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Nail Withdrawal Behavior for Domestic Small Diameter Logs*[1]

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ABSTRACT

Nail withdrawal tests were conducted on clear wood of domestic small diameter logs. Nails were driven into the cross and longitudinal sections of each specimen, then nail withdrawal tests were performed. Nail withdrawal loads are strongly dependent on the direction of nail positions. The average load values for the nail withdrawal both in cross section and longitudinal section are higher in high specific gravity (SG) wood of sawtooth oak (*Quercus acutissima* Carr.) than those in low SG wood of Korean red pine (*Pinus densiflora* Sieb. et Zucc.) and pitch pine (*Pinus rigida* Mill.). The average ratio of the nail withdrawal loads for side-grain and end-grain are higher in the low SG wood than that in the high SG of wood. Both linear and non-linear regression analyses were conducted on nail withdrawal load with SG, good correlations were obtained between nail withdrawal load and SG.

Keywords: nail withdrawal load, domestic small diameter log and specific gravity

1. INTRODUCTION

Nails are the most common mechanical fasteners used in structural construction. For good performance, a nail must be able to resist a large force when the nail used in structural construction. Design loads have been specified according to the provision (NDS, 1991) that nails are located in visually clear, defect-free wood of an appreciate density. These requirements are not always met in practice, and joints may be made with low density wood. These problems are relevant in joist fabrications where nails are used with fast-grown plantation wood. There is a need to determine possible changes in load capacity of nail joints where nails are used with low density wood. The density of wood generally increases markedly with distance from the pith at first. The low density wood near the pith is often of somewhat difference in appearance and anatomical structure than the wood formed later. Short cells and thin cell walls of wood formed in the early stage of a tree growth are low in density of wood and the corresponding low physical/mechanical properties in comparison to wood formed later.

Nails in use resist either withdrawal loads or lateral loads, or combination of two. Both nail withdrawal and lateral resistance are affected by the wood, nail and its condition of use. Proper-

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ties of fast-grown plantation wood also gives a distinctly different appearance to that of slow-growing wood. Many sources (FPL, 1987: Cha, 1998) provide empirical formulas and tables for finding the maximum nail withdrawal load. However, none of these gives maximum withdrawal load for fast-grown domestic plantation wood. Domestic wood such as Korean red pine (*Pinus densiflora* Sieb. et Zucc.), pitch pine (*Pinus rigida* Mill.), etc. was planted for last 30 years and some may be thinned in Korea. Because these planted resources tend to have a different wood quality characteristics than natural wood. Thus a knowledge of properties for domestic fast-grown plantation wood is essential. This information is also necessary to ascertain the suitability of wood from natural stands for a variety of potential use. Therefore, main objective of this study is to determine the nail withdrawal loads by nail orientation on radial/tangential surface and both ends. In addition, this study investigated the influence of SG on nail withdrawal loads.

2. MATERIALS and TEST METHODS

The test specimens for Korean red pine, pitch pine and sawtooth oak (*Quercus acutissima* Carr.) were collected from sawmills in Kyung-gi province. All the test specimens were made from fast-grown domestic plantation wood by 50 mm by 50 mm by 100 mm, then were randomly selected. Care was taken any material that had knots or other defects were discarded. All the specimens were conditioned at 21°C and 65% relative humidity chamber. The specimens were conditioned to a uniform MC of 11.9 (Korean red pine), 12.2 (pitch pine) and 12.8% (sawtooth oak), respectively. Table 1 shows that the densities of each species were 0.54 (Korean red pine), 0.55 (pitch pine) and 0.81 gr/cm^3 (sawtooth oak). The nails were 2.5 mm common with a length of 51 mm and were obtained from a local supply store. Table 1 also shows the shank diameter and length used for this study.

