Withdrawal Strength of Nail-Timber Joints for Kenyan Grown Cypress and Pines

Muisu[1] N. F., Muthike[2] G. M. and Githiomi[2] J. K.

[1]Department of Forestry and Wood Science, Chepkoilel Campus, Moi University
P. O. Box 1125 Eldoret, e-mail: muisuf@yahoo.com

[2] Forest Products Resource Centre, Kenya Forestry Research Institute, P.O. Box 64636-00620, Mobil Plaza, Nairobi, Email: muthikegm@yahoo.com

Abstract

Nailed joint specimens of general structural and special structural grade cypress and pine timber were constructed and tested to determine the withdrawal resistance in order to generate a database for basic withdrawal loads for nailed Kenyan grown cypress and pine timber joints for use in the development of design codes. Timber specimens were obtained from graded 150mm by 50mm timber while nails were purchased from local hardware dealers. Seventy two pairs of matched 50mm by 25mm by 300mm joint members were prepared from the timber then conditioned to an equilibrium moisture content of about 16 to 18 percent. The members were laid on flat surface and nails driven into them using a claw hammer in a direction perpendicular to grain. Each specimen was subjected to a withdrawal load and strength determined according to British Standards (BS 6948: 1989). The maximum load and mode of failure were recorded. Data analysis was done using General Linear Model tools in SPSS. Results show that wood species, grade, nail size and penetration have a significant effect on the nail withdrawal strength. The differences were probably due to variation in specific gravity of the wood species and increased fastener contact area with penetration. Selected structural grade wood and 15 cm nails yielded significantly higher strength for both pine and cypress. Nailed pine and cypress joint strengths were comparable to those of species with similar specific gravity. Withdrawal strength design values should therefore put into account the combined effect of these factors.

Keywords: withdrawal strength, nails, timber grade, nailed timber joints.

Introduction

The strength and stability of any structure depends to a large extend on the joints that hold its parts together. The design and construction of joints is very critical because they form the weakest links in most engineered wooden structures (Soltis *et al.*, 1994; Mohammad, 1996). Wood can easily be joined together with a wide variety of fasteners including nails, screws, bolts, staples and metal connectors of different types and shapes (USDA Forest Service, 1987).

Nails are the most commonly used fasteners for structural construction such as trusses, as they are light and easily applied using hammers or nailing guns. Nailed joints are considered effective when nails are driven into the wood without visible splitting of the wood. In addition, strong joints are achieved if wood is nailed at moisture content at or close to the equilibrium moisture content of the exposure conditions (Mohamad and Smith, 1996). Smooth round wire nails for example tend to lose some grip on the wood when moisture is lost from the wood due to wood shrinkage around the nail. In timber construction, nails can resist forces tending to cause direct separation of the joined members (Mohamad and Smith, 1994). Such forces include withdrawal and lateral loads or a combination of both. The strength of the joint depends on the resistance to the joint failure.

Nail resistance to withdrawal depends on wood density, nail diameter, depth of penetration, surface conditions of the nail at the time of driving in and use conditions (USDA Forest Service, 1987; Soltis *et al.*, 1994). Higher withdrawal resistance could result from high wood density, large nail diameter, deeper penetration and clean, rust free nail surface (USDA Forest Service, 1987) as well as increased spacing for nail rows (Blass, 1994). However, high density wood split easily hence limiting the end distances of members and nail diameters applicable to timber joints.

Less dense wood on the other hand split less and can thus allow the use of more nails or nails of large diameters. This knowledge has for a long been applied in design and construction of structures in Kenya using British and other Standards. However, the use of such design codes locally may lead to design deficiencies because the design information is specific to temperate wood species whose characteristics differ appreciably from locally grown species. Variations in wood density of locally grown pines and cypress have been recorded between species (Ringo, 1983) and within species (Chikamai, 1987).

Similarly, within tree variation in wood density has been observed in juvenile and mature wood. Further still, grading has been shown to affect the utilization potential of timber irrespective of the species and application (Chikamai, *et al*, 2001). A good design code must therefore put into account the variability in wood physical and mechanical properties as well as the differences in joint capacities due to such variability.

