross-section of a typical flooring assembly (b).

each of the six panel combinations for a total of twelve system combinations utilizing unfinished flooring. For comparison purposes, four systems were constructed, two on EP3 and two on WP3, using 2" cleats applied at an angle of 30°. One EP3N2 system and one WP3N2 system were tested at both the beginning of the accelerated environmental simulation and again at the end. Four systems were constructed using the factory finished flooring. The variables included EP5 and WP5 with both 2" cleats and 1.5" staples. These were tested in the final phase of the treatment.

The fastener withdrawal testing schedule, by treatment phase, is as follows:

- 1) Coupon – Combination of Phases II and III. MC of the systems was kept at constant 12% and the strip flooring was installed. Installations were followed by a series of fastener withdrawal tests (coupon tests) including 6 panel types by two fastener types (1.5" cleats, 1.5" staples) plus 2 panel types with 2" cleats for a total of 14 systems.
- 2) Phase IV – Described the first "summer" period simulation with a target MC of 10%. Six days after the target MC was achieved, fastener withdrawal test were performed including 6 panel types by two fastener types (1.5" cleats, 1.5" staples) for a total of 12 systems.
- 3) Phase V – Described the "second" winter period simulation. Target MC was 6% and after being held for six days, a series of fastener withdrawal tests was performed including 6 panel types by two fastener types (1.5" cleats, 1.5" staples) for a total of 12 systems.
- 4) Phase VI – Simulation of the second "summer" period where a target MC of 12% was reached and then held for a period of six days. This was followed by a series of fastener withdrawal tests including 6 panel types by two fastener types (1.5" cleats, 1.5" staples) for a total of 12 systems.
- 5) Phase VII – Simulation of the third "winter" period with a target MC of 6%. Target MC was held for six days followed by a series of fastener withdrawal tests including 6 panel types by two fastener types (1.5" cleats, 1.5" staples) plus 2 panel types with 2" cleats and 4 finished floors (2 panel types by two fastener types) for a total of 18 systems

3.4 Chamber Construction

In order to simulate the two and a half-year moisture cycle, a temporary walk-in environmental chamber was constructed (Figures 3.5a and b). Dimensions of the chamber were as follows: 28' in length by 11' wide by 7'6" in height. The framing of the chamber consisted of 8 frames made of nominal 2"x4" s-p-f lumber fastened using 3" drywall screws. The frame structure was covered with 6 mil thickness polyethylene foil attached with standard ½" staples. The entire frame was housed atop a 12' by 30' piece of green indoor/ outdoor mildew resistant all-weather carpet. An access door was constructed and placed in the front wall of the chamber. Duct tape and silicone caulking were used where necessary in order to make the chamber as airtight as possible.

Within the chamber were the climate controls. These included two 40-pint/day Kenmore dehumidifiers elevated by means of constructed stands. Clear plastic tubing was installed between the dehumidifiers and two 30-gallon garbage cans outside the chamber where the water from the dehumidifiers was collected. Two variable speed box fans, suspended from the roof and two variable speed oscillating fans provided ample air circulation.

3.5 Moisture Cycling

The treatment for the project involved alternately increasing and decreasing the moisture content of the flooring systems through manipulation of relative humidity. Moisture cycling began at the conclusion of the coupon tests. The RH within the chamber was increased by periodically spraying the interior walls with water via a

a.

b.

Figure 3.5 Environmental chamber midway through construction (a); front view of completed environmental chamber (b).

commercial garden sprayer. In order to make sure that the panels did not come in direct contact with the spray, plastic foil was placed over each stack of panels before moisturizing the chamber walls. Phases of the simulated moisture cycle that called for a lower EMC simply required turning on two 40 pint/day dehumidifiers and allowing them to run continually until the target EMC was reached.

Temperature and relative humidity measurements were taken within the chamber with the use of an ERTCO Exact-Temp temperature/humidity datalogger. Windows based software installed on a computer outside the chamber imported the information from the datalogger. Once the data was imported into the computer, the software graphed the readings on a continuous curve. At the conclusion of each treatment phase, data was saved in the computer and the datalogger was cleared and reset. Figure 3.6a shows the actual RH and temperature values within the chamber during the accelerated moisture cycle simulation. In an attempt to simulate the conditions panels might experience after installation but before a building is enclosed, a mild exposure site simulation was performed. During this phase of the project, all panels were moisturized up to 16% MC and then immediately dried back to approximately 7-8%, at which time the flooring was installed. Figure 3.6b shows the actual RH and temperature during this period.

3.6 Specimen Manufacture

The manufacturing of flooring fastener withdrawal test specimens took place at the beginning of the project (coupon tests) and at the end of each phase of the accelerated simulation. The coupon tests served as a control for comparison with the

Figure 3.6 Relative humidity and temperature of test floor systems and panels during a.) occupancy simulation phase and b.) mild exposure site simulation.

data from subsequent tests. These specimens were manufactured in the form of a cross with the hardwood flooring portion oriented above and perpendicular to the sub-floor portion of the specimen. The cross-shaped specimens were cut out from each of the system configurations (Figure 3.7).

The initial step in manufacturing the specimens involved taking a system from the chamber and removing the portion of the panel between the floor joists. At this point, a series of table saw cuts was used to cut strips consisting of both hardwood flooring and sub-floor panels. The next step involved marking each of the fasteners, which were now visible. Another series of cuts on a band saw finished the specimens, which were then placed into airtight plastic bags to await testing. A minimum of 25 specimens was manufactured for each of the panel combinations resulting in approximately 1,800 data observations.

3.7 Fastener Withdrawal Tests

Fastener withdrawal tests were performed using an MTS Universal Servo-Hydraulic testing machine with a specially manufactured testing jig setup (Figures 3.8a and b). The machine was operated under displacement control. The load cell of the machine had a 20,000-lb capacity with a 0.5-lb sensitivity. Speed of testing was 0.10 in/min, according to ASTM Standard D 1761-88, Standard Test Methods for Mechanical Fasteners in Wood.

The maximum load value for each of the sample specimens was recorded. Immediately following each withdrawal test, moisture content measurements were taken using a handheld Delmhorst electronic, conductance moisture meter using 1 7/16" non-

Figure 3.7 Cross-shaped fastener withdrawal test specimens.

a.

b.

Figure 3.8 MTS unit set up for specimen testing (a); special withdrawal testing jig with specimen in place (b).

insulated pins. To further validate the readings from the moisture meter, the moisture contents of the sub-floor specimens in the coupon and final phase were found gravimetrically, according to ASTM D 2395-93, Standard Test Methods for Specific Gravity of Wood and Wood-Base Materials.

To further investigate the fastener withdrawal behavior of the flooring specimens, load-displacement data was collected for one sample of each of the system combinations using GPA brand data acquisition software. This data acquisition took place during both the coupon and final phases. When plotted, this data created a visualization of the failure based on a load-displacement curve.

3.8 Standard Nail Withdrawal Tests

Standard nail withdrawal tests were performed according to ASTM Standard D 1761-88, Standard Test Methods for Mechanical Fasteners in Wood (Figure 3.9a). This allowed for comparison with the fastener withdrawal resistance tests. Ten 6" by 6" specimens were manufactured creating six panel types: EO3, EP3, EP5, WO3, WP3, and WP5. This provided sixty total specimens. Five 6d common wire nails were driven into each of the sixty panels. These five nails represented each of the test phases (Figure 3.9b). Coupon tests were performed immediately and then one nail was pulled from each of the specimens at the end of each treatment cycle. In addition, a moisture content reading was taken from each panel with a Delmhorst handheld moisture meter.

a.

b.

Figure 3.9 Standard nail withdrawal test setup (a); standard nail withdrawal test specimen (b).

3.9 Sub-floor Thickness Change

The standard nail withdrawal specimens also served as specimens for thickness change measurements. This test was performed in order to understand the degree to which the panels shrank and swelled during cycling. The center point of each of the four edges for each specimen was identified and numbered 1 to 4. Initial thickness measurements were taken at the time the coupon tests were performed and thereafter measurements were taken coinciding with the removal of each nail. This was performed for each of the phases in the moisture cycle.

3.10 Moisture Meter Calibration

For the duration of this project, it was necessary to constantly measure and record the moisture content of both the hardwood flooring and the subfloor panels in a non-destructive manner. For this purpose, a Delmhorst RDM 2-S hand-held conductance moisture meter was utilized (Figure 3.10). This unit allows for direct species and temperature alterations. Non-insulated pins measuring 1 7/16" were used throughout the project. In order to obtain accurate readings of composite panel products, calibration of the moisture meter was performed. Forty 3" by 3" specimens were cut randomly from each of the six panel types. Ten samples of each panel type were placed into four areas of differing environmental conditions ranging from 28% RH to 85% RH. Data for P3 and P5 paneling was combined for each geographic location. Calibration was performed according to ASTM Standard D 4444-92, Standard Test Methods for Use and Calibration of Hand-Held Moisture Meters, Method A, for Conductance Meters. Meter values for each panel type were plotted against the actual

Figure 3.10 Delmhorst RDM 2-S moisture meter.

moisture content values obtained by gravimetric method. The resulting regression equations [1,2] provided the necessary correction factors. All data fit into first or second order polynomial equations in the following forms:

$$Y = b_0 + b_1X \quad [eq. 1]$$

$$Y = b_0 + b_1X + b_2X^2 \quad [eq. 2]$$

Where: Y – MC by gravimetric method [%];

X – MC by handheld meter [%];

b's – regression coefficients.

