Tensile and dimensional properties of wood strands made from plantation southern pine lumber

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Abstract

Working stresses and performance of strand composite lumber largely depend upon the properties of each individual strand. Southern pine strands from plantation lumber grown in southern Louisiana were investigated in this study in order to understand strand behaviors. The effects of hot-pressing and resin application on tensile modulus, strength, and dimensional expansions (in three directions) were discussed. The mechanical properties of the untreated control strands were similar to those of solid wood products, while their dimensional expansions were larger than the reported values for solid wood. Hot-pressing and resin application had a significant impact on strand performances. Strands located in face layers of the mat were even more sensitive to hot-pressing and resin usage than strands in the core layer, and their strength and modulus increased significantly due to initial high press temperature and pressure applied to them.

Increasing demand for high-quality structural lumber has accelerated the development of new strand-based composite lumber as substitutes. The most common composite lumber products on the market for light commercial and residential construction are laminated veneer lumber (LVL), parallel strand lumber (Parallam® PSL), and laminated strand lumber (Timberstrand® LSL). With uniform and consistent performance, composite lumber has gained tremendous market share with projected production volume at 2 million m^3 over the next decade (Smulski 1997). Working stresses for the composite lumber are available for general design purposes, but a more detailed enumeration of property values would be needed for advanced mechanical and engineering analyses (Janowiak et al. 2001). Physical and mechanical behavior data for the strands that are used to produce these strand composite lumber products are essential for detailed analysis.

Strand composite lumber (e.g., LSL and PSL) is generally made from strands with thicknesses up to 0.42 cm and varying lengths ripped from veneers (Janowiak etal. 2001). The bonding agents for the composite lumber are typically phenol-formaldehyde (PF) or emulsified polymeric isocyanate resins. Strands applied with resin are directionally formed into mats and consolidated with a hot-press. After consolidation and resin curing, the final strand composites consist of the compacted array of strands and un-eliminated voids among them. Clearly, the mechanical and physical behavior of strand composite lumber is largely dependent upon the performance of each individual strand and its bonding.

The effect of tensile properties of thin sweetgum and Douglas-fir flakes on the performance of flakeboard in association with the effect of hot-pressing has been investigated (Price 1975, Geimer et al. 1985). However, the effect of strand dimensional changes (thickness in particular) on the tensile and dimensional stability properties of strand composite materials is less well documented. Most of the studies on strand effect are lim-

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This study was supported by the USDA National Research Initiative Competitive Grant Program (99-35103-8298 and 2003-02341). The financial contribution to the project is gratefully acknowledged. This paper (No: 03-40-1536) is published with the approval of the Director of the Louisiana Agricultural Experiment Station. This paper was received for publication in August 2003. Article No. 9748.
*Forest Products Society Member.
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Forest Prod. J. 55(2):87-92.

Table 1. — Summary of the southern pine strand properties measured.

Treatment	Group	SG[a]	MC	TenE	TenS
			(%)	(GPa)	(MPa)
Control	Low	0.45	11.3	9.02	31.39
	Medium	0.56	10.8	12.78	48.86
	High	0.64	11.9	17.23	69.86
	Mean	0.58	11.3	12.84	49.98
Hot-pressed	Core-layer	0.58	4.7	12.83	53.40
	Face-layer	--	4.8	15.75	56.70
Resinated and hot-pressed	Core-layer	0.59	6.1	14.91	47.10
	Face-layer	--	6.2	17.17	63.20

[a]Initial strand SG based on weight and volume shown in the table for various samples.

ited to its length or width effect rather than its thickness (Geimer et al. 1985, Lee and Wu 2003). Hankinson's formula was used to predict the tensile strength of oriented strandboard (OSB) based on the given strand thickness, but limited experimental work was attempted to verify the reliability (Barnes 2000). Few experimental studies, if any, have been conducted to provide information on the engineering constants of thick and long strands. Without full understanding of the properties of strands with dimensions similar to those used in strand composites manufacturing, there is no reliable prediction of mechanical and physical properties of the strand composites (Lee and Wu 2003).

The purposes of this study were to investigate the tensile strength and dimensional expansion of thick strands and the effect of hot-pressing and resin application on these properties.

