Thickness Swelling and its Relationship to Internal Bond Strength Loss of Commercial Oriented Strandboard

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ABSTRACT

Samples from four types of commercial OSBs (two made of mixed hardwoods and two made of southern pine) were tested to study thickness swelling (TS) and its relationship to internal bond (IB) strength loss of the products. The treatment conditions included four equilibrium moisture contents (EMCs) and 24-hour water soaking at room temperature. It was shown that the OSBs swelled, on average, 31.1% over an EMC change of 24 percent and 18.5% after 24-hour water soaking. The corresponding non-recoverable TS was 19.8% and 14.0%, respectively. Residual IB strength decreased nearly linearly with increases in non-recoverable TS in the panel. Regardless of the way OSB absorbed moisture, there was an average IB strength loss of about 2.0 psi (0.29 KPa) for every percent of non-recoverable TS in the specimens. In-plane density variation and non-uniform resin application due to curled flakes were found to play a significant role for the large TS and IB loss in these products.

Thickness swelling (TS) of wood composites in relation to moisture content (MC) change and panel manufacturing parameters has been extensively studied. It was shown (2, 6,10) that total thickness swelling (TTS) has two components: recoverable thickness swelling (RTS) and non-recoverable thickness swelling (NTS). RTS is the swelling of the wood due to MC change within the hygroscopic range, while NTS is a result of the combined effect of the compression stress release from the pressing operation and differential swelling potential due to inherent in-plane density variation. The latter results in normal swelling stresses between high and low density areas in the plane of the panel. These stresses are often large enough to break the adhesive bonds, leading to significant NTS (4, 7).

A large negative consequence of the NTS is the reduction of strength properties of wood composites. Lehmann (3) studied the effects of single or multiple water-exposure and drying cycles on strength and stability of a series of structural flakeboards of varying resin and wax contents. It was shown that bending stiffness and strength and internal bond (IB) strength all decreased after various treatments applied to the test panels. Resin content was shown to have a significant effect in reducing TS and maintaining panel strength. Winistorfer and DiCarlo (8) tested randomly formed flakeboard made of mixed hardwoods for the effects of furnish moisture content (MC), resin nonvolatile content and assembly time on stability and strength retention properties. The study demonstrated that ovendry-vacuum/pressure/soak treatment led to significant IB strength loss of the panels due to large TS involved. Suchsland and Xu

(7), using a model consisting of thin veneer strips, demonstrated that the development of large TS and severe reduction of IB strength due to in-plane density variation in laboratory-made flakeboards.

Limited work was done directly relating strength loss to TS (especially NTS) in commercial OSB currently marketed. The product is normally made with relatively large flakes and low resin content. Its flake alignment level and mat structure are significantly different from those of laboratory panels. Thus, test data on TS and its relationship to strength loss from laboratory panels may not directly apply to commercial OSB products. Wu and Suchsland (10) and Wu (11) demonstrated that commercial OSBs can suffer significant stiffness, strength, bending and breaking resistance loss at higher MC conditions. The study showed that both strength and stiffness losses were directly proportional to the amount of TS in the panel. It was speculated that the strength loss in OSB was mainly due to breakage of adhesive bonds in the panel, which causes NTS. Therefore, studies on the relationship between IB strength and TS may shed more light on how OSB products lose strength when they get wet.

The objectives of this study were: (a) to characterize the TS behavior of OSB in relation to high humidity exposure and short-term water soaking; (b) to determine residual IB strength after various treatments; and (c) to examine the relationship between IB strength loss and permanent TS as influenced by product type and manufacturing parameters.

MATERIALS AND METHODS

Material Selection and Specimen Preparation

Four types of commercial OSB were selected for the study (Table 1). These included two OSBs made of mixed hardwoods for sheathing (MHS) and two OSBs made of southern pine for sheathing (SPS) and for flooring (SPF). Table 1 lists panel nominal thickness, span rating and dry specific gravity (SG). Two 4-foot by 4-foot (122-cm x122-cm) panels for each OSB were directly obtained from the OSB manufacturers. It is known that all panels were made with liquid phenol-formaldehyde adhesive at a face-to-core flake weight ratio of approximately 50:50. Other manufacturing variables were not known.

Fifty 2-inch by 2-inch (50.8-mm by 50.8-mm) specimens were cut from each of the four OSBs for TS and IB strength test in this study. The fifty specimens from each OSB were randomly separated into five groups with ten samples in each group. Each specimen was labeled on one edge according to OSB type, group number and replication number for easy identification during testing. The labeled specimens for a given group from all four OSBs were then combined to form a set (ten specimens from each OSB). A total of five sets were prepared. They were stored in an air-conditioned room at 55% relative humidity (RH) and 25°C before testing.

Test Condition and Procedure

During testing, one of the five sets of specimens was selected. They were tested according to the following scheme: oven-drying -> treatment -> oven- drying -> IB strength testing. The treatment conditions included four RH exposures corresponding to four target EMCs (5, 10, 15, and 25%) and 24-hour water soaking at room temperature.