For each nail withdrawal test specimens, 6 nails were driven. Four nails were driven on the radial/tangential surface, and two on cross surface of specimen. Total 216 nail withdrawal tests were conducted. Since the nail driving method influences the joint characteristics and splitting, the 2.0 mm diameter holes were predrilled in the specimen using a table type drill. The nails were then manually driven by hammer into the predrilled hole perpendicular to the surface to a depth of 32 mm. Tests were conducted immediately after the nails were driven into the specimen. Specimen were attached to a specially designed frame (Fig. 1). The nail head was attached to a grip, which was connected to a test specimens. Testing was conducted

Table 1. Summary of test details.

Characteristics			Description
Nail	Diameter		2.60 mm (0.02 mm*)
	Length		51.56 mm (0.49 mm)
	Penetration		32.16 mm (0.56 mm)
Wood	Density (gr/cm^3)	*Pinus densiflora* Sieb. et Zucc.	0.54 (0.02)
		Pinus rigida Mill.	0.55 (0.03)
		Quercus acutissima Carr.	0.81 (0.02)

* Standard deviation

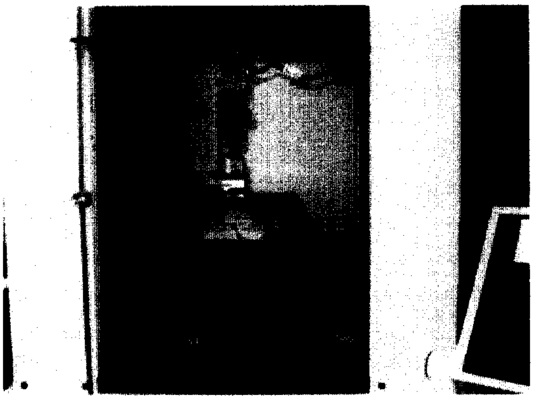

Fig. 1. Testing arrangement.

with Hounsfield universal testing machine. The testing machine was operated at a constant withdrawal rate by a crosshead movement of 2 mm/min.

After nail withdrawal test, a small piece of wood was cut from each specimen to determine moisture content (MC) and specific gravity (SG). In total, 36 specimens were prepared to measure MC and SG. SG and MC of each specimen were determined using standard test methods. Volume and weight were measured from each sample. The samples were dried at 104°C in drying oven until constant weight was reached.

3. RESULTS

The results from nail withdrawal test are summarized in Table 2. Table 2 shows the average MC and SG of the specimens.

Table 2 also shows the nail withdrawal loads by different nail driving positions. The loads represent the average values per cm. Since the nails in use are negligible to driving positions on longitudinal sections the loads on side grain was average values of radial and tangential section. Nail withdrawal loads are strongly dependent on the direction of nail position. There are also significantly different in nail withdrawal load among species. This indicates that heavy woods offer greater resistance in nail withdrawal loads than light weight ones. The average value of nail withdrawal load was 14.97 kgf/cm at side-grain and 8.64 kgf/cm at end-grain for Korean red pine. However, the average values of nail withdrawal load for pitch pine and sawtooth oak were 26.21 kgf/cm and 45.86 kgf/cm on side-grain and 15.31 and 29.82 kgf/cm on end-grain, respectively. Table 2 shows the load difference between side-grain (S) and end-grain (E). The difference between side-grain and end-grain is less for dense wood than softer wood. Nail withdrawal load of Korean red pine were significantly higher in S/E ratio than

Table 2. Summary of physical properties of testing specimen and nail withdrawal loads.

Characteristics		Physical properties		Nail withdrawal load (kgf/cm)		
		MC (%)	SG	Side-grain (S)	End-grain (E)	Ratio S/E
Pinus densiflora Sieb. et Zucc.	Average	11.9	0.48	14.97	8.64	1.73
	SD*	0.28	0.02	2.50	1.38	
Pinus rigida Mill.	Average	12.2	0.49	26.21	15.31	1.71
	SD	0.29	0.03	3.86	2.26	
Quercus acutissima Carr.	Average	12.8	0.71	45.86	29.82	1.54
	SD	0.65	0.02	4.06	3.75	

* Standard deviation

sawtooth oak. Nail withdrawal loads on side-grain is 1.73 and 1.71 times greater than those on end-grain for Korean red pine and pitch pine, while the ratio of nail withdrawal loads on longitudinal/cross section is 1.54 for sawtooth oak.