3.11 Statistical Analysis of the Data

Fastener withdrawal data was analyzed using SAS statistical software with the General Linear Model procedure as well as the Means procedure. Three classes were involved in the GLM model: 1). Moisture cycle, which had five levels including coupon, phase IV, phase V, phase VI, and phase VII; 2). Panel type, which had six levels including EO3, EP3, EP5, WO3, WP3, and WP5; and 3). Fastener type, which had two levels and included 1.5" long nails and 1.5" long staples. The dependent variable for the model was the maximum fastener withdrawal value. The Means procedure drew pair-wise comparisons based on mean values for different combinations of levels.

One-Way Analysis of Variance was performed using SigmaStat software for each panel/fastener combination in order to screen out the moisture cycling effect. If both the normality and the equal variance tests passed, Dunnett's Method was used. This method draws multiple comparisons versus a control (coupon) group. If either the normality or equal variance tests failed, a Kruskal-Wallis one way ANOVA on ranks was

performed using Dunn's Method. This too draws multiple comparisons versus a control group following rank-based ANOVA. SigmaStat generated paired t-tests were performed for EP3N2 and WP3N2 in order to determine if there was a significant difference in the means between the coupon and the final (3rd 6% MC) group. Likewise, paired t-tests were performed for finished flooring comparing both 2" nails and 1.5" staples. Because no coupon tests were set up utilizing the finished flooring, coupon values for EP5N, EP5S, WP5N, and WP5S were used as a control. All pair-wise comparisons for nail coupon and staple coupon were performed with a Tukey test. This method is less conservative than a test such as Duncan's New Multiple Range test, which may fail to detect a Type I error, but more conservative than a Student-Newman-Keul's test, which may fail to detect a Type II error.

Data analysis of standard nail withdrawal tests fell into two parts. As was done in the flooring fastener withdrawal tests, One-way ANOVA was performed to screen out the moisture cycling effects on the standard nail withdrawal force of each panel type. Multiple comparisons versus a control (coupon) group were done using either Dunnett's Method or Dunn's Method. A follow up comparison of all pair-wise values was performed using a Tukey Test. This test could identify any significant difference in the initial mean fastener withdrawal values of the six panel types.

Results and Discussion

4.1 Moisture Meter Calibration

Moisture meter calibration for composite panels included 240 samples; sixty each for EO3, EP, WO3, and WP. A Delmhorst RDM 2-S was calibrated for East Coast and West Coast plywood and OSB. Both EP3 and WP3 followed a linear regression (Figures 4.1a and b) with r^2 values of 0.960 and 0.928 respectively. The regression for EO3 was linear (Figure 4.2a) while WO3 fit a second order polynomial (Figure 4.2b). Their r^2 values were 0.985 and 0.995 respectively. Percentage of error between moisture meter values and gravimetric values was calculated for each panel type resulting in the following: East Coast OSB, 14.7%; East Coast plywood, 39.0%; West Coast OSB, 20.7%; West Coast plywood, 43.6%. Moisture meter values were then corrected based on the regression equations and the percentage of error was again computed. East Coast OSB showed an error percentage of 6.5% while the remaining three panel types showed errors of less than 1%. This proved that the regression equations may be used to correct moisture content meter readings on the four panel types with acceptable accuracy.

4.2 Horizontal Density Distribution of Panels

Horizontal density distribution measurements were taken from each of six panel types resulting in 688 observations. Density measurements taken from panels with East Coast origin were higher than density measurements of panels originating on the West Coast. For example, EO3 exhibited higher density values than did WO3. Similar results

Figure 4.1 Regression equation for oven-dry MC vs. moisture meter MC with 95% confidence and prediction intervals; a. East Coast plywood, b. West Coast plywood

Figure 4.2 Regression equation for oven-dry MC vs. moisture meter MC with 95% confidence and prediction intervals; a. East Coast OSB, b. West Coast OSB

were noted with P3 as well as P5. A summary of descriptive statistics for horizontal density distribution data is found in Table 4.1. Average SG values for EO (0.62) and WO (0.54) agreed well with those values, 0.64 and 0.55 respectively, discovered by Wu and Suchsland (1997). The average SG value that was found for WP3 (0.49) was similar to the literature value of 0.50 (Chow 1976). Whereas the average SG value for EP3 (0.56) was higher than the literature value (0.47). Histograms with the appropriate probability density functions were compiled using ExpertFit software describing the horizontal density distribution of the six panel types (Figures 4.3-4.5). EO3, EP3 and WP3 all fit a 2-parameter Lognormal function while a 3-parameter Weibull function best described the distribution of WO3, WP5 and EP5.

In order to determine whether or not there is a relationship between fastener holding capacity and panel density, regressions were plotted for fastener withdrawal strength versus panel specific gravity for both O3S and O3N before cycling (Figures 4.6a and b) and again after cycling (Figures 4.7a and b). The fastener holding capacity values for the plywood panels were normalized to a one-inch thickness by dividing the fastener withdrawal strength values by the panel thickness. Regression lines for P3S and P3N were found after cycling (Figures 4.8a and b). Low r^2 values indicated that there was insignificant correlation between the two factors for plywood while moderate r^2 values for OSB indicated that a positive correlation may indeed exist between panel density and fastener holding capacity.

Table 4.1 Summary of descriptive statistics for horizontal density distribution data.

PANEL CODE	SAMPLE SIZE	SPECIFIC GRAVITY			
		MEAN	STD. DEV.	MIN	MAX
EO3	148	0.620	0.041	0.52	0.75
EP3	110	0.563	0.035	0.47	0.64
EP5	135	0.557	0.043	0.49	0.69
WO3	149	0.543	0.042	0.46	0.68
WP3	111	0.491	0.071	0.37	0.70
WP5	135	0.469	0.069	0.37	0.67

Figure 4.3 Histogram of horizontal density distribution with probability density function overlaid; a. panel code EO3, b. panel code WO3

Figure 4.4 Histogram of horizontal density distribution with probability density function overlaid; a. panel code EP3, b. panel code WP3

Figure 4.5 Histogram of horizontal density distribution with probability density function overlaid; a. panel code EP5, b. panel code WP5

Figure 4.6 Regression analysis of fastener withdrawal strength versus specific gravity for OSB (coupon); a. staple fastener, b. nail fastener

Figure 4.7 Regression analysis of fastener withdrawal strength versus specific gravity for OSB (post treatment); a. nail fastener, b. staple fastener

Figure 4.8 Regression analysis of fastener withdrawal strength versus specific gravity for plywood (post treatment); a. staple fastener, b. nail fastener

4.3 Moisture Cycling

Moisture cycling began with a mild exposure site simulation where installed sub-flooring was moisturized up to an equilibrium moisture content (EMC) of approximately 16%. This lasted fourteen days and attempted to simulate the conditions sub-flooring might be exposed to after installation but before building enclosure. One hundred and fifty nine days were required to complete the accelerated simulation. For the duration of the simulated moisture cycling, relative humidity and temperature were recorded at six-hour intervals through the use of an ERTCO brand datalogger.

4.4 Fastener Withdrawal Tests

Fastener withdrawal tests were performed over the course of this project resulting in 1815 data observations. Table 4.2 shows descriptive statistics, including mean and standard deviation, for maximum fastener holding capacity of the five cycle fastener withdrawal tests. Staple fasteners 1.5" long provided higher maximum mean values than did 1.5" nails for all panel types during all phases except for EP3 during the final phase. Table 4.3 provides a summary of descriptive statistics for floors fastened with 2" nails on EP3 and WP3 panels driven at an angle of 30°. Descriptive statistics for finished flooring fastened with both 2" nails and 1.5" staples on EP5 and WP5 panels can be found in Table 4.4. For quick visual evaluation, box plot diagrams were constructed by exposure (Figures 4.9-4.17) and by panel code (Figures 4.18-4.22). Table 4.5 shows the percent change in mean fastener-holding capacity between phases for each sub-floor panel type/fastener combination.

Table 4.2 Summary of descriptive statistics from five series of fastener withdrawal tests.

Subfloor Code	Fastener	STATUS OF EXPOSURE														
		Coupon			10% MC			2 nd 6% MC			12 % MC			3 rd 6% MC		
		STATISTICS OF MAXIMUM NAIL WITHDRAWAL FORCE (LBS)														
		n ¹	Mean	Std. Dev.	n ¹	Mean	Std. Dev.	n ¹	Mean	Std. Dev.	n ¹	Mean	Std. Dev.	n ¹	Mean	Std. Dev.
EP3	NAIL	34	92	14.878	25	111	17.634	25	88	11.865	25	85	15.232	25	93	15.866
	STAPLE	34	118	14.149	25	119	16.594	25	89	20.469	25	86	20.857	25	69	23.773
EP5	NAIL	29	74	22.094	25	85	17.482	25	63	16.472	25	75	21.637	27	61	21.243
	STAPLE	34	101	14.126	27	101	19.661	25	95	12.449	25	93	16.004	25	78	15.140
EO3	NAIL	29	77	14.270	24	78	17.756	25	68	13.482	25	68	15.740	25	65	17.614
	STAPLE	34	122	23.372	25	114	23.826	25	98	24.042	25	92	22.913	25	91	29.547
WP3	NAIL	35	95	16.908	25	105	21.545	25	71	15.825	25	82	17.088	25	70	20.229
	STAPLE	35	125	16.153	25	110	14.678	25	119	17.049	25	90	22.829	26	106	15.083
WP5	NAIL	31	63	13.026	25	57	13.723	25	63	13.350	25	77	19.930	25	42	15.878
	STAPLE	32	100	14.134	25	104	20.112	25	79	17.261	25	84	17.651	25	66	14.475
WO3	NAIL	31	59	12.985	25	52	11.427	25	61	13.572	25	46	14.347	25	37	12.514
	STAPLE	33	87	19.904	25	99	21.786	25	82	24.737	25	68	27.274	25	63	28.595

¹ sample size

Table 4.3. Summary of descriptive statistics for floors fastened with 2" cleats at an angle of 30°.