The test procedure at each EMC condition was as follows. A group of forty pre-prepared specimens was selected (10 samples from each OSB). They were first oven-dried at 105°C for 24 hours. Specimen weight and size (length, width and thickness) were measured after the oven-drying. The specimens were then placed in a climate-control room, which was set at the target EMC, until equilibrium was reached. They were removed from the conditioning room and specimen weight and size (length, width and thickness) were re-measured. The specimens were then subjected to a second oven drying and their weight and size measured again. Finally, all specimens were tested for IB strength according to ASTM D1037-96 (1). To help stabilize the MC condition in the specimens after they were glued to aluminum blocks for IB testing with hot-melt glue, all specimens were conditioned at the room condition (55% RH and 25°C) for a period of seven days. Immediately after IB testing, a small piece of sample was taken from the failed specimens and its MC was measured with the oven-dry method.

Tests under water soaking condition were conducted as follows. After the first oven-drying, specimens were submerged 1 inch (25.4 mm) below the surface of water at room temperature. To determine the swelling rate as a function of time, specimens were removed after 1 hour, 2, 3, 5, 10, 15 and 24 hours water soaking. Their thickness and weight were measured. Before each measurement, water on the surface of each specimen was wiped off using a paper towel. After a 24-hour soaking, all specimens were oven-dried at 105 °C for 24 hours. Specimens' weight and thickness were measured again. Finally, all specimens were tested for IB strength as described above.

Data Reduction

Total thickness swelling, TTS (%), after each EMC treatment was calculated as:

$$TTS = \frac{(T_2 - T_1)}{T_1} \times 100\% \quad \textbf{(1)}$$

where

TTS = total thickness swelling (%)

T_2 = specimen thickness after treatment (in.)

T_1 = specimen thickness after first oven-drying (in.)

Non-recoverable thickness swelling, NTS (%), was calculated as:

$$NTS = \frac{(T_3 - T_1)}{T_1} \times 100\% \quad \textbf{(2)}$$

where

NTS = non-recoverable thickness swelling (%)

T_3 = specimen thickness after the second oven-drying (in.).

Recoverable thickness swelling, RTS (%), was calculated as:

$$RTS = (TTS - NTS) \quad \textbf{(3)}$$

Water absorption (WA, %) as a function of soaking time was calculated as:

$$WA_N = \frac{(W_N - W_1)}{W_1} x\ 100\% \qquad (4)$$

where

WA_N = water absorption after N hours of water soaking (%)

W_N = specimen weight after N hours of water soaking (gram)

W_1 = specimen weight after the first oven-drying (gram).

Total thickness swelling as a function of soaking time was calculated as:

$$TTS_N = \frac{(T_N - T_1)}{T_1} x\ 100\% \qquad (5)$$

where

TTS_N = Total thickness swelling after N hours of water soaking (%)

T_N = specimen thickness after N hours of water soaking (in.)

T_1 = specimen thickness after the first oven-drying (in.).

TTS_N was expressed as a function of WA_N for each individual specimen of a given OSB and for all specimens from each OSB combined as a group. A linear regression procedure was used to determine the slope (i.e. the swelling rate from water soaking):

$$TTS_N = a + b\, WA_N \qquad (6)$$

where a and b are the regression constants. NTS and RTS after 24-hour soaking were calculated using Equations 2 and 3 respectively.

Finally, a backward selection procedure (5) was used to determine the relationships among thickness swelling (TTS, NTS and RTS), IB strength and MC. The model used has the following form:

$$Y = a_0 + a_1 X + a_2 X^2 + a_3 X^3 \qquad \textbf{(7)}$$

where

Y = TTS (%), NTS (%), RTS (%) or IB strength (psi);

X = MC (%), TTS (%) or NTS(%); and

a_0, a_1, a_2 and a_3 = regression coefficients.

The backward selection procedure removed insignificant terms (at the 5% confidence level) from the model. The first derivative of the established regression equations for TTS and NTS was taken to examine the relationship between thickness swelling rates and MC.

RESULTS AND DISCUSSION

Thickness Swelling in Relation to High Humidity Exposure

Test data on TS, specimen specific gravity (SG) and treatment MC are summarized in Table 2. Table 3 shows regression results on the relationship between TTS, NTS, RTS and MC. Typical plots showing TS as a function of MC are shown in Figure 1 (a: MHS1 and b: SPS). In each graph, the area between the RTS line and the TTS line represents NTS.

TTS increased non-linearly with increases in MC (Figure 1 and Table 3). For MC change up to the 5 to 6% level, very little NTS developed. This can be seen from Figure 1 as data points for TTS and RTS overlap. As MC increased further, however, NTS developed gradually up to the 10 to 12% MC level, and then increased quickly with further increases in MC. The observed TS behavior agreed with earlier results on commercial OSBs (10). After the 25% EMC treatment, flakes in the panels were practically saturated. The mean TTS reached was 33, 32, 37 and 29 percent for MHS1, MHS2, SPS and SPF respectively. The corresponding mean NTS was 19, 20, 24 and 17 percent for the four OSBs. SPS had the largest TTS and NTS among the four OSBs. NTS accounted, on average, for 61 percent of TTS under this treatment condition. This large component of NTS led to significant IB strength loss in the products as shown later.

The polynomial function (Equation 5) fitted the TS-MC data well with coefficient of determination from 0.93 to 0.99 (Table 3). The combined TTS-MC and NTS-MC relationships for the four OSBs (pooled data) are, respectively:

$$TTS = 0.83 - 0.52\,MC + 0.13\,MC^2 - 0.002\,MC^3 \qquad r^2=0.97 \qquad \textbf{(8)}$$

and

$$NTS = 0.60 - 0.67\,MC + 0.10\,MC^2 - 0.002\,MC^3 \qquad r^2=0.93 \qquad \textbf{(9)}$$

Equations 8 and 9 can be used to estimate TTS and NTS for commercial OSBs as a function of MC.