The efficient utilization of timber for structural purposes requires adequate knowledge of strength properties of mechanically fastened joints (Lee, 2007). Test standards used in different countries give the basic requirements for nailed joints based on wood materials in those countries. As a result of differences in wood characteristics, especially density, such standards are only reliable when designing with wood whose characteristics are considered in the development of the standard. The current design codes in Kenya do not address this adequately hence the need for local standards that are directly applicable to design with Kenyan grown wood.

There is no data available on basic joint capacity for Kenyan species fastened with standard mechanical fasteners. This necessitates evaluation of basic joint strength for various species and fasteners. This study focused on determination of the basic withdrawal strength for various mechanically fastened joints made from Kenyan grown cypress and pine timber. These two species are commonly used in the Kenyan construction industry where structural engineers need to know the fasteners basic design loads for design purposes. Performance of these species and various sizes of nails were determined. The data obtained from this study will be used in developing structural design codes for smooth round wire nails used in design with Kenyan grown cypress and pines. The main objective of this study was to generate basic withdrawal loads for nailed Kenyan grown cypress and pines timber joints for use in development of timber design codes. The specific objectives were to determine (i) basic withdrawal loads for smooth round wire nails driven at right angles to the grain, (ii) the effects of nail diameter, nail penetration, timber species and grade on withdrawal strength.

Materials and methods

Withdrawal Fixtures and Fasteners

Test fixtures for nail withdrawal were designed and fabricated using mild steel following the specifications of British Standards (BS 6948, 1989). Preliminary tests were conducted to establish the accuracy of the test fixtures. Six inch long (5.73mm diameter), Four inch (3.91mm diameter) and three inch (3.40mm diameter) round nails were selected from different hardware stores to ensure that they are representative of the stock in the market.

Wood material and Specimen Assembly

Trees were selected from forest stands representative of cypress and pine species in Kenya. The trees were sawn into full-size 150mm by 50mm by 4m long beams and a batch randomly selected and graded into select structural (SS) and general structural (GS) according to Kenya standards (KS 02-771: 1989). The beams were tested to determine the strength of full-size members in a separate study and the remaining un-failed timber used for joint specimens. Seventy two pairs of defect-free timber specimens, half of them flat sawn and the other half quarter sawn were extracted for each of the species. Timber specimens for the three nail sizes were end–matched or side-matched where end matching was not possible. The specimens were stored in controlled air conditions of 20 ± 2^{o} C temperature and 65 ± 5 % relative humidity to provide an equilibrium moisture content of 16 to 18 percent or air dry material as much as possible.

Twenty four joint specimens for each nail size were prepared from the pairs of timber specimens. The nails were driven into the member using a hammer such that the shank of the nail was as perpendicular to the long axis as possible. The maximum nail penetration achieved was seven times the nominal diameter of the fastener with a minimum penetration of 30mm or a depth equal to nail length leaving a sufficient allowance for grip in the case of nails having a length less than seven times its diameter.

Strength Testing

The joint specimens were tested at 20 ± 2^{o} C temperature and 65 ± 5 % relative humidity. A withdrawal load was applied at the underside of the head of the fastener at a continuous rate of movement of machine crosshead of 2.5 ± 0.625 mm/min for a withdrawal of at least 10 mm. The mode of failure for each specimen was noted. The maximum load for each specimen was recorded.

In order to determine moisture content and relative density, a small full cross-section sample of each member of a specimen was taken close to the fastener and weighed to an accuracy of 0.05g. The samples were dried in an oven at a temperature 103 ± 2^{o} C to a constant mass and the moisture content expressed as the percentage change in mass. The relative density was expressed as the ratio of the oven dry mass to the specimen volume. Statistical analysis was done using General Linear Models (GLM) tools in Statistical Package for Social Sciences (SPSS) programme at a level of significance of $p= 0.05$.

Results and discussion

Analysis of variance results for the various effects are shown in Table 1. The predominant mode of failure was nail withdrawal from the main member. Results show that wood species and wood grade have a significant effect on the nail withdrawal strength. The differences in species are mainly due to variations in the nature of the two wood species.

Although clear wood was chosen for the tests in both grades, the differences attributed to other wood characteristics like grain orientation. Difference in wood density could also have contributed to the different effects due to wood species. Nail sizes penetration had significant effects on withdrawal strength with penetration influencing strength more than nail diameter. This is due to the effect of the nail diameter differences and the depth differences achieved in each level of penetration (USDA Forest Service,1987).