SUBFLOOR CODE	STATUS OF EXPOSURE					
	Coupon			Final (3 rd 6% MC)		
	n	Mean (lbs)	Std. Dev (lbs)	n	Mean (lbs)	Std. Dev. (lbs)
EP3	35	97	14.987	25	92	20.081
WP3	35	101	21.503	25	104	21.040

Table 4.4. Summary of descriptive statistics for finished floor combinations

SUBFLOOR CODE	FASTENER	n	Mean (lbs)	Std. Dev. (lbs)
EP5	2" Nail	25	106	17.451
	Staple	25	80	16.969
WP5	2" Nail	25	87	18.742
	Staple	25	105	13.576

Figure 4.9 Changes in fastener holding capacity by exposure.
a. panel code EO3N; b. panel code WO3N

Figure 4.10 Changes in fastener holding capacity by exposure.
a. panel code EO3S; b. panel code WO3S

Figure 4.11 Changes in fastener holding capacity by exposure.
a. panel code EP3N; b. panel code WP3N

Figure 4.12 Changes in fastener holding capacity by exposure.
a. panel code EP3S; b. panel code WP3S

Figure 4.13 Changes in fastener holding capacity by exposure.
a. panel code EP5N; b. panel code WP5N

Figure 4.14 Changes in fastener holding capacity by exposure.
a. panel code EP5S; b. panel code WP5S

Figure 4.15 Changes in fastener holding capacity by exposure.
a. panel code EP3N2; b. panel code WP3N2

Figure 4.16 Changes in fastener holding capacity by exposure.
a. panel code EP5N2f; b. panel code WP5N2f

Figure 4.17 Changes in fastener holding capacity by exposure.
a. panel code EP5Sf; b. panel code WP5Sf

Figure 4.18 Comparison of fastener holding capacity by panel code for coupon phase; a. nail fastener, b. staple fastener

Figure 4.19 Comparison of fastener holding capacity by panel code for phase IV; a. nail fastener, b. staple fastener

Figure 4.20 Comparison of fastener holding capacity by panel code for phase V; a. nail fastener, b. staple fastener

Figure 4.21 Comparison of fastener holding capacity by panel code for phase VI; a. nail fastener, b. staple fastener

Figure 4.22 Comparison of fastener holding capacity by panel code for phase VII; a. nail fastener, b. staple fastener

Table 4.5 Percent (%) change in mean fastener holding capacity.

SUBFLOOR CODE	FASTENER	COUPON – 10% MC	COUPON – 2 ND 6% MC	COUPON – 12% MC	COUPON – 3 RD 6% MC
EP3	NAIL	+20.1	-4.3	-7.6	+1.1
	STAPLE	+0.08	-24.6	-27.1	-41.5
EP5	NAIL	+14.9	-14.9	+1.4	-17.6
	STAPLE	0.0	-5.9	-7.9	-22.8
EO3	NAIL	+1.3	-11.7	-11.7	-15.6
	STAPLE	-6.6	-19.7	-24.6	-25.4
WP3	NAIL	+10.5	-25.3	-13.7	-26.3
	STAPLE	-12.0	-4.8	-28.0	-15.2
WP5	NAIL	-9.5	0.0	+22.2	-33.3
	STAPLE	+4.0	-21.0	-16.0	-34.0
WO3	NAIL	-11.9	+3.4	-22.0	-37.3
	STAPLE	+13.8	-5.7	-21.8	-27.6
EP3	2" NAIL	-----	-----	-----	-5.1
WP3	2" NAIL	-----	-----	-----	+3.0

Raw data was analyzed using SAS statistical software applying a General Linear Model Procedure as well as a Means Procedure. Results of the GLM Procedure by cycle indicate that the mean values of the coupon (93.83 lbs.) and 10% MC phase (94.53 lbs.) were nearly the same. Mean values of all subsequent phases, Phase V (81.44 lbs.), Phase VI (78.92 lbs.) and Phase VII (70.11 lbs.) declined fairly uniformly. This indicated that fastener holding capacity does not start to decline until the second 6% (Phase V) is reached. GLM Procedure for panel type showed similar mean values for EP3 (95.74 lbs.) and WP3 (98.34 lbs.) with EO3 (88.34 lbs.) only slightly lower. EP5 (83.05 lbs.) was next followed by WP5 (73.90 lbs.) and WO3 (66.00 lbs.), which had the lowest value. GLM Procedure by fastener type showed the mean value for 1.5" staples (95.95 lbs.) was considerably higher than the mean value for 1.5" nails (72.48 lbs.). GLM Procedure for panel type by fastener type showed WP3S (111.18 lbs.) as the combination which provided the highest fastener withdrawal strength. The combination which provided the lowest mean strength value was WO3N (51.47 lbs.). A complete ranking of panel type by fastener type is listed in Table 4.6 with the results in descending order in Table 4.7.

The Means Procedure took a holistic approach to describing panel performance. It grouped all fastener withdrawal values into categories based on a single factor. For example, it provided mean values for all East Coast products independent of panel type, thickness, or fastener type. Mean values based on geographic origin showed East Coast products (89.08 lbs.) being superior to West Coast products (79.59 lbs.). Mean values based on panel type, either plywood or OSB, showed plywood (87.89 lbs.) as being superior to OSB (77.13 lbs.). P3 (97.04 lbs.) provided substantially

Table 4.6 GLM results of panel type by fastener type.

PANEL TYPE BY FASTENER TYPE					
Panel Type	Fastener Type	Sample Size	Mean (lbs)	St. Dev. (lbs)	Rank
EO3	N	128	71.49	16.337	10
EO3	S	134	104.43	27.514	2
EP3	N	134	93.61	17.351	5
EP3	S	134	97.87	27.340	3
EP5	N	129	71.56	21.557	9
EP5	S	135	94.06	17.502	4
WO3	N	131	51.47	15.825	12
WO3	S	133	80.31	27.170	8
WP3	N	135	85.40	22.510	7
WP3	S	136	111.18	20.999	1
WP5	N	131	60.46	19.725	11
WP5	S	131	87.35	21.778	6

Table 4.7 Rank of panel type by fastener type in descending order.

Rank Number	Panel Code
1	WP3S
2	EO3S
3	EP3S
4	EP5S
5	EP3N
6	WP5S
7	WP3N
8	WO3S
9	EP5N
10	EO3N
11	WP5N
12	WO3N

higher values than did P5 (78.50 lbs.). Complete SAS data analysis printouts are included in Appendix II.

Mean coupon values of fastener withdrawal tests performed by Lang *et al.* (1992) were compared with current coupon values for O3, P3 and P5 (Table 4.8). However, the previous project utilized 2" long fasteners while the current project results are based on 1.5" long fasteners. Therefore, any comparisons that may be drawn are done with caution. Based on the time of purchase of the raw materials for the respective projects, these comparisons spanned approximately ten years. The purpose of this comparison was to determine the change, if any, in the maximum fastener holding capacity of the panels over time. All panel type/fastener combinations experienced a decline in maximum fastener holding capacity. The percent loss of maximum fastener holding capacity over time ranged from 15.1% for P5S to 43.8% for P3S. All other panel type/fastener combinations fell within this range. This decline may be attributed to the difference in the length of the fasteners, but all indications point toward the growth of the panel products industry and the subsequent use of inferior raw materials as the major cause of this decline. This conclusion is based upon the visual inspection of the panels conducted in this study. It was noted that, upon disassembly of the various panel types, that the quality of the veneers in the plywood panels contained a rather inordinate amount of defects and voids. Furthermore, the core layers of the dismantled OSB panels exhibited high amounts of "fines", or constituents of inferior size and quality.

Table 4.8 Comparison of results from two different fastener withdrawal studies done ten years apart.

Coupon Test Results				
Panel Type	Fastener	Previous Mean Value ¹ (lbs)	Current Mean Value ² (lbs)	Fastener Holding Strength Loss (%)
O3	Nail	87.0	67.4	22.5
	Staple	155.9	104.7	32.8
P3	Nail	151.2	93.7	38.2
	Staple	217.1	121.9	43.8
P5	Nail	96.7	68.3	29.4
	Staple	118.2	100.4	15.1

¹1990

²2000

4.5 Standard Nail Withdrawal Tests

Standard nail withdrawal tests were performed throughout this project resulting in 300 data observations. A summary of descriptive statistics for five standard nail withdrawal tests is found in Table 4.9. EO3 had the highest initial maximum withdrawal mean value (81 lbs) while EP3 had the highest final mean value (20 lbs). Available literature data for comparison purposes of plywood panels does exist, but panel thickness' needed to be normalized in order to utilize that data. Ultimate withdrawal data expressed in the literature for 3/8" and 1/2" thick plywood was normalized to 1" by dividing the ultimate withdrawal load by the panel thickness. This resulted in an average ultimate withdrawal value of 98 lbs for a series of 245 tests (Elias 1982). Consequently, normalized coupon data from this project resulted in an average maximum fastener holding capacity of 76 lbs. This represents a loss of approximately 22% over an eighteen-year period, supporting the theory that the maximum fastener holding capacity of composite panels is on a decline.