Materials and methods

Logs from plantation stands of southern pine grown in Louisiana were sliced into veneers to produce long and thick strands. Strand specimens with an average dimension of 15.24 cm long by 2.54 cm wide by 0.38 cm thick were clipped from the veneers. A total of 240 test specimens were randomly selected from the population of more than 3,000 specimens. All strand specimens were then sorted into three groups (low, medium, and high) according to their annual ring counts (ARC). For example, the low group, which had the lowest specific gravity (SG), included specimens with the fewest ARC per 2.54 cm and most of them were found to be sliced along the tangential direction. After being given identification numbers, these strands in each group were completely mixed and evenly divided into three subgroups for the different treatments: hot-pressed without resin, hot-pressed with resin, and the control (with no resin and no pressing). Liquid PF resin was applied to the strands in the group hot-pressed with resin at an application rate of 6 percent (ovendry wood weight basis). Each resinated strand was wrapped with aluminum foil coated with nonstick agent, and the wrapped strands were then mixed with other non-resinated strands to form a mat with random strand orientation. The resinated strands were placed either in the face layers or the core layer. The mat was hot-pressed for 7 minutes under a press temperature of 200°C and the initial pressure of 45.7 kg/cm^2. The target density of the pressed board was 0.75 g/cm^3. Strands with their vertical positions at either face or core layers were collected from the pressed board and conditioned under a target room temperature of 25°C and 55 percent relative humidity (RH) for a few weeks before being tested.

Another 102 long strands (27.94 by 2.54 by 0.38 cm) from the same veneers were used in evaluation of the hygroscopic expansions along the three major directions. Two small nails were anchored for each strand specimen at the two ends, 25.4 cm apart along the longitudinal direction. Each nail was cross-marked on its head for easy reading of its position. Strands were placed in an automatically controlled environmental chamber and went through a stepwise change in RH from 0, 35, 55, 75, 85, to 95 percent at a constant temperature of 25°C. When the specimens reached the equilibrium at each RH condition, their dimensions in three major directions (i.e., longitudinal, transverse, and thickness) were measured and used to determine the expansion. In order to investigate the effect of hot-pressing on thickness swelling, the 80 strands in the group hot-pressed without resin application for the tensile test were carefully recollected after tensile testing. The specimens were then conditioned under both ovendrying and 95 percent RH. Thickness swellings from 0 to 95 percent RH were measured and compared with the control group.

Both tensile and dimension tests were carried out according to the ASTM Standard D 1037 (ASTM 1999). A specially designed microscope was used to measure linear expansion of the strands. All tensile tests were performed on an MTS testing machine equipped with hydraulic pressure-driven grips and an MTS extensometer (2.54-cm gauge length). The slope of the stress-strain curve obtained was used in determining the tensile modulus of elasticity (TenE) and the maximum failure load was used to calculate the tensile strength (TenS). It was noted that the TenE determined by a deformation reading from the extensometer in this study was much closer to the values determined by using strain gauges (Price 1975), but different from those by reading deformation through the crosshead movement of the test machine (Price 1975, Geimer et al. 1985). It seems that the deformation determined from the crosshead movement, which included variation of slippage between the testing grips and the strand, was not accurate.

Results and discussions

Physical properties of strands

Average values of SG, moisture content (MC), and mechanical properties of specimens in different groups are shown in Table 1. The average SG of the control strands was 0.584 with a standard deviation of 0.095 at the MC of 12.7 percent. As expected, the average SGs of the three groups followed the same pattern as low, medium, and high. Further statistical analysis (Fig. 1) indicated a good linear relationship (r^2 = 0.64) between strands' ARC (number of annual rings within 2.54-cm width) and SG.

Average thickness of the untreated control strands before hot-pressing was 0.380 cm with a standard deviation of 0.116 cm. After pressing, a significant reduction in the thickness of strands induced by thermo-mechanical stress was observed. Usually, the compression ratio (defined as ratio of thickness before and after pressing) was used to estimate the effect of pressing on thickness. An average compression ratio of 1.332 was achieved in this study with 1.360 for the face layers and 1.304 for the core layer. The high compression ratio in the face layers re-