Table 1. Analysis of Variance for the effect of wood and nail parameters on strength

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	*F value*	*Sig.*
Wood Grade	984.331	48	20.507	104.322	0.000
Nail Size	1.233	1	1.233	6.273	0.013
Penetration	15.399	2	7.700	39.169	0.000
Wood Species	33.678	3	11.226	57.108	0.000
Wood Grade × Nail Size	0.998	1	0.998	5.078	0.025
Wood Grade × Penetration	4.315	2	2.157	10.975	0.000
Wood Grade × Wood Species	0.223	3	0.074	0.378	0.769
Nail Size × Penetration	0.748	1	0.748	3.806	0.052
Nail Size × Wood Species	1.411	6	0.235	1.196	0.307
Penetration × Wood Species	1.669	2	0.834	4.244	0.015
Grade × Nail Size × Penetration	3.366	3	1.122	5.708	0.001
Grade × Nail Size × Wood Species	0.721	6	0.120	0.611	0.721
Nail Size × Penetration × Wood Species	0.304	2	0.152	0.774	0.462
Grade × Nail Size × Penetration × Wood Species	1.083	6	0.181	0.919	0.481
Error	3.228	9	0.359	1.825	0.062
Total	84.919	432	0.197		

The 2-way interactions had significant effect to the withdrawal strength except for those between wood grades and wood species, nail size and penetration and nail size and wood species. These indicate that wood species have relatively little effect on the withdrawal strength and that inherent characteristics such as specific gravity have greater effect. Three-way interactions for withdrawal strength were not significant, except for wood grade/nail size/penetration.

Table 2 shows the mean comparison results for all the factors. As mentioned earlier, wood species show significant effect on the nail withdrawal strength. Cypress wood had the highest withdrawal resistance of 1.425 kN and was significantly different from that of pine wood of 1.332 kN.

For wood grades, SS grade gave nail withdrawal strength of 1.434 kN, which was significantly higher than 1.326 kN for GS grade. This difference could be attributed to the fact that for GS grade, although the wood used was visually knot free, it may have contained other invisible defects like spiral grain whose effect, although not assessed could have decreased the withdrawal strength.

Table 2: Mean comparisons for the main effects of wood species, grade, nail size and penetration

Experimental Factor	**Mean Withdrawal Strength (kN)**			
Wood Species	**Cypress**	**Pine**		
	1.425	1.332		
Wood Grades	**SS**	**GS**		
	1.434	1.326		
Nail length (inches)	**6**	**4**	**3**	
	1.599	1.391	1.145	
Penetration	**30mm**	**40mm**	**50mm**	**60mm**
	0.990	1.343*	1.476*	1.715

***** Values marked with an asterisk are not significantly different at 0.05 level of significance.

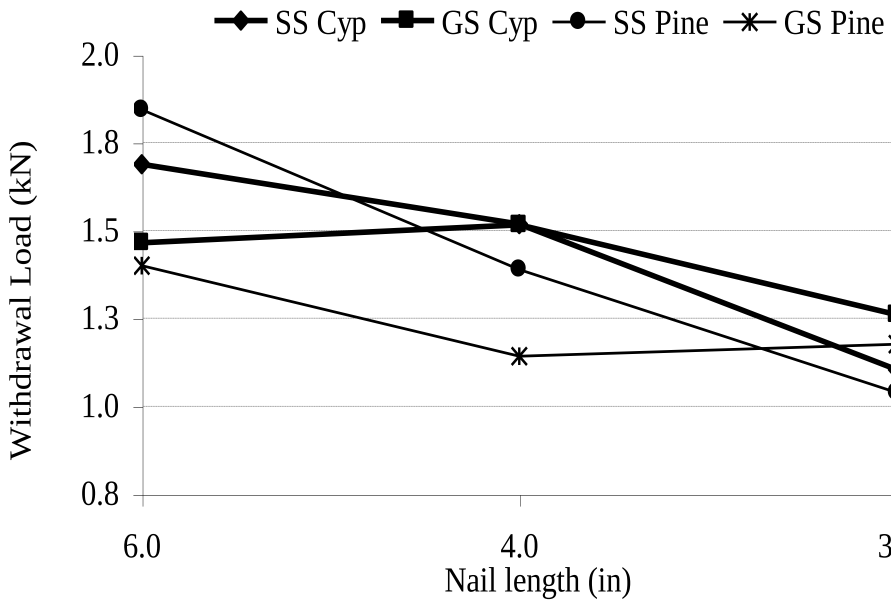

Figure 1: Influence of nail length and wood grade on withdrawal strength

Withdrawal strengths for joints with different nail length and diameter were significantly different. Six inch (5.73mm diameter) nails produced withdrawal strengths of 1.599 kN, which was significantly higher than 1.391 kN for the four inch (3.91mm diameter) nails.