Box plot diagrams were constructed by panel code (Figures 4.23-4.25) and by exposure (Figures 4.26-4.28). Results of the One-way ANOVA for both EO3 and WO3 show that there is a significant difference between the coupon values and the values obtained from each of the four remaining moisture phases. All plywood panels showed no significant difference between the coupon, 10% MC, and 12% MC phases while there was a statistically significant difference between the coupon, second 6% MC, and third 6% MC phases. Pair comparisons of the coupon data were drawn using a Tukey test and are shown in Table 4.10. A detailed summary of ANOVA tables is included in the Appendix I.

Table 4.9 Summary statistics for five standard nail withdrawal tests.

PANEL CODE	STATUS OF EXPOSURE														
	Coupon			10% MC			2 nd 6% MC			12% MC			3 rd 6% MC		
	STATISTICS OF MAXIMUM NAIL WITHDRAWAL FORCE FOR STANDARD NAIL TESTS (LBS)														
	n ¹	MEAN	STD. DEV.	n ¹	MEAN	STD. DEV.	n ¹	MEAN	STD. DEV.	n ¹	MEAN	STD. DEV.	n ¹	MEAN	STD. DEV.
EO3	10	81	15.521	10	55	15.000	10	27	16.665	10	59	18.414	10	15	6.896
EP3	10	76	15.702	10	67	9.620	10	21	4.435	10	73	17.928	10	20	13.256
EP5	10	38	11.245	10	39	14.598	10	17	7.625	10	57	17.913	10	10	3.795
WO3	10	50	12.841	10	32	6.099	10	15	6.667	10	31	10.587	10	9	5.116
WP3	10	57	19.535	10	58	16.248	10	17	9.615	10	60	18.403	10	11	4.881
WP5	10	41	17.296	10	44	8.468	10	15	4.059	10	52	13.180	10	13	9.637

¹ sample size

Figure 4.23 Changes in fastener holding capacity by exposure for standard nail withdrawal; a. panel code EO3, b. panel code WO3

Figure 4.24 Changes in fastener holding capacity by exposure for standard nail withdrawal; a. panel code EP3, b. panel code WP3

Figure 4.25 Changes in fastener holding capacity by exposure for standard nail withdrawal; a. panel code EP5, b. panel code WP5

Figure 4.26 Comparison of fastener holding capacity of standard nail withdrawal by panel code; a. coupon phase, b. phase IV

Figure 4.27 Comparison of fastener holding capacity of standard nail withdrawal by panel code; a. phase V, b. phase VI

Figure 4.28 Comparison of fastener holding capacity of standard nail withdrawal by panel code for phase VII

Table 4.10 Results of Tukey Test for standard nail withdrawal.

Initial Properties "Coupon Test"				
Tukey Grouping ¹			Mean	Panel Code
A			81.1	EO3
A	B		76.3	EP3
		C	38.2	EP5
		C	49.5	WO3
	B	C	56.6	WP3
		C	41.1	WP5

¹Similar letters indicate panels with means that are not statistically different.

In a direct comparison with flooring fastener tests, the standard nail withdrawal tests exhibited coupon $f_{\max}$ values that were close to the flooring fastener tests. However, after the first moisture cycle, the $f_{\max}$ values of the standard nail tests dropped off abruptly and continued to be poor during each subsequent test. This showed that the standard nail withdrawal was more effected by panel degradation due to the simulated moisture cycling. In contrast, the $f_{\max}$ of the flooring fasteners declined at a much more gradual rate and the effect of panel degradation was less pronounced. Furthermore, the flooring fastener $f_{\max}$ values tended to fluctuate up and down in a gradual manner while the standard nail withdrawal values fluctuated up and down in a more exaggerated manner, depending on whether the cycle was experiencing a “summer” or a “winter” phase.

4.6 Subfloor Thickness Change

Average moisture content values as well as average thickness values were measured for ten samples of each panel type. This was performed at the beginning of the project (coupon values) as well as at the conclusion of each moisture phase. Calculations, including average percentage moisture content change, thickness change in millimeters, and percentage of shrinkage and swelling compared to percentage of moisture content change were done for the following intervals: coupon to 10% MC, 10% MC to second 6% MC, second 6% MC to 12% MC, and 12% MC to third 6% MC (Figures 4.29-4.34). Moisture content and thickness change measurements were straightforward and found by subtracting the initial value from the final value. This resulted in positive values during moisturizing intervals and negative values during

Figure 4.29 Moisture content change (a), thickness change (b), shrinkage and swelling ratios (c) of EO3 panels during exposure cycle.

Figure 4.30 Moisture content change (a), thickness change (b), shrinkage and swelling ratios of EP3 panels during exposure cycle.

Figure 4.31 Moisture content change (a), thickness change (b), shrinkage and swelling ratios (c) of EP5 panels during exposure cycle.

Figure 4.32 Moisture content change (a), thickness change (b), shrinkage and swelling ratios (c) of WO3 panels during exposure cycle.

Figure 4.33 Moisture content change (a), thickness change (b), shrinkage and swelling ratios (c) of WP3 panels during exposure cycle.

Figure 4.34 Moisture content change (a), thickness change (b), shrinkage and swelling ratios (c) of WP5 panels during exposure cycle.

drying down intervals. Equation [3] approximated the shrinkage and swelling coefficients of the composite panels:

$$\beta = \left[\frac{\left(\frac{\Delta t}{t_{initial}} \right) x 100}{\Delta MC} \right] \quad [eq. 3]$$

where:

β - shrinkage and swelling coefficients [%/%MC]

Δt - the change in thickness [mm]

$t_{initial}$ - the initial thickness [mm] and

ΔMC - the change in moisture content [%]

Shrinkage and swelling coefficients for OSB were approximately twice those found for plywood. This shows that OSB shrinks and swells more with changes in moisture content than does plywood. This may be best explained by the uniformity and homogeneity in the layers of the plywood products as compared to OSB. Due to the smaller relative size of the constituents in OSB as compared to plywood, there is a much greater chance in random variability within the panel. This may explain why OSB shrinks and swells to a greater degree than does plywood. However, coefficient values for WO3 experienced here (0.65 %/%MC) are somewhat lower than published data for TS coefficients in WO3 (0.95 %/%MC) (Wu and Suchsland 1997).

Summary and Conclusions

5.1 Summary

Fastener holding capacity was investigated for OSB and plywood material in relation to hardwood flooring performance in cyclic environmental conditions. The study involved the evaluation of composite panels from two geographic locations. The treatment was designed to simulate a two and one-half year moisture cycle that hardwood flooring would experience after installation. The main criterion for the evaluation was the fastener holding retention of the composite panels using 1.5" long nails and staples. Supplemental fastener strength values were found by testing 2" long nails driven at an angle of 30° as well as factory finished flooring with both 2" long nails and 1.5" long staples. Additionally, the thickness, swelling, and standard nail withdrawal strength of the panels were evaluated.

5.2 Conclusions

Based on the findings of the research outlined in this project, the following conclusions may be drawn:

1. Average strength loss for all panel types with both nails and staples over the entire moisture cycle was approximately 25%.
2. Staples provided higher average strength values than did nails.
3. Plywood $\frac{3}{4}$ " thick provided the highest fastener holding capacity regardless of geographic location.
4. There is no significant correlation between fastener holding capacity and panel specific gravity for plywood panels while a positive correlation may exist between fastener holding capacity and panel specific gravity for OSB.

5. Strength values for O3, P3, and P5 declined by an average of 30% over a ten-year period.
6. OSB proved to be more homogeneous than plywood based on mean horizontal density distribution values.
7. Shrinkage and swelling coefficients were higher in OSB than in plywood indicating that OSB tended to shrink and swell to a greater degree than did plywood.
8. The fastener holding capacity for standard nail withdrawal tests, for all panels, declined by an average of 77%.
9. Coupon $f_{\max}$ values were similar for both standard nail withdrawal and flooring fastener withdrawal; standard nail withdrawal values declined at a much faster rate than did flooring fastener withdrawal values.

Recommendations

In order to increase the knowledge in the area of composite panel products, flooring fastener withdrawal strength, and the effect of moisture cycling on hardwood flooring systems, several recommendations for further research may be made. These include:

- Continuing the simulated moisture cycle through one to several more phases in order to determine whether or not the current trend in fastener holding strength loss continues;
- Further investigating the relationship between fastener holding capacity and panel density;
- Increasing the number of replications to at least two for each panel/sub-floor combination;
- Performing fastener withdrawal tests utilizing 2" long nails and 2" long staples with all types of panels.

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Appendices

Appendix I. Results of One-Way ANOVA for flooring fastener withdrawal and standard nail withdrawal.