Recoverable thickness swelling, RTS, followed a linear relationship with MC increase for all four OSBs (Figure 1 and Table 3). The swelling rate, coefficient a_1 in Table 2 under RTS, was practically the same for MHS1, SPS and SPF, while it was sightly smaller for MHS2. Suchsland (6) demonstrated that RTS is equal to the volume of water absorbed within the hygroscopic range for wood based composites. Thus, the magnitude of RTS is independent of the structure of the board. This component could not be reduced unless the hygroscopicity of the wood flakes is changed.

The range of MC at which a large TS rate starts to occur varied with types of products studied (2). Table 4 lists the obtained equations on total and non-recoverable TS rates, RTTS=d(TTS)/d(MC) and RNTS=d(NTS)/d(MC), as a function of MC. Typical plots of the swelling rates as a function of MC are shown in Figure 2 (a: MHS1 and b: SPS). It can be seen that both TTS and NTS rates increased with an increase in MC. RTTS and RNTS in MHS1 and RTTS in MHS2 showed a linear increase over the MC range studied. Thus, there was no obvious MC range at which TS dramatically increased for these products. RNTS in MHS2, RTTS and RNTS in both southern pine products followed a quadratic relation with MC change. In this case, large thickness swelling rates appeared to occur after about the 13% MC level. Most of the earlier work (2) reported a 15% to 16% MC level at which large TS started to occur in wood-based products manufactured under hot pressing.

Thickness Swelling in Relation to Water Soaking

A linear relationship existed between TTS and WA of the OSBs (Figure 3 - a: MHS1 and b: SPS). The linear equations obtained from the data accounted for 83% to 93% of the observed behavior (Table 5). Lehmann (3) studied single or multiple water-soaking processes of structural flakeboards of varying resin and wax contents. He showed a similar linear TS-WA relationship for his laboratory-made panels.

The swelling rates (coefficient b - regression slope of the linear TTS-WA curve) of the three sheathing products are practically the same, 0.31 %TTS/%WA (Table 5). Since the first two OSBs were made of mixed hardwoods and the third one made of southern pine, wood species seemed to show insignificant effects on the swelling rate from short-term water soaking. SPF (southern pine OSB for floor underlayment) had the lowest swelling rate in response to water soaking. This was thought to be due to its lower panel density. Lehmann (3) reported a swelling rate of 0.495 %TTS/%WA from his combined data at various water-soaking conditions. Lehmann's swelling rate value was significantly higher than those obtained from this study for commercial OSB. The difference may be due to different board types and soaking processes (e.g. water temperature) used between the two studies.

Density variation exited within a given OSB panel and among different products. Earlier work in the field (9) showed that density had a large influence on the TS properties of OSB. To show the effect of specimen density on the swelling rate of the products, the regression slope of each individual specimen from all four OSBs was combined and is plotted against specimen density in Figure 4. It can be seen that the swelling rate increased with increase in specimen density. This implies that for a given OSB panel, large in-plane density variation can lead to different rates of swelling. This would create out-of-plane swelling stresses between high and low density areas, which in-turn lead to internal damage of the panel. Thus, improving the forming process for uniform properties would greatly improve moisture resistance of the panel.

After the 24-hour soaking, the flakes were not fully saturated. Average TTS reached 18, 18, 16 and 17 percent for MHS1, MHS2, SPS and SPF, respectively (last row under each OSB in Table 2). The corresponding average NTS was 16, 15, 9 and 13 percent for the four OSBs. The overall mean NTS among the four OSBs accounted for 75 percent of the TTS. Compared with the long-term exposure condition at 25% EMC, both TTS and NTS were smaller. Since NTS is directly related to the breakdown of adhesive bonds between the flakes in the panel, the smaller thickness swelling, especially NTS, after 24-hour water soaking would lead to less severe damage to the strength properties of OSB.

Internal Bond Strength

Test data on IB strength are summarized in Table 2. Specimen MC at the time of testing averaged at about 7.5% for all groups. As shown, there were variations in IB values (i.e. large standard deviation as shown in Table 2) at a given treatment condition for all OSBs. This was caused by density variation among specimens within a group and problems associated with curled flakes - a common problem for most commercial OSB mills. Commercial flakes are fairly large (up to 4 inches long and 3 inches wide).

Some wide flakes curled after they lost moisture in drying. During resin application, the inner surface of the curled flakes did not receive any adhesive. As a result, no glue bond was developed on the inner surface of these flakes. Those specimens often failed along the un-bound places.

IB strength for all OSBs varied with treatment conditions applied. The strength values were the highest from the specimens treated with the first two EMC conditions. For all four OSBs, statistical comparison showed no significant difference in the IB values among the two treatments. This indicated that an MC change up to the 7% to 8% level did not cause noticeable mechanical damage in the panel. The average IB strength from the two treatments was 63.1, 62.9, 70.0 and 54.1 psi (9.2, 9.1, 10.2 and 7.9 KPa) for MHS1, MHS2, SPS and SPF, respectively. These values were used as a basis for further comparison.