The three inch long (3.10 mm diameter) nails had withdrawal strength of 1.391 kN, which was significantly lower than the other two. This shows that large diameter nails would be better for joinery in terms of withdrawal resistance if the wood size is large enough to allow for their use.

Nail penetration showed a variation in terms of its effect to withdrawal strength. Withdrawal strengt … y millimeter penetr… higher than the res… nd 1.476 kN respec… ils penetrate into th… however to consid… penetration to avo… ng the joint. Penetr… ffect on the withdr…

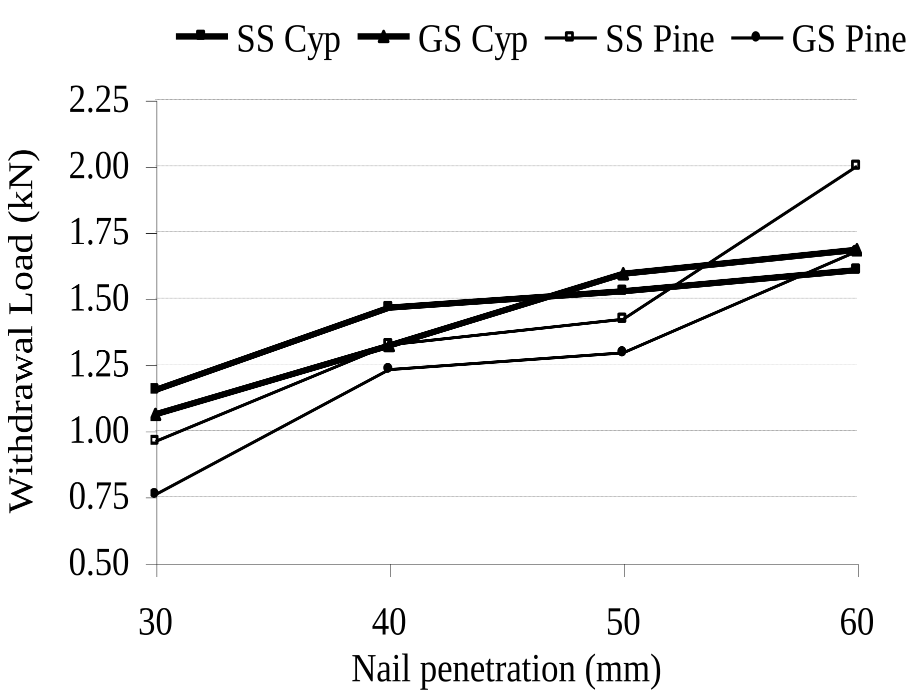

Figure 2. Influence of penetration and wood grade on withdrawal strength

The values plotted in Figure 2 are means for the four penetrations for each of the combinations of species, nail length and grade. Increased nail penetration produced increase in resistance to nail withdrawal irrespective of wood species and grade. These trends are consistent with those for related dowel-shape fasteners (Soltis *et al*., 1994; Yamada *et al*., 1991). The increase in withdrawal strength with penetration is due to the increased contact between the wood and the fastener.

Conclusions and Recommendations

The results of this study indicate that resistance to nail withdrawal for nailed cypress and pine joints increases with nail diameter and penetration and the effect is dependent on the timber species and grade. The effect of timber grade on withdrawal strength implies that grading is important in improving performance of joinery where nails are involved since wood defects negatively affect nail withdrawal strength. There is however need to evaluate the effect of wood defects on withdrawal strength. The effect of wood characteristics such as grade on nail withdrawal strength is smaller than that of nail parameters including diameter and length. The data obtained from this study can be used in deriving basic loads for use in cypress and pine nailed joint design codes. There is also need to derive empirical equations for predicting the withdrawal strength for all possible nail diameters and penetrations.

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