One Way Analysis of Variance

Thursday, March 15, 2001, 17:34:29

Data source: EO3N

Normality Test: Passed (P = 0.420)

Equal Variance Test: Passed (P = 0.698)

Group	N	Missing
Coupon EO3N	29	0
10% MC	24	0
2nd 6% MC	25	0
12% MC	25	0
3rd 6% MC	25	0

Group	Mean	Std Dev	SEM
Coupon EO3N	76.924	14.270	2.650
10% MC	77.833	17.756	3.624
2nd 6% MC	68.200	13.481	2.696
12% MC	68.400	15.740	3.148
3rd 6% MC	65.440	17.614	3.523

Power of performed test with alpha = 0.050: 0.642

The power of the performed test (0.642) is below the desired power of 0.800. You should interpret the negative findings cautiously.

Source of Variation	DF	SS	MS	F	P
Between Treatments	4	3246.436	811.609	3.251	0.014
Residual	12330	707.206	249.652		
Total	12733	953.642			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.014).

Multiple Comparisons versus Control Group (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q'	P<0.05
Coupon EO3N vs. 10% MC	0.909	5.000	0.295	No
Coupon EO3N vs. 12% MC	-8.524	5.000	2.796	No
Coupon EO3N vs. 2nd 6% MC	-8.724	5.000	2.861	No
Coupon EO3N vs. 3rd 6% MC	-11.484	5.000	3.766	No

Appendix I. (Cont.)

One Way Analysis of Variance

Thursday, March 15, 2001, 17:39:22

Data source: EO3S

Normality Test: Failed (P = 0.012)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Thursday, March 15, 2001, 17:39:23

Data source: EO3S

Group N Missing

Coupon EO3S	34	0
10% MC	25	0
2nd 6% MC	25	0
12% MC	25	0
3rd 6% MC	25	0

Group	Median	25%	75%
Coupon EO3S	121.000	113.800	135.400
10% MC	118.000	104.000	126.000
2nd 6% MC	99.000	81.750	111.750
12% MC	94.000	72.500	110.000
3rd 6% MC	99.000	77.750	111.000

H = 34.439 with 4 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

Multiple Comparisons versus Control Group (Dunn's Method) :

Comparison	Diff of Ranksp	Q	P<0.05
12% MC vs Coupon EO3S	46.502 5	4.546	Yes
3rd 6% MC vs Coupon EO3S	44.102 4	4.312	Yes
2nd 6% MC vs Coupon EO3S	39.062 3	3.819	Yes
10% MC vs Coupon EO3S	10.562 2	1.033	No

Appendix I. (Cont.)

One Way Analysis of Variance

Thursday, March 15, 2001, 17:45:11

Data source: EP3N

Normality Test: Passed (P = 0.659)

Equal Variance Test: Passed (P = 0.658)

Group	N	Missing
CouponEP3N	34	0
10% MC	25	0
2nd 6% MC	25	0
12% MC	25	0
3rd 6% MC	25	0

Group	Mean	Std Dev	SEM
CouponEP3N	92.118	14.878	2.552
10% MC	110.880	17.634	3.527
2nd 6% MC	87.880	11.865	2.373
12% MC	84.800	15.232	3.046
3rd 6% MC	92.840	15.866	3.173

Power of performed test with alpha = 0.050: 1.000

Source of Variation	DF	SS	MS	F	P
Between Treatments	4	10308.069	2577.017	11.172	<0.001
Residual	129	29755.449	230.662		
Total	134	40063.519			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Multiple Comparisons versus Control Group (Dunnett's Method) :

Comparisons for factor:

Comparison	Diff of Means	p	q'	P<0.05
CouponEP3N vs. 10% MC	18.762	5.000	4.689	Yes
CouponEP3N vs. 3rd 6% MC	0.722	4.000	0.181	No
CouponEP3N vs. 2nd 6% MC	-4.238	3.000	1.059	No
CouponEP3N vs. 12% MC	-7.318	2.000	1.829	No

Appendix I. (Cont.)

t-test

Thursday, March 15, 2001, 17:47:32

Normality Test: Passed (P = 0.277)

Equal Variance Test: Passed (P = 0.200)

Group	N	Missing
CouponEP3N2	35	0
3rd 6% MC	25	0

Group	Mean	Std Dev	SEM
CouponEP3N2	97.354	14.987	2.533
3rd 6% MC	91.680	20.081	4.016

Difference 5.674

t = 1.254 with 58 degrees of freedom. (P = 0.215)

95 percent confidence interval for difference of means: -3.382 to 14.731

The difference in the mean values of the two groups is not great enough to reject the possibility that the difference is due to random sampling variability. There is not a statistically significant difference between the input groups (P = 0.215).

Power of performed test with alpha = 0.050: 0.108

The power of the performed test (0.108) is below the desired power of 0.800. You should interpret the negative findings cautiously.

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 10:32:27

Data source: EP3S

Normality Test: Passed (P = 0.810)

Equal Variance Test: Failed (P = 0.010)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, March 16, 2001, 10:32:27

Data source: EP3S

Group	N	Missing
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CouponEP3S	34	0
10% MC	25	0
2nd 6% MC	25	0
12% MC	25	0
3rd 6% MC	25	0

Group	Median	25%	75%
CouponEP3S	117.400	107.600	127.200
10% MC	121.000	105.250	130.000
2nd 6% MC	91.700	75.650	107.575
12% MC	87.000	76.500	96.750
3rd 6% MC	68.000	45.250	91.250

H = 73.427 with 4 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

Multiple Comparisons versus Control Group (Dunn's Method) :

Comparison	Diff of Ranks	p	Q	P<0.05
3rd 6% MC vs CouponEP3S	70.560	5	6.898	Yes
12% MC vs CouponEP3S	51.140	4	5.000	Yes
2nd 6% MC vs CouponEP3S	46.380	3	4.534	Yes
10% MC vs CouponEP3S	0.760	2	0.0743	No

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 10:35:21

Data source: EP5N

Normality Test: Passed (P = 0.599)

Equal Variance Test: Passed (P = 0.863)

Group	N	Missing
CouponEP5N	29	0
10% MC	25	0
2nd 6% MC	25	0
12% MC	25	0
3rd 6% MC	25	0

Group	Mean	Std Dev	SEM
CouponEP5N	74.317	22.094	4.103
10% MC	84.720	17.482	3.496
2nd 6% MC	62.560	16.472	3.294
12% MC	75.200	21.637	4.327
3rd 6% MC	60.480	21.243	4.249

Power of performed test with alpha = 0.050: 0.973

Source of Variation	DF	SS	MS	F	P
Between Treatments	4	9975.477	2493.869	6.237	<0.001
Residual	124	49581.561	399.851		
Total	128	59557.038			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Multiple Comparisons versus Control Group (Dunnett's Method) :

Comparisons for factor:

Comparison	Diff of Means	p	q'	P<0.05
CouponEP5N vs. 10% MC	10.403	5.000	1.906	No
CouponEP5N vs. 12% MC	0.883	4.000	0.162	No
CouponEP5N vs. 2nd 6% MC	-11.757	3.000	2.154	No
CouponEP5N vs. 3rd 6% MC	-13.837	2.000	2.536	Yes

Appendix I. (Cont.)

t-test

Data Source: EP5N2f

Friday, March 16, 2001, 10:37:26

Normality Test: Passed (P = 0.154)

Equal Variance Test: Passed (P = 0.945)

Group	N	Missing
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CoupEP5N2f	29	0
------------	----	---

3rd 6% MC	25	0
-----------	----	---

Group	Mean	Std Dev	SEM
-------	------	---------	-----

CoupEP5N2f	74.317	22.094	4.103
------------	--------	--------	-------

3rd 6% MC	105.960	17.451	3.490
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Difference -31.643

t = -5.773 with 52 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: -42.642 to -20.643

The difference in the mean values of the two groups is greater than would be expected by chance; there is a statistically significant difference between the input groups (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 10:40:02

Data source: EP5S

Normality Test: Passed (P = 0.402)

Equal Variance Test: Passed (P = 0.688)

Group	N	Missing
CouponEP5S	34	0
10% MC	26	0
2nd 6% MC	25	0
12 % MC	25	0
3rd 6% MC	25	0

Group	Mean	Std Dev	SEM
CouponEP5S	100.588	14.126	2.423
10% MC	101.385	19.661	3.856
2nd 6% MC	95.320	12.449	2.490
12 % MC	92.524	16.004	3.201
3rd 6% MC	77.960	15.140	3.028

Power of performed test with alpha = 0.050: 1.000

Source of Variation	DF	SS	MS	F	P
Between Treatments	4	9422.763	2355.691	9.686	<0.001
Residual	130	31616.075	243.201		
Total	134	41038.837			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Multiple Comparisons versus Control Group (Dunnett's Method) :

Comparisons for factor:

Comparison	Diff of Means	p	q'	P<0.05
CouponEP5S vs. 10% MC	0.796	5.000	0.196	No
CouponEP5S vs. 2nd 6% MC	-5.268	4.000	1.282	No
CouponEP5S vs. 12 % MC	-8.064	3.000	1.963	No
CouponEP5S vs. 3rd 6% MC	-22.628	2.000	5.507	Yes

Appendix I. (Cont.)

t-test

Data Source: EP5Sf

Friday, March 16, 2001, 10:41:50

Normality Test: Passed (P = 0.228)

Equal Variance Test: Passed (P = 0.110)

Group	N	Missing
-------	---	---------

CoupEP5Sf	34	0
-----------	----	---

3rd 6% MC	25	0
-----------	----	---

Group	Mean	Std Dev	SEM
CoupEP5Sf	100.588	14.126	2.423
3rd 6% MC	79.880	16.969	3.394