Further increases in the treatment MC, however, led to increased IB strength losses. After the 25% EMC treatment, residual IB strength averaged at 21.9, 21.1, 34.9 and 16.3 psi (3.2, 3.1, 5.1 and 2.4 KPa) for MHS1, MHS2, SPS and SPF respectively. This implies an IB strength loss of 65.3%, 66.5%, 50.1% and 69.8%, respectively, for the four OSBs, compared with the undamaged panels. There seemed to be no particular trend on the percent of IB reduction as influenced by wood species and product type.

Although specimens reached higher MCs during water soaking (last row under each OSB in Table 2), these specimens were not completely saturated with water. Also, water penetrated into the specimens from the sides and filled the internal voids within the specimens. Therefore, the specimens from water soaking did not swell as much as the specimens from the 25% EMC treatment. As a result, higher residual IB strength remained in the specimens from soaking tests. The average IB strength loss after 24-hour soaking were respectively, 45.7%, 50.8%, 42.3% and 38.2% for MHS1, MHS2, SPS and SPF. This result provides direct evidence that the strength loss in OSB is directly related to the amount of NTS, not the amount of water, in the panel.

Since the decrease in IB strength is directly related to the degree of internal glue bond damage due to excess TS, IB strength is plotted against NTS for each of the four OSBs (Figure 5) with the combined data from the EMC treatments and water soaking for a given OSB. As shown, IB strength for all OSBs decreased almost linearly with increase in the amount of NTS in the specimens. Regression analysis shown in Table 6 indicated that for every percent of NTS that occurred in the specimens, there was, on average, 2.0 psi (0.29 KPa) IB strength loss. The average rate of IB strength reduction for the two mixed hardwood OSBs was about 0.3 psi (0.044 KPa) higher compared with that of the two southern pine products. Curled flakes were found to play a significant role in causing the IB strength reduction of the hardwood OSBs. The large amount of IB strength reduction would certainly lead to reduction in bending strength and stiffness of OSBs as demonstrated in the earlier studies (10,11).

The NTS can occur through exposing the panels to high humidity conditions and directly contacting with water. Therefore, efforts to improve durability properties of OSB should be concentrated on developing techniques to reduce the amount of NTS in the panel.

CONCLUSIONS

Four types of commercial OSBs were tested to investigate their swelling behavior in relation to both high humidity exposure and direct contact with water and to assess associated IB strength losses. From the study the following conclusions can be drawn.

1). MC changes in commercial OSBs up to the 7% to 8% level did not cause significant NTS and IB strength loss in the panel.

2). MC increases above the 12% level led to large NTS and IB strength loss. For an MC change of about 25% in the panel, TTS and NTS reached, on average, 31.1% and 19.8 % respectively, for the four OSBs. This resulted in an average IB strength loss of 62.9%, compared with the undamaged control groups.

3). Thickness swelling from a short-term soaking test followed a linear relationship with the amount of water absorbed. The swelling rate varied with specimen density within a given panel and among different products.

4). Average TTS and NTS for the four OSBs after 24-hour water soaking reached 17.5% and 13.1% respectively. The average IB strength loss was 49.2% for the four products.

5). Regardless of the way OSB absorbed moisture, there was, on average, 2 psi (0.29 KPa) IB strength loss for every percent of NTS that occurred in the specimens. Wood species and product type showed no obvious effects on the IB reduction rate. Therefore, efforts to improve durability properties of OSB products should be concentrated on developing techniques to reduce the amount of NTS in the panel.

LITERATURE CITED

1. American Society for Testing and Materials (ASTM). 1996. Annual Book of ASTM Standard D1037-96. American Society for Testing and Materials. Philadelphia, PA. 646 pp.

2. Halligan, A. F. 1970. A review of thickness swelling in particleboard. Wood Sci. Technol. 4:301-312.

3. Lehmann, W. F. 1978. Cyclic moisture conditions and their effect on strength and durability of structural flakeboards. Forest Prod. J. 28(6):23-31.

4. Liu, J. Y. and J. D. McNatt. 1991. Thickness swelling and density variation in aspen flakebaords. Wood Sci. Technol. 25: 73-82.

5. Sas Institute Inc. 1994. SAS/STAT User's guide. Version 6. SAS Institute Inc., Cary, NC. 1688 pp.

6. Suchsland, O. 1966. Some performance characteristics of 'interior' and 'exterior' type particle board. Michigan Agri. Experimental Station Quarterly Bulletin. 49(2):200-210.

7. Suchsland, O. and H. Xu. 1991. Model analysis of flake board variables. Forest prod. J. 41(11/12):55-60.

8. Winistorfer. P. M. and D. DiCarlo. 1988. Furnish moisture content, resin nonvolatile content, and assembly time effects on properties of mixed hardwood strandboard. Forest Prod. J. 38(11/12):57-62.

9. Winistorfer, P. M. and W. Xu. 1996. Layer water absorption of medium density fiberboard and oriented strandboard. Forest Prod. J. 46(6):69-72.

10. Wu, Q. and O. Suchsland. 1997. Effect of moisture on the flexural properties of commercial oriented strandboard. Wood Fiber Sci. 29(1):47-57.

11. Wu, Q. 1998. Effect of moisture on bending and breaking resistance of commercial oriented strandboard. Wood Fiber Sci. 30(2):205-209.

Table 1. Basic Properties of Commercial OSBs Tested.