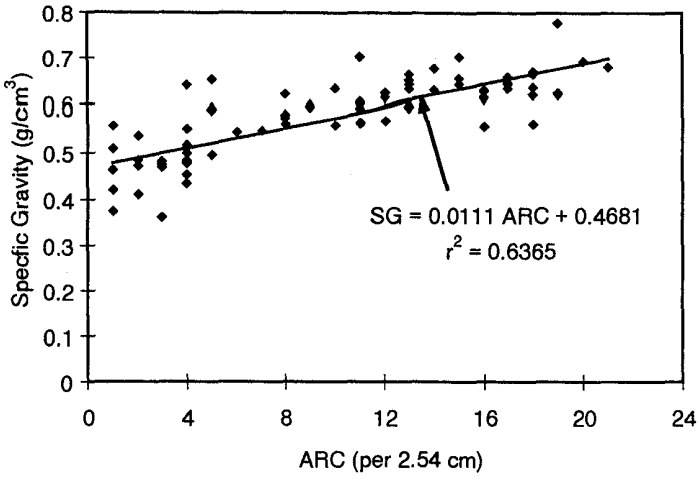

Figure 1. — Relationship between sample SG and annual ring count for southern pine strands.

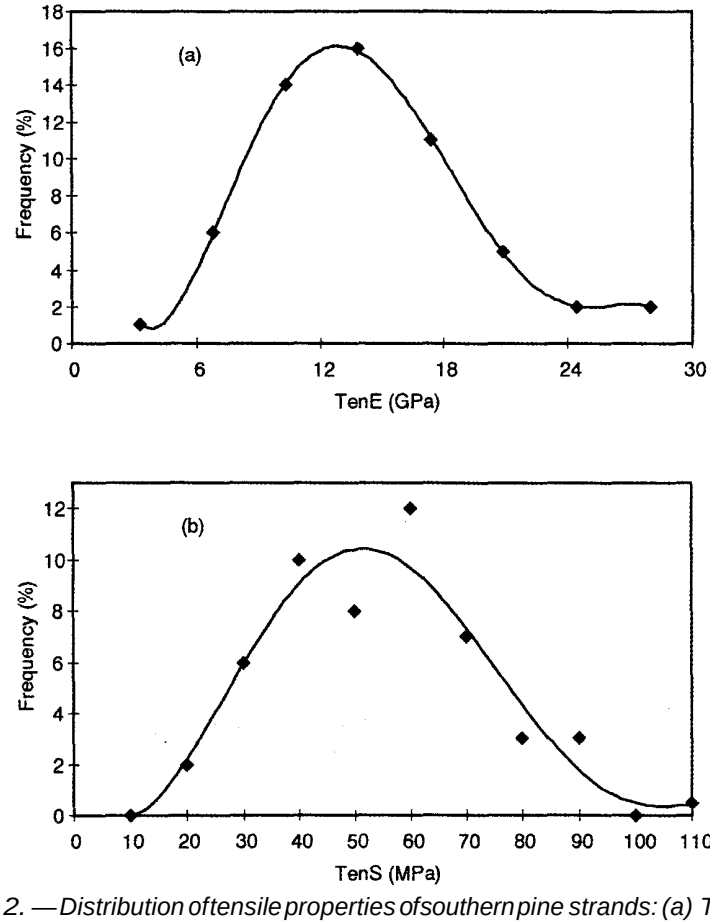

Figure 2. — Distribution of tensile properties of southern pine strands: (a) TenE and (b) TenS.

sulted in high density in the face. The compact ratio (average strand SG divided by the target board SG) was another parameter used to describe the pressing process. It was 1.284 in this study and was lower than the compression ratio. Due to the irregular surface of the pressed strands, the SG of each strand after pressing was estimated using its SG before pressing and the average compact ratio.

Tensile modulus (TenE)

The overall TenE distribution of all three groups of control strands (untreated) shown in **Figure 2a** was similar to the normal distribution, with a mean of 12.84 GPa and standard deviation of 5.52 GPa. The overall average TenE of the control strands was close to that of solid southern pine. But when compared with thin strands (<0.267 cm) of the same species in earlier research (Wu and Lee 2003), the average TenE in this study was about 48 percent higher. This observation could help composite manufacturers to produce better products by selecting an appropriate strand thickness. The TenE usually depends upon the strand SG, and the general trend of the data shown in **Table 1** was that the strands with higher SG had higher TenE. This observation coincided with the results of the statistical analysis. Reasonable linear correlations between the TenE and SG ($r^2 = 0.562$) and TenE and ARC ($r^2 = 0.604$) are shown in **Figure 3.**