Difference 20.708

t = 5.108 with 57 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: 12.590 to 28.826

The difference in the mean values of the two groups is greater than would be expected by chance; there is a statistically significant difference between the input groups (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 11:21:34

Data source: Standard Nail Coupon (All Pairwise Comparisons)

Normality Test: Passed (P = 0.326)

Equal Variance Test: Passed (P = 0.307)

Group	N	Missing
Coupon EO3 10	0	
Coupon EP3 10	0	
Coupon EP5 10	0	
Coupon WO3 10	0	
Coupon WP3 10	0	
Coupon WP5 10	0	

Group	Mean	Std Dev	SEM
Coupon EO381.100	15.521	4.908	
Coupon EP376.300	15.702	4.965	
Coupon EP538.230	11.245	3.556	
Coupon WO349.540	12.841	4.061	
Coupon WP356.560	19.535	6.178	
Coupon WP541.100	17.296	5.470	

Power of performed test with alpha = 0.050: 1.000

Source of Variation	DF	SS	MS	F	P
Between Treatments	516	141.533	3228.307	13.271	<0.001
Residual	5413	135.969	243.259		
Total	5929	277.502			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P<0.05
Coupon EO3 vs. Coupon EP5	42.870	6	8.692	Yes
Coupon EO3 vs. Coupon WP5	40.000	6	8.110	Yes
Coupon EO3 vs. Coupon WO3	31.560	6	6.399	Yes
Coupon EO3 vs. Coupon WP3	24.540	6	4.976	Yes
Coupon EO3 vs. Coupon EP3	4.800	6	0.973	No
Coupon EP3 vs. Coupon EP5	38.070	6	7.719	Yes
Coupon EP3 vs. Coupon WP5	35.200	6	7.137	Yes
Coupon EP3 vs. Coupon WO3	26.760	6	5.426	Yes
Coupon EP3 vs. Coupon WP3	19.740	6	4.002	No
Coupon WP3 vs. Coupon EP5	18.330	6	3.716	No
Coupon WP3 vs. Coupon WP5	15.460	6	3.135	No
Coupon WP3 vs. Coupon WO3	7.020	6	1.423	No
Coupon WO3 vs. Coupon EP5	11.310	6	2.293	No
Coupon WO3 vs. Coupon WP5	8.440	6	1.711	No
Coupon WP5 vs. Coupon EP5	2.870	6	0.582	No

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 11:06:07

Data source: Standard Nail EO3

Normality Test: Passed (P = 0.632)

Equal Variance Test: Passed (P = 0.442)

Group	N	Missing
Coupon EO3	10	0
10% MC	10	0
2nd 6% MC	10	0
12% MC	10	0
3rd 6% MC	10	0

Group	Mean	Std Dev	SEM
Coupon EO3	381.100	15.521	4.908
10% MC	54.980	15.000	4.743
2nd 6% MC	26.980	16.665	5.270
12% MC	58.770	18.414	5.823
3rd 6% MC	15.010	6.896	2.181

Power of performed test with alpha = 0.050: 1.000

Source of Variation	DF	SS	MS	F	P
Between Treatments	4	27885.067	6971.267	30.840	<0.001
Residual	45	10172.222	226.049		
Total	49	38057.289			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Multiple Comparisons versus Control Group (Dunnett's Method) :

Comparisons for factor:

Comparison	Diff of Means	sp	q'	P<0.05
Coupon EO3 vs. 12% MC	-22.330	5.000	3.321	Yes
Coupon EO3 vs. 10% MC	-26.120	4.000	3.885	Yes
Coupon EO3 vs. 2nd 6% MC	-54.120	3.000	8.049	Yes
Coupon EO3 vs. 3rd 6% MC	-66.090	2.000	9.829	Yes

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 11:08:36

Data source: Standard Nail EP3

Normality Test: Passed (P = 0.229)

Equal Variance Test: Passed (P = 0.052)

Group	N	Missing
Coupon EP3	10	0
10% MC	10	0
2nd 6% MC	10	0
12% MC	10	0
3rd 6% MC	10	0

Group	Mean	Std Dev	SEM
Coupon EP3	76.300	15.702	4.965
10% MC	66.540	9.620	3.042
2nd 6% MC	21.010	4.435	1.402
12% MC	73.160	17.928	5.669
3rd 6% MC	20.230	13.256	4.192

Power of performed test with alpha = 0.050: 1.000

Source of Variation	DF	SS	MS	F	P
Between Treatments	4	32178.367	8044.592	46.996	<0.001
Residual	45	7702.858	171.175		
Total	49	39881.225			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Multiple Comparisons versus Control Group (Dunnett's Method) :

Comparisons for factor:

Comparison	Diff of Means	p	q'	P<0.05
Coupon EP3 vs. 12% MC	-3.140	5.000	0.537	No
Coupon EP3 vs. 10% MC	-9.760	4.000	1.668	No
Coupon EP3 vs. 2nd 6% MC	-55.290	3.000	9.450	Yes
Coupon EP3 vs. 3rd 6% MC	-56.070	2.000	9.583	Yes

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 11:11:28

Data source: Standard Nail EP5

Normality Test: Passed (P = 0.107)

Equal Variance Test: Failed (P = 0.028)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, March 16, 2001, 11:11:28

Data source: Data 1 in Notebook

Group	N	Missing
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Coupon EP5	10	0
10% MC	10	0
2nd 6% MC	9	0
12% MC	10	0
3rd 6% MC	10	0

Group	Median	25%	75%
Coupon EP5	34.100	30.800	43.300
10% MC	37.800	27.000	47.600
2nd 6% MC	14.500	10.300	21.100
12% MC	56.250	45.900	67.000
3rd 6% MC	9.700	6.100	12.100

H = 35.477 with 4 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

Multiple Comparisons versus Control Group (Dunn's Method) :

Comparison	Diff of Ranks	p	Q	P<0.05
3rd 6% MC vs Coupon EP5	23.500	5	3.678	Yes
2nd 6% MC vs Coupon EP5	16.678	4	2.541	Yes
12% MC vs Coupon EP5	9.600	3	1.502	No
10% MC vs Coupon EP5	1.421E-015	2		2.224E-016 No
Test Needed				

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 11:25:39

Data source: Standard Nail Phase VII (All Pairwise Comparisons)

Normality Test: Failed (P = 0.003)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, March 16, 2001, 11:25:39

Data source: Standard Nail Phase VII

Group	N	Missing
EO3	10	0
EP3	10	0
EP5	10	0
WO3	10	0
WP3	10	0
WP5	10	0

Group	Median	25%	75%
EO3	13.050	9.500	19.600
EP3	15.150	12.800	18.900
EP5	9.700	6.100	12.100
WO3	7.800	5.100	10.800
WP3	10.550	6.200	14.700
WP5	10.850	5.100	15.100

H = 13.154 with 5 degrees of freedom. (P = 0.022)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.022)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Student-Newman-Keuls Method) :

Comparison	Diff of Ranksp	q	P<0.05
EP3 vs WO3	241.500 6	4.373	Yes
EP3 vs EP5	201.500 5	4.371	Yes
EP3 vs WP3	173.500 4	4.693	Yes
EP3 vs WP5	162.000 3	5.819	Yes
EP3 vs EO3	70.500 2	3.768	Yes
EO3 vs WO3	171.000 5	3.710	No
EO3 vs EP5	131.000 4	3.544	No Test Needed
EO3 vs WP3	103.000 3	3.700	No Test Needed
EO3 vs WP5	91.500 2	4.891	No Test Needed
WP5 vs WO3	79.500 4	2.150	No Test Needed
WP5 vs EP5	39.500 3	1.419	No Test Needed
WP5 vs WP3	11.500 2	0.615	No Test Needed
WP3 vs WO3	68.000 3	2.443	No Test Needed
WP3 vs EP5	28.000 2	1.497	No Test Needed
EP5 vs WO3	40.000 2	2.138	No Test Needed

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 11:13:59

Data source: Standard Nail WO3

Normality Test: Passed (P = 0.234)

Equal Variance Test: Failed (P = 0.024)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, March 16, 2001, 11:13:59

Data source: Standard Nail WO3

Group	N	Missing
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Coupon WO3	10	0
10% MC	10	0
2nd 6% MC	10	0
12% MC	10	0
3rd 6% MC	10	0

Group	Median	25%	75%
Coupon WO3	48.800	37.400	56.000
10% MC	29.000	27.400	35.200
2nd 6% MC	13.050	11.100	21.900
12% MC	31.350	18.500	39.200
3rd 6% MC	7.800	5.100	10.800

H = 37.974 with 4 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunnnett's Method) :

Comparison	Diff of Ranksp	q'	P<0.05
3rd 6% MC vs Coupon WO3	355.000 5	5.445	Yes
2nd 6% MC vs Coupon WO3	288.500 4	5.518	Yes
10% MC vs Coupon WO3	126.000 3	3.200	Yes
12% MC vs Coupon WO3	125.500 2	4.743	Yes

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 11:16:03

Data source: Standard Nail WP3

Normality Test: Passed (P = 0.226)

Equal Variance Test: Failed (P = 0.037)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, March 16, 2001, 11:16:03

Data source: Standard Nail WP3

Group	N	Missing
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Coupon WP3	10	0
10% MC	10	0
2nd 6% MC	10	0
12% MC	10	0
3rd 6% MC	10	0