Board Type	Thickness (inch)	Span rating	Specific [a] Gravity
Mixed hardwoods			
Sheathing 1 (MHS1)	15/32	32/16	0.70
Sheathing 2 (MHS2)	7/16	24/16	0.70
Southern pine			
Sheathing (SPS)	7/16	24/16	0.70
Floor underlayment (SPF)	23/32	24 OC	0.62

[a]. Specific gravity is based on oven-dry weight and volume.

Table 2. Summary of test data on commercial OSBs [a].

OSB Type	Specific Gravity [b]	MC (%)	TTS (%)	NTS (%)	IB [c] (psi)
MHS1	0.70 (0.06)	4.75 (0.06)	1.93 (0.72)	0.52 (0.71)	66.38 (19.00)
	0.69 (0.06)	6.49 (0.08)	3.26 (0.98)	0.83 (0.56)	59.95 (13.46)
	0.69 (0.04)	12.68 (0.17)	9.21 (1.05)	3.62 (0.93)	58.46 (15.14)
	0.70 (0.06)	24.33 (0.95)	33.03 (4.03)	18.65 (3.41)	21.95 (8.30)
	0.75 (0.07) [d]	51.31 (6.48)	17.60 (4.13)	16.15 (6.09)	34.28 (11.70)
MHS2	0.70 (0.06)	4.79 (0.09)	1.96 (0.54)	0.21 (0.48)	60.33 (19.40)
	0.67 (0.07)	6.35 (0.46)	3.36 (0.54)	0.72 (0.34)	65.52 (15.26)
	0.67 (0.04)	12.97 (0.26)	6.32 (1.04)	3.56 (1.15)	57.64 (24.37)
	0.73 (0.06)	24.05 (0.82)	32.03 (3.65)	20.17 (3.86)	21.10 (11.80)
	0.71 (0.03)	61.36 (6.86)	22.79 (4.09)	18.48 (3.51)	30.70 (9.74)
SPS	0.69 (0.03)	4.99 (0.08)	2.15 (0.23)	0.10 (0.12)	73.90 (21.80)
	0.69 (0.07)	6.71 (0.11)	4.44 (0.41)	0.99 (0.27)	66.14 (11.52)
	0.67 (0.04)	12.57 (0.26)	9.13 (2.24)	3.79 (1.14)	65.45 (11.95)
	0.71 (0.04)	24.62 (4.95)	37.15 (5.18)	24.24 (4.13)	34.97 (6.20)
	0.74 (0.07)	46.68 (6.77)	17.50 (3.40)	12.68 (1.11)	40.42 (19.50)
SPF	0.61 (0.03)	4.88 (0.34)	4.88 (0.15)	0.13 (0.10)	50.51 (11.02)
	0.62 (0.04)	6.65 (0.29)	6.65 (0.48)	0.87 (0.24)	57.78 (17.60)
	0.59 (0.06)	12.75 (0.16)	12.75 (1.40)	3.33 (1.21)	44.84 (14.91)
	0.62 (0.02)	22.31 (0.59)	29.31 (3.37)	17.47 (2.99)	16.31 (4.20)
	0.66 (0.06)	35.42 (4.34)	16.33 (2.67)	8.75 (1.39)	33.42 (16.40)

[a]. Values in parentheses are standard deviations based on ten specimens.
[b]. Specific gravity is based on oven-dry weight and volume.
[c]. Specimen MC at the time of IB strength testing averaged at 7.5% for all groups and 1 psi = 6.894 KPa.
[d]. Data from the soaking group.

Table 3. Regression results on the relationship between thickness swelling (TTS, NTS, or RTS) and MC. Model : TTS, NTS, or RTS = $a_0 + a_1$ MC + a_2 MC^2 + a_3 MC^3.

OSB Type	Regression Coefficients				Coefficient of determination, r^2
	a_0	a_1	a_2	a_3	
			TTS (%)		
MHS1	0.54	0	0.055	0	0.98
MHS2	0.53	0	0.054	0	0.98
SPS	0.20	0.410	0	0.0020	0.99
SPF	0.14	0.380	0	0.0018	0.99
			NTS (%)		
MHS1	0.13	0	0.031	0	0.94
MHS2	0.24	0	0	0.0014	0.96
SPS	0.13	0	0.014	0.0006	0.97
SPF	0.12	0	0	0.0015	0.98
			RTS (%)		
MHS1	-0.936	0.565	0	0	0.95
MHS2	-0.404	0.493	0	0	0.94
SPS	-0.507	0.522	0	0	0.97
SPF	-0.516	0.566	0	0	0.93

Table 4. TTS and NTS swelling rates as a function of MC in commercial OSB panels from high humidity exposure treatments.

OSB Type	Total TS Rate (%TTS/%MC)	Non-recoverable TS Rate (%NTS/%MC)
MHS1	$d(TTS)/d(MC) = 0.11\ MC$	$d(NTS)/d(MC) = 0.06\ MC$
MHS2	$d(TTS)/d(MC) = 0.11\ MC$	$d(NTS)/d(MC) = 0.004\ MC^2$
SPS	$d(TTS)/d(MC) = 0.41+0.006\ MC^2$	$d(NTS)/d(MC) = 0.03\ MC+0.002\ MC^2$
SPF	$d(TTS)/d(MC) = 0.76+0.005\ MC^2$	$d(NTS)/d(MC) = 0.005\ MC^2$

Table 5. Regression results on TTS-WA relationship from water soaking test with a linear model (TTS = a + b WA).