Hot-pressing had significant influences on TenE, and the influences might be dependent upon the strand location within the mat. Strands in the face layers were usually compressed more than the core strands because of the initial high press pressure and high temperature. After hot-pressing, the pressed strand could have become stiffer due to the change of the section modulus. On the other hand, the thermo-mechanical stress during the hot-pressing could have produced damage to the pressed strands, lowering the mechanical performance. The effect of hot-pressing on mechanical performance was complicated; it could depend upon many parameters including pressing, mat forming, and even properties of the strand itself. In this study, on the average, the strand TenE of the face layers increased about 23 percent, while the strand TenE of the core layer remained the same as the control strand. This observation was different from the results of earlier work performed on thin strands (Wu and Lee 2003), which showed no significant increase in the strand TenE of the face layers. This probably indicated the thicker strands could resist damage produced from the thermo-mechanical stress during hot-pressing.

Wood composite panels are typically made with a thermosetting resin that binds the wood material together. The resin not only had a significant effect on the overall behavior of wood composites, but also influenced the performance of each individual wood element (i.e., strand, particle, or fine fiber). Resinated strands after hot-pressing in this study showed 12 and 25 percent increases in TenE values based on their averages when compared with the pressed and

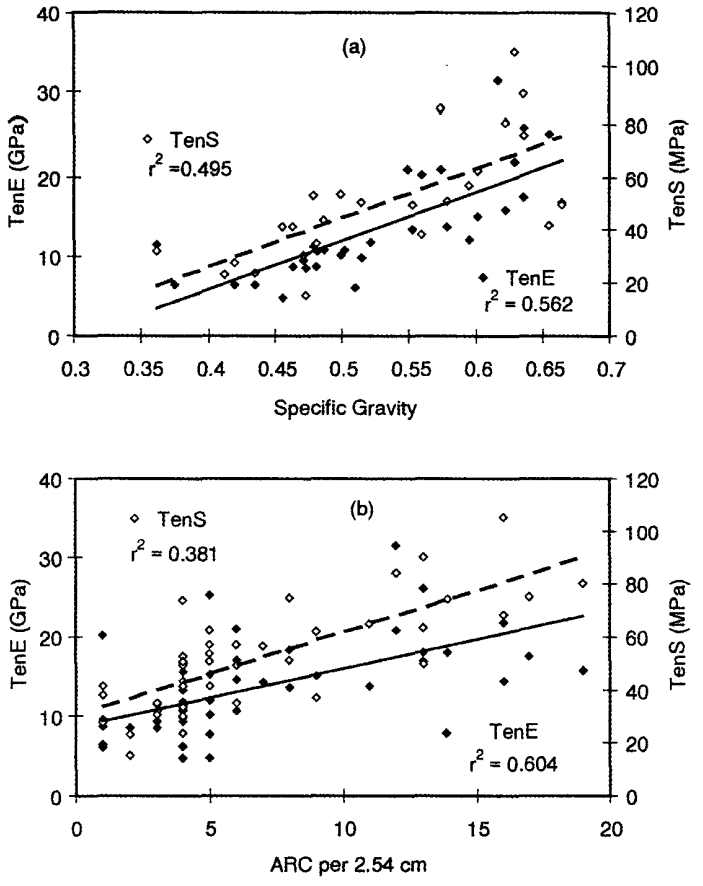

Figure 3. — Correlations between tensile properties and strand density and annual ring count: a) TenE and TenS vs. SG and b) TenE and TenS vs. ARC.

control strands, respectively. As shown in **Figure 4a,** the resinated strands placed both in the core and face layers had high TenE values. Resin penetrated into strands could reinforce the strand performances to resist thermo-mechanically induced damage. Although the resin had an impact on the performance of each individual strand, the effect of resin application on the effective modulus of the overall composite would be different. It was expected that a continuous film of resin between strands would increase the mechanical properties of composites, but further experimental verifications would be needed.

Tensile strength (TenS)

A fairly good normal distribution on TenS of all control strands was obtained with a mean of 49.98 MPa and a standard deviation of 19.12 MPa **(Fig. 2b).** The trend of the three TenS groups was very similar to that of the corresponding TenE. The average TenS values of the three groups are 31.39 MPa, 48.86 MPa, and 69.86 MPa for low, medium, and high, respectively. It was surprising that the average TenS of the high SG group was over twice higher than that of the low SG group. **Figure 3a** and **b** showed a fair linear regression relationship between TenS and SG (r^2 = 0.495), but less linear dependency between TenS and ARC (r^2 = 0.381).