Group	Median	25%	75%
Coupon WP3	55.000	41.200	72.200
10% MC	58.400	43.600	70.000
2nd 6% MC	13.650	12.000	18.100
12% MC	53.400	43.800	76.700
3rd 6% MC	10.550	6.200	14.700

H = 34.913 with 4 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunnett's Method) :

Comparison	Diff of Ranks	p	q'	P<0.05
3rd 6% MC vs Coupon WP3	262.000	5	4.019	Yes
2nd 6% MC vs Coupon WP3	216.000	4	4.131	Yes
12% MC vs Coupon WP3	15.000	3	0.381	No
10% MC vs Coupon WP3	8.000	2	0.302	No Test Needed

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 11:18:19

Data source: Standard Nail WP5

Normality Test: Passed (P = 0.312)

Equal Variance Test: Failed (P = <0.001)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, March 16, 2001, 11:18:19

Data source: Standard Nail WP5

Group	N	Missing
Coupon WP5	10	0
10% MC	10	0
2nd 6% MC	10	0
12% MC	10	0
3rd 6% MC	10	0

Group	Median	25%	75%
Coupon WP5	35.000	27.000	59.800
10% MC	43.500	39.800	54.000
2nd 6% MC	14.850	12.000	18.800
12% MC	51.550	44.400	60.600
3rd 6% MC	10.850	5.100	15.100

H = 34.729 with 4 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunnett's Method) :

Comparison	Diff of Ranksp	q'	P<0.05
3rd 6% MC vs Coupon WP5	227.500 5	3.490	Yes
2nd 6% MC vs Coupon WP5	193.500 4	3.701	Yes
12% MC vs Coupon WP5	71.500 3	1.816	No
10% MC vs Coupon WP5	24.500 2	0.926	No Test Needed

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 10:45:06

Data source: WO3N

Normality Test: Passed (P = 0.133)

Equal Variance Test: Passed (P = 0.837)

Group	N	Missing
CouponWO3N	31	0
10% MC	25	0
2nd 6% MC	25	0
12% MC	25	0
3rd 6% MC	25	0

Group	Mean	Std Dev	SEM
CouponWO3N	58.542	12.985	2.332
10% MC	51.600	11.427	2.285
2nd 6% MC	61.040	13.572	2.714
12% MC	46.360	14.347	2.869
3rd 6% MC	36.880	12.514	2.503

Power of performed test with alpha = 0.050: 1.000

Source of Variation	DF	SS	MS	F	P
Between Treatments	4	9807.703	2451.926	14.496	<0.001
Residual	126	21311.695	169.140		
Total	130	31119.398			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Multiple Comparisons versus Control Group (Dunnett's Method) :

Comparisons for factor:

Comparison	Diff of Means	p	q'	P<0.05
CouponWO3N vs. 2nd 6% MC	2.498	5.000	0.715	No
CouponWO3N vs. 10% MC	-6.942	4.000	1.986	No
CouponWO3N vs. 12% MC	-12.182	3.000	3.485	Yes
CouponWO3N vs. 3rd 6% MC	-21.662	2.000	6.196	Yes

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 10:47:12

Data source: WO3S

Normality Test: Passed (P = 0.362)

Equal Variance Test: Passed (P = 0.124)

Group	N	Missing
CouponWO3S	33	0
10% MC	25	0
2nd 6% MC	25	0
12% MC	25	0
3rd 6% MC	25	0

Group	Mean	Std Dev	SEM
CouponWO3S	87.279	19.904	3.465
10% MC	98.680	21.786	4.357
2nd 6% MC	82.080	24.737	4.947
12% MC	67.840	27.274	5.455
3rd 6% MC	63.360	28.595	5.719

Power of performed test with alpha = 0.050: 0.999

Source of Variation	DF	SS	MS	F	P
Between Treatments	421	187.411	5296.853	8.894	<0.001
Residual	12876	232.315	595.565		
Total	13297	419.726			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Multiple Comparisons versus Control Group (Dunnett's Method) :

Comparisons for factor:

Comparison	Diff of Means	p	q'	P<0.05
CouponWO3S vs. 10% MC	11.401	5.000	1.762	No
CouponWO3S vs. 2nd 6% MC	-5.199	4.000	0.803	No
CouponWO3S vs. 12% MC	-19.439	3.000	3.004	Yes
CouponWO3S vs. 3rd 6% MC	-23.919	2.000	3.696	Yes

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 10:49:05

Data source: WP3N

Normality Test: Passed (P = 0.579)

Equal Variance Test: Passed (P = 0.404)

Group	N	Missing
CouponWP3N	35	0
10% MC	25	0
2nd 6% MC	25	0
12% MC	25	0
3rd 6% MC	25	0

Group	Mean	Std Dev	SEM
CouponWP3N	95.166	16.908	2.858
10% MC	104.800	21.545	4.309
2nd 6% MC	71.200	15.825	3.165
12% MC	82.200	17.088	3.418
3rd 6% MC	69.720	20.229	4.046

Power of performed test with alpha = 0.050: 1.000

Source of Variation	DF	SS	MS	F	P
Between Treatments	4	24190.481	6047.620	17.991	<0.001
Residual	130	43698.919	336.146		
Total	134	67889.400			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Multiple Comparisons versus Control Group (Dunnett's Method) :

Comparisons for factor:

Comparison	Diff of Means	p	q'	P<0.05
CouponWP3N vs. 10% MC	9.634	5.000	2.007	No
CouponWP3N vs. 12% MC	-12.966	4.000	2.701	Yes
CouponWP3N vs. 2nd 6% MC	-23.966	3.000	4.992	Yes
CouponWP3N vs. 3rd 6% MC	-25.446	2.000	5.300	Yes

Appendix I. (Cont.)

t-test

Friday, March 16, 2001, 10:51:21

Data Source: WP3N2

Normality Test: Passed (P = 0.210)

Equal Variance Test: Passed (P = 0.838)

Group N Missing

CouponWP3N2 35 0

3rd 6% MC 25 0

Group Mean Std Dev SEM

CouponWP3N2 101.314 21.503 3.635

3rd 6% MC 103.800 21.040 4.208

Difference -2.486

t = -0.445 with 58 degrees of freedom. (P = 0.658)

95 percent confidence interval for difference of means: -13.657 to 8.686

The difference in the mean values of the two groups is not great enough to reject the possibility that the difference is due to random sampling variability. There is not a statistically significant difference between the input groups (P = 0.658).

Power of performed test with alpha = 0.050: 0.050

The power of the performed test (0.050) is below the desired power of 0.800. You should interpret the negative findings cautiously.

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 10:54:02

Data source: WP3S

Normality Test: Passed (P = 0.413)

Equal Variance Test: Failed (P = 0.033)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, March 16, 2001, 10:54:02

Data source: WP3S

Group N Missing

CouponWP3S 35 0

10% MC 25 0

2nd 6% MC 25 0

12% MC 25 0

3rd 6% MC 26 0

Group Median 25% 75%

CouponWP3S 125.000 115.150 134.950

10% MC 111.000 99.500 117.250

2nd 6% MC 115.000 112.500 131.000

12% MC 92.000 71.000 110.500

3rd 6% MC 100.500 97.000 118.000

H = 42.998 with 4 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

Multiple Comparisons versus Control Group (Dunn's Method) :

Comparison	Diff of Ranksp	Q	P<0.05
12% MC vs CouponWP3S	61.709 5	5.981	Yes
3rd 6% MC vs CouponWP3S	40.340 4	3.955	Yes
10% MC vs CouponWP3S	32.169 3	3.118	Yes
2nd 6% MC vs CouponWP3S	11.749 2	1.139	No

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 10:56:29

Data source: WP5N

Normality Test: Passed (P = 0.720)

Equal Variance Test: Passed (P = 0.117)

Group	N	Missing
CouponWP5N	31	0
10% MC	25	0
2nd 6% MC	25	0
12% MC	25	0
3rd 6% MC	25	0

Group	Mean	Std Dev	SEM
CouponWP5N	62.645	13.026	2.340
10% MC	56.680	13.723	2.745
2nd 6% MC	63.360	19.350	3.870
12% MC	77.280	19.930	3.986
3rd 6% MC	41.880	15.878	3.176

Power of performed test with alpha = 0.050: 1.000

Source of Variation	DF	SS	MS	F	P
Between Treatments	4	16418.680	4104.670	15.132	<0.001
Residual	126	34179.257	271.264		
Total	130	50597.936			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Multiple Comparisons versus Control Group (Dunnett's Method) :

Comparisons for factor:

Comparison	Diff of Means	p	q'	P<0.05
CouponWP5N vs. 12% MC	14.635	5.000	3.306	Yes
CouponWP5N vs. 2nd 6% MC	0.715	4.000	0.161	No
CouponWP5N vs. 10% MC	-5.965	3.000	1.347	No
CouponWP5N vs. 3rd 6% MC	-20.765	2.000	4.690	Yes

Appendix I. (Cont.)

t-test

Friday, March 16, 2001, 10:58:10

Data Source: WP5N2f

Normality Test: Passed (P = 0.151)

Equal Variance Test: Passed (P = 0.327)

Group	N	Missing
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CoupWP5N2f	31	0
------------	----	---

3rd 6% MC	25	0
-----------	----	---

Group	Mean	Std Dev	SEM
-------	------	---------	-----

CoupWP5N2f	62.645	13.026	2.340
------------	--------	--------	-------

3rd 6% MC	86.600	18.742	3.748
-----------	--------	--------	-------

Difference -23.955

t = -5.632 with 54 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: -32.482 to -15.427

The difference in the mean values of the two groups is greater than would be expected by chance; there is a statistically significant difference between the input groups (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

Appendix I. (Cont.)