OSB Type	Regression coefficients		Coefficient of determination, r^2
	Constant, a (%TTS)	Slope, b (%TTS/%WA)	
MHS1	0.42	0.32	0.83
MHS2	- 0.71	0.31	0.83
SPS	2.26	0.32	0.86
SPF	0.46	0.24	0.93

Table 6. Regression results on IB-NTS relationship for commercial OSBs with a linear model ($IB = a_0 + a_1$ NTS).

OSB Type	Regression coefficients		Coefficient of determination, r^2
	Constant, a_0 (psi)	Slope, a_1 (psi/%NTS)	
MHS1	61.62	-1.973	0.52
MHS2	60.64	-2.234	0.51
SPS	72.15	-1.633	0.63
SPF	50.77	-1.983	0.47

Figure Captions:

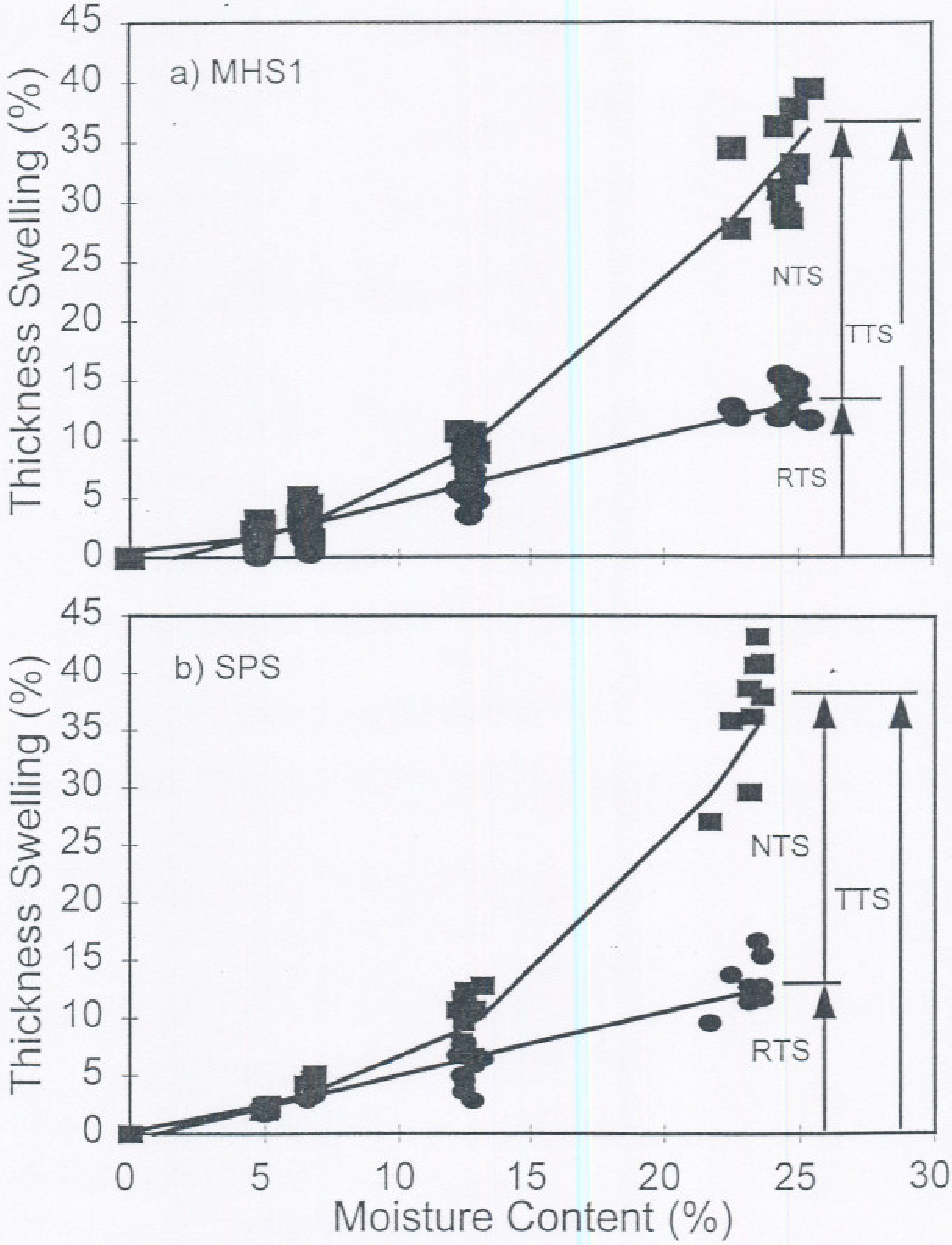
Figure 1. Thickness swelling as a function of MC (a: MHS1 and b: SPS). Lines showing the regression fit of the data.