The Wood Handbook (FPL, 1987) shows an empirical equation for withdrawal load for bright, common wire nails driven into side grain of seasoned wood. Although the formula for nail withdrawal resistance indicates that nail withdrawal loads are affected by many factors, such as wood SG, diameter of nail, length of penetration. However, none of these gives maximum nail withdrawal loads for fast-grown domestic plantation wood. Therefore, in this study both linear and non-linear regression analyses were conducted between the nail withdrawal load and SG values for each species and combining all species. The correlations between nail withdrawal loads and SG were obtained from linear regression analysis, Y = A(SG) + B. The constants, A and B, and coefficients of determination are shown in Table 3. The correlations for each species between nail withdrawal load and SG were very weak. This was probably caused by narrow range of SG. When all the species are combined, the coefficients of determinant (R^2) at side-grain and end-grain was 0.87 and 0.83. The influence of SG for nail withdrawal load is also shown in Fig. 2, where a good trend between nail withdrawal load and SG was confirmed.

Table 3. Linear regression relationships between nail withdrawal load and SG.

Characteristics	Nail withdrawal load = A*SG+ B		R^2
	A	B	
End-grain	77.54	-25.50	0.87
Side-grain	109.15	-32.13	0.83

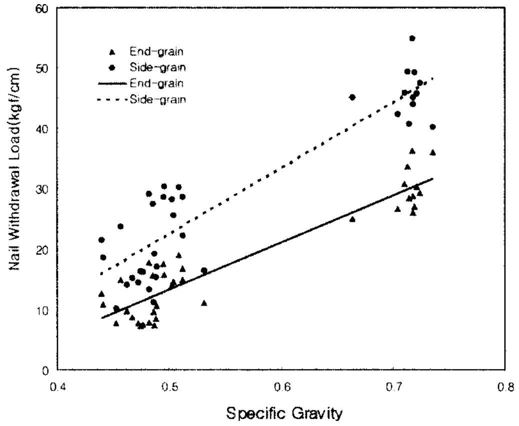

Fig. 2. The relations between nail withdrawal loads and SG.

Table 4. Nonlinear regression relationships between nail withdrawal load and SG.

Characteristics	Nail withdrawal load = $A*SG^B$		R^2
	A	B	
End-grain	68.09	2.46	0.78
Side-grain	95.84	2.18	0.73

To compare with Wood Handbook equation, the nonlinear regression analysis, $Y=A\ (SG^B)$, was conducted between nail withdrawal load and SG. The constants, A and B, and coefficients of determination are shown in Table 4. Comparing with the linear regression analysis, there are a little difference between the two type regression analyses. Regression coefficients at each species between nail withdrawal load for side- and end-grain, and SG also shows a poor relationship. When the species were combined, the correlations were 0.78 and 0.73, respectively. This result differ from Wood Handbook (FPL, 1987). The best fit was nonlinear analysis model at Wood Handbook. However, the coefficients of determination ($R^2 = 0.78$ and 0.73) indicated that approximately

78% and 73% respectively of the observed behavior can be explained by the non-linear regression model.

4. CONCLUSIONS

On the basis of investigations conducted on nail withdrawal test in Korean red pine, pitch pine and sawtooth oak the following conclusions are drawn:

1) As expected, high SG wood of sawtooth oak has greater nail withdrawal load than low SG wood of Korean red pine and pitch pine.

2) The average ratio of the nail withdrawal load values for side-grain and end-grain are higher in the low SG wood than that in the high SG wood.

3) Good correlations by linear and non-linear regression analyses are obtained between nail withdrawal load and SG. However, there is a little difference in correlations between non-linear and linear regression equations. Therefore, more study is required to ascertain the difference between nonlinear and linear regression equations.

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