The effect of hot-pressing and of both hot-pressing and resin on the strand TenS is shown in **Figure 4b.** The hot-pressing itself did not seem to have much influence on strand TenS no matter where the strand was located (face or core layers). However, when the strand was resinated and hot-pressed, its TenS could be affected. **Figure 4b** shows an opposite effect on TenS when the strands were placed differently (i.e., the face and core layers). Strands in the face layers showed an average 26.4 percent increase in the strength, while those at the core layer showed a 25.8 percent decrease. The reason could be that resin application on the strands in the face layers was more uniformly distributed and penetrated into the strand surfaces because of the high temperature, pressure, and moisture. This could be helpful in reinforcing the strand performance. On the other hand, the resin curing of the strand in the core layer under slowly increasing temperature and decreasing pressure was more complicated and could affect the resin bonding and reinforcement.

Linear expansion (LE)

Linear expansion along the longitudinal direction (LEL) and linear expansion in the transverse direction (LET) of strands were investigated. **Figure 5** shows the average LEL and LET values of the strands when MC was changed from 0 to 25 percent. Rapid increase in LEL was observed in low MC (0% to 6%), and it was stabilized with MC greater than 6 percent. LET, on the other hand, showed a uniform increase throughout the moisture change. The average LEL (from 0% to 25% MC) was 0.64 percent, which was much larger than the 0.1 percent of average LEL reported for solid wood (from 0% to 30% MC). Similarly, a relatively larger LET of 6.08 percent (from 0% to 25% MC) was obtained. Microscopic surface damage of the strands and relatively low surface-volume ratio made water easy to penetrate into the whole strand and caused the strand to expand without too much restriction. Large LE expansions of strands could cause the overall composite made from the strands to be more dimensionally unstable. No linear relationship between LE and SG or ARC was observed.

Thickness swelling (TS)

Thickness expansion changes the section modulus, which could affect the mechanical performance of wood strands. **Figure 5** shows a curvilinear relationship between TS of control strands and MC. The rate of TS change became constant after MC reached 6 percent, which was very similar to LET. The average TS (from 0% to 25% MC) was 7.85 percent with a standard deviation of 3.69 percent. The average TS (from 0% to 25% MC) of the pressed strands was 17.61 percent, which was about 2.2 times larger than that of control strands due to larger springback after hot-pressing. But the average TS of pressed strands was lower than that of thin strands (0.267 cm) (Wu and Lee 2003). Again, this was another example that the thickness of strands affected the strand performance.

Equilibrium MC (EMC)

The relationship between sample EMC and ARC is shown in **Figure 6.** As expected, EMC of given strands showed weak linear dependency on numbers of