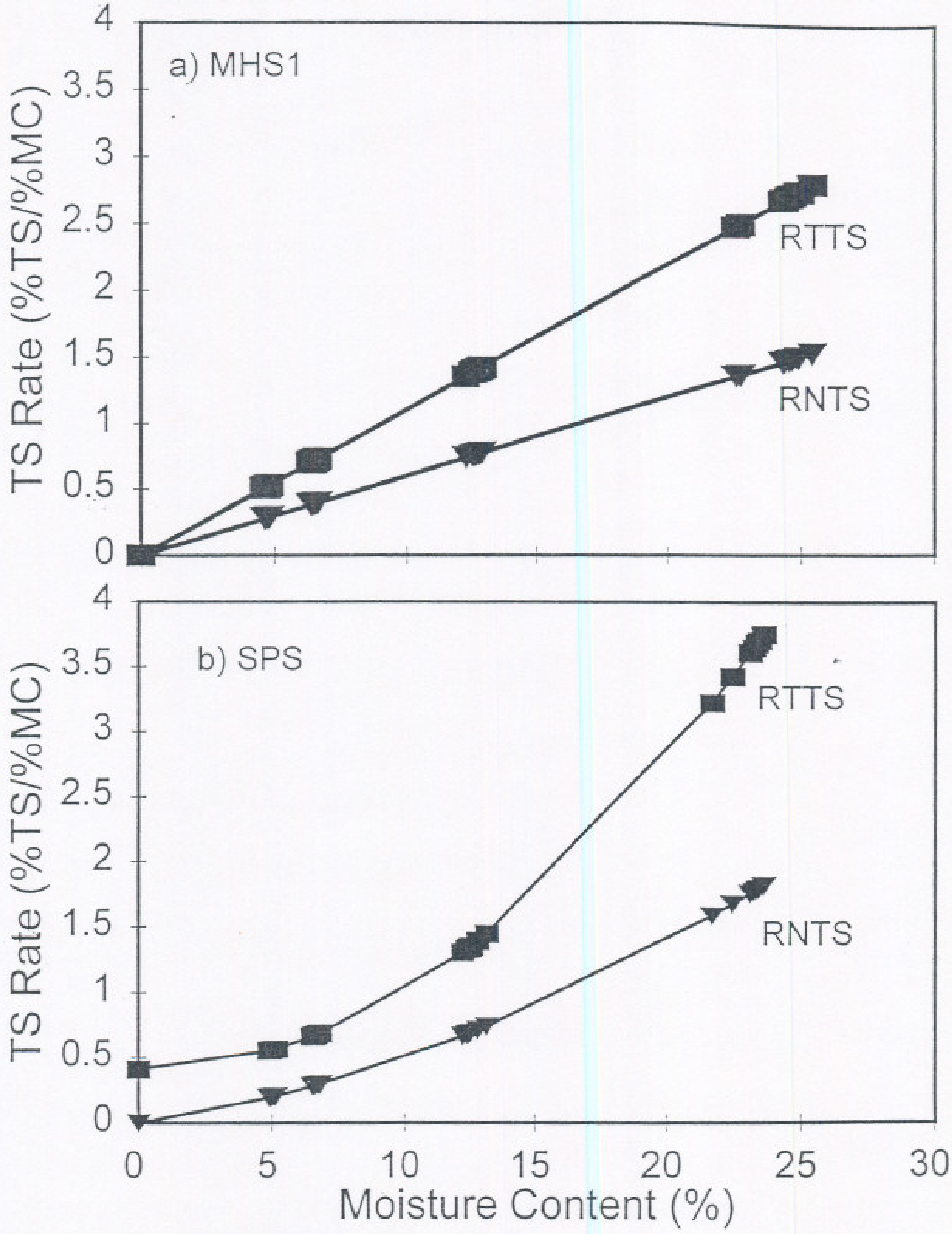
Figure 2. TTS and NTS swelling rates as a function of MC from high humidity exposure conditions (a: MHS1 and b: SPS).