One Way Analysis of Variance

Friday, March 16, 2001, 11:00:40

Data source: WP5S

Normality Test: Passed (P = 0.272)

Equal Variance Test: Passed (P = 0.475)

Group	N	Missing
CouponWP5S	31	0
10% MC	25	0
2nd 6% MC	25	0
12% MC	25	0
3rd 6% MC	25	0

Group	Mean	Std Dev	SEM
CouponWP5S	100.245	14.134	2.538
10% MC	104.400	20.112	4.022
2nd 6% MC	79.096	17.261	3.452
12% MC	84.320	17.651	3.530
3rd 6% MC	65.520	14.474	2.895

Power of performed test with alpha = 0.050: 1.000

Source of Variation	DF	SS	MS	F	P
Between Treatments	4	268.835	6567.209	23.403	<0.001
Residual	126	357.186	280.613		
Total	130	626.021			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Multiple Comparisons versus Control Group (Dunnett's Method) :

Comparisons for factor:

Comparison	Diff of Means	p	q'	P<0.05
CouponWP5S vs. 10% MC	4.155	5.000	0.923	No
CouponWP5S vs. 12% MC	-15.925	4.000	3.537	Yes
CouponWP5S vs. 2nd 6% MC	-21.149	3.000	4.697	Yes
CouponWP5S vs. 3rd 6% MC	-34.725	2.000	7.712	Yes

Appendix I. (Cont.)

t-test

Friday, March 16, 2001, 11:02:26

Data source: WP5Sf

Normality Test: Failed (P = 0.004)

Test execution ended by user request, Rank Sum Test begun

Mann-Whitney Rank Sum Test

Friday, March 16, 2001, 11:02:26

Data source: WP5Sf

Group N Missing

CoupWP5Sf 31 0

3rd 6% MC 25 0

Group	Median	25%	75%
CoupWP5Sf	98.800	90.100	108.050
3rd 6% MC	100.000	95.750	115.000

T = 797.500 n(small)= 25 n(big)= 31 (P = 0.164)

The differences in the median values among the two groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.164)

Appendix II. SAS output for the General Linear Model Procedure and Means Procedure for fastener withdrawal tests.

```

                                The GLM Procedure

                                Class Level Information

Class          Levels      Values
Cycle          5      coupon phaseIV phaseV phaseVI phaseVII
Type           6      EO3 EP3 EP5 WO3 WP3 WP5
Fast           2      N S

                                Number of observations      1591
```

Appendix II. (Cont.)

The GLM Procedure

Dependent Variable: Value

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	59	688375.718	11667.385	34.44	<.0001
Error	1531	518603.701	338.735		
Corrected Total	1590	1206979.419			

R-Square	Coeff Var	Root MSE	Value Mean
0.570329	21.82486	18.40476	84.32935

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cycle	4	138526.8749	34631.7187	102.24	<.0001
Type	5	207599.8559	41519.9712	122.57	<.0001
Fast	1	216480.8268	216480.8268	639.09	<.0001
Cycle*Type	20	30218.3607	1510.9180	4.46	<.0001
Cycle*Fast	4	18542.4184	4635.6046	13.69	<.0001
Type*Fast	5	33430.4978	6686.0996	19.74	<.0001
Cycle*Type*Fast	20	43576.8839	2178.8442	6.43	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cycle	4	131959.1235	32989.7809	97.39	<.0001
Type	5	201025.9483	40205.1897	118.69	<.0001
Fast	1	205504.6572	205504.6572	606.68	<.0001
Cycle*Type	20	29963.9057	1498.1953	4.42	<.0001
Cycle*Fast	4	18855.2688	4713.8172	13.92	<.0001
Type*Fast	5	35687.0400	7137.4080	21.07	<.0001
Cycle*Type*Fast	20	43576.8839	2178.8442	6.43	<.0001

Appendix II. (Cont.)

The GLM Procedure

Level of Cycle	N	-----Value-----	
		Mean	Std Dev
coupon	390	93.8307692	26.7110999
phaseIV	300	94.5333333	27.8199338
phaseV	300	81.4433333	24.1564048
phaseVI	300	78.9200000	23.0652760
phaseVII	301	70.1162791	27.4439386

Level of Type	N	-----Value-----	
		Mean	Std Dev
EO3	262	88.3396947	28.0675681
EP3	268	95.7388060	22.9526231
EP5	264	83.0643939	22.5658231
WO3	264	66.0000000	26.5130716
WP3	271	98.3357934	25.2720342
WP5	262	73.9045802	24.7290772

Level of Fast	N	-----Value-----	
		Mean	Std Dev
N	788	72.4847716	23.7467263
S	803	95.9526775	26.0477741

Level of Type	Level of Fast	N	-----Value-----	
			Mean	Std Dev
EO3	N	128	71.492188	16.3370002
EO3	S	134	104.432836	27.5136187
EP3	N	134	93.611940	17.3508295
EP3	S	134	97.865672	27.3393575
EP5	N	129	71.558140	21.5565778
EP5	S	135	94.059259	17.5017112
WO3	N	131	51.473282	15.8246780
WO3	S	133	80.308271	27.1703884
WP3	N	135	85.400000	22.5097657
WP3	S	136	111.176471	20.9994294
WP5	N	131	60.458015	19.7247441
WP5	S	131	87.351145	21.7782261

Appendix II. (Cont.)

The GLM Procedure

Dependent Variable: Value

Tests of Hypotheses Using the Type III MS for Cycle*Type*Fast as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Cycle	4	131959.1235	32989.7809	15.14	<.0001
Type	5	201025.9483	40205.1897	18.45	<.0001
Fast	1	205504.6572	205504.6572	94.32	<.0001
Cycle*Type	20	29963.9057	1498.1953	0.69	0.7952
Cycle*Fast	4	18855.2688	4713.8172	2.16	0.1103
Type*Fast	5	35687.0400	7137.4080	3.28	0.0254

Tests of Hypotheses Using the Type III MS for Cycle*Type*Fast as an Error Term

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
east vs west	1	35390.15861	35390.15861	16.24	0.0007
sboard vs pwood	1	40146.68924	40146.68924	18.43	0.0004
pwood 3 vs pwood 5	1	86916.93441	86916.93441	39.89	<.0001
e vs w x s vs p	1	29737.85402	29737.85402	13.65	0.0014
e vs w x p 3 vs p 5	1	8336.97088	8336.97088	3.83	0.0646
comparison 1 x fast	1	6317.38704	6317.38704	2.90	0.1041
comparison 2 x fast	1	10830.99106	10830.99106	4.97	0.0374
comparison 3 x fast	1	6767.45884	6767.45884	3.11	0.0933
comparison 4 x fast	1	6002.34276	6002.34276	2.75	0.1126
comparison 5 x fast	1	5620.86437	5620.86437	2.58	0.1239

Appendix II. (Cont.)

----- coast=E -----

The MEANS Procedure

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
794	89.0831234	25.1547171	17.0000000	168.0000000

----- coast=W -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
797	79.5934755	28.9988365	15.0000000	159.0000000

Steve Cook Fastener Data

09:05 Friday, February 9, 2001

----- wood=O -----

The MEANS Procedure

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
526	77.1273764	29.4751700	15.0000000	168.0000000

----- wood=P -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
1065	87.8863850	25.8340069	15.0000000	165.0000000

Appendix II. (Cont.)

----- thick=3 -----

The MEANS Procedure

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
539	97.0445269	24.1592044	31.0000000	159.0000000

----- thick=5 -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
526	78.5019011	24.0857792	15.0000000	165.0000000

Steve Cook Fastener Data

09:05 Friday, February 9, 2001

----- coast=E Fast=N -----

The MEANS Procedure

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
391	79.0946292	21.2664114	17.0000000	158.0000000

----- coast=E Fast=S -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
403	98.7741935	24.8647311	22.0000000	168.0000000

----- coast=W Fast=N -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
397	65.9748111	24.2829360	15.0000000	140.0000000

Appendix II. (Cont.)

----- coast=W Fast=S -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
400	93.1100000	26.9208047	15.0000000	159.0000000

Steve Cook Fastener Data

09:05 Friday, February 9, 2001

----- wood=O Fast=N -----

The MEANS Procedure

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
259	61.3667954	18.9241811	17.0000000	109.0000000

----- wood=O Fast=S -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
267	92.4157303	29.8476617	15.0000000	168.0000000

----- wood=P Fast=N -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
529	77.9281664	23.9834725	15.0000000	158.0000000

----- wood=P Fast=S -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
536	97.7145522	23.7654948	26.0000000	165.0000000

Appendix II. (Cont.)

----- thick=3 Fast=N -----

The MEANS Procedure

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
269	89.4907063	20.4858184	43.0000000	156.0000000

----- thick=3 Fast=S -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
270	104.5703704	25.2054873	31.0000000	159.0000000

----- thick=5 Fast=N -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
260	65.9653846	21.3507831	15.0000000	158.0000000

----- thick=5 Fast=S -----

Analysis Variable : Value

N	Mean	Std Dev	Minimum	Maximum
266	90.7556391	19.9712167	26.0000000	165.0000000