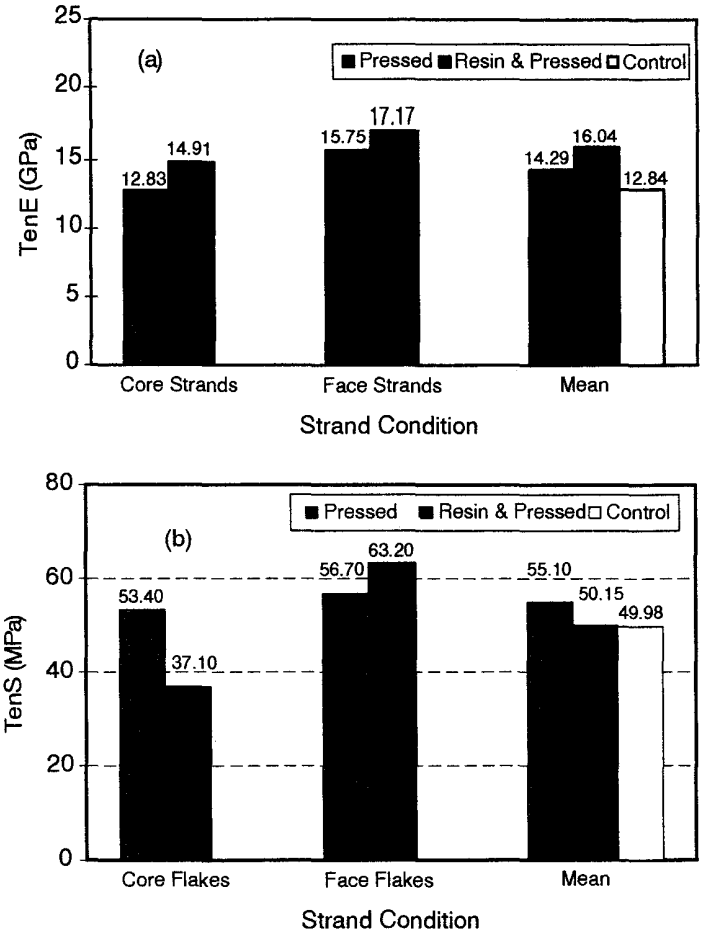

Figure 4.—Comparison of tensile properties of southern pine strands as affected by treatments: a) TenE and b) TenS.

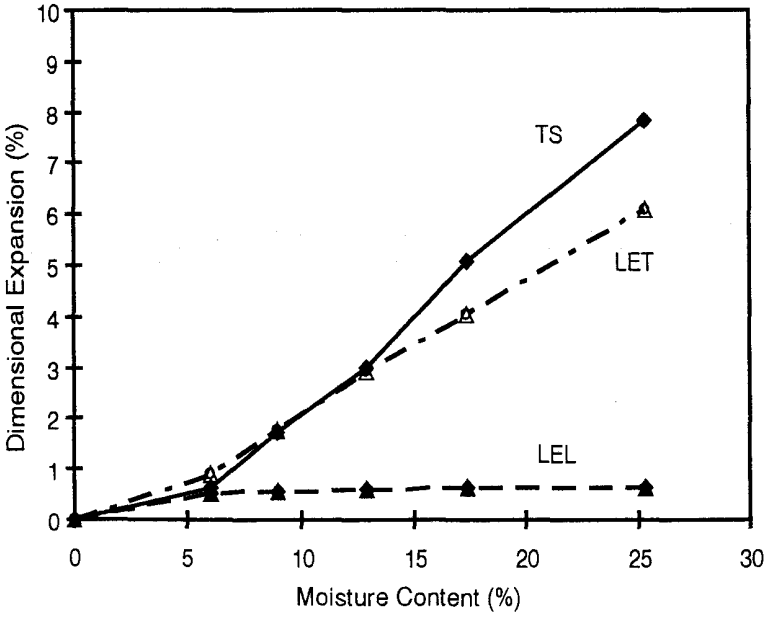

Figure 5. —Dimensional expansions of southern pine strands as a function of MC.

annual rings. In general, the denser wood strands sometimes resulted in less water absorption.

Conclusions

Tensile and dimensional properties of strands from plantation southern pine under different conditions were investigated to provide information for strand composites manufacturers. Mechanical properties (both TenE and TenS) of thick strands (0.38 cm) were similar to those of solid wood. However, strand dimension expansions in all three directions were much larger than the solid wood products. Hot-pressing and resin application affected the mechanical and dimensional performance of strands. These effects depended upon the strand thickness and location (face or core). Strands located in face layers were even more sensitive to hot-pressing and resin usage than the strands in the core layer, and their tensile strength and modulus increased significantly due to initial high press temperature and pressure.

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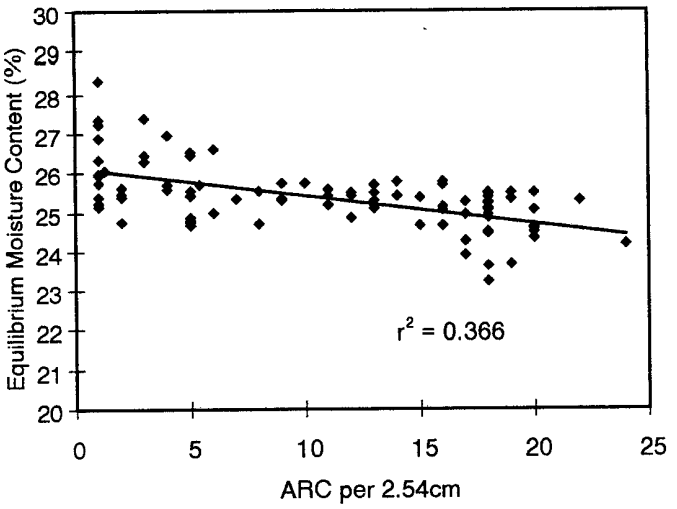

Figure 6.—Relationship between EMC at 95 percent RH and annual ring count per 2.54 cm for southern pine strands.