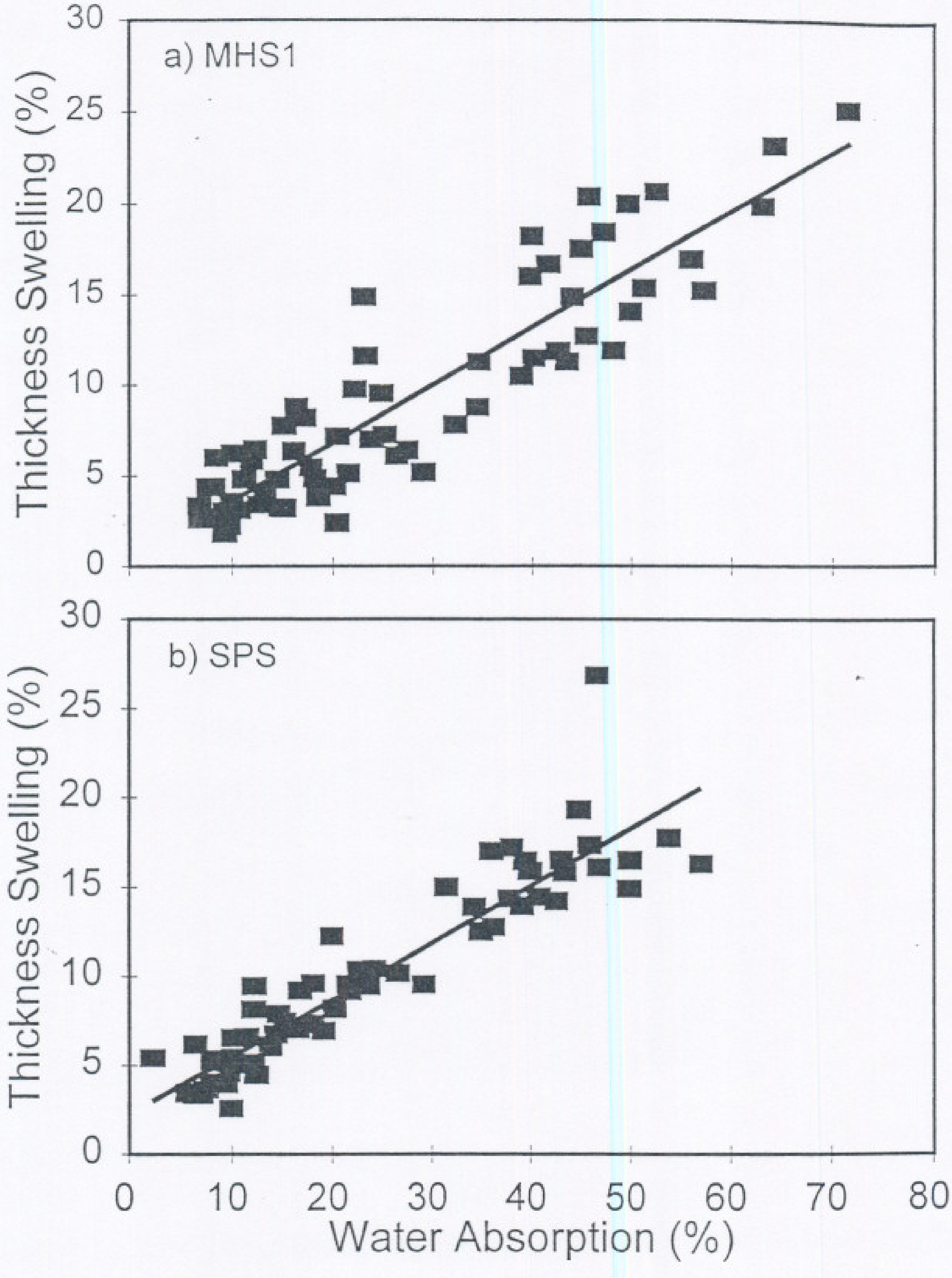
Figure 3. TTS and WA relationship from 24-hour water soaking at room temperature (a: MHS1 and b: SPS). Lines showing a linear fit of the data.

Figure 4. Thickness swelling rate from the 24-hour water soaking as a function of sample specific gravity of the combined data.

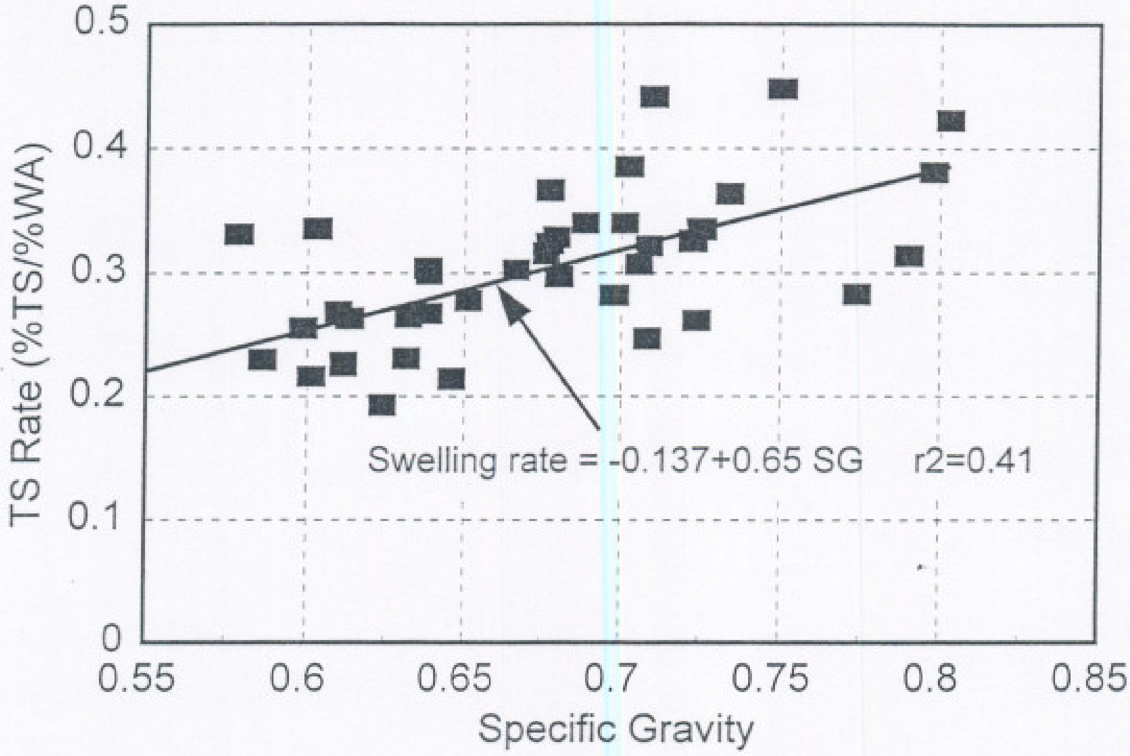
Figure 5. Internal bond strength as a function of non-recoverable thickness swelling (a: MHS1, b: MHS2, c: SPS and d: SPF). Lines showing a linear fit of the data.


a) MHS1
b) SPS
Thickness Swelling (%)
Moisture Content (%)
NTS
TTS
RTS
0
5
10
15
20
25
30
35
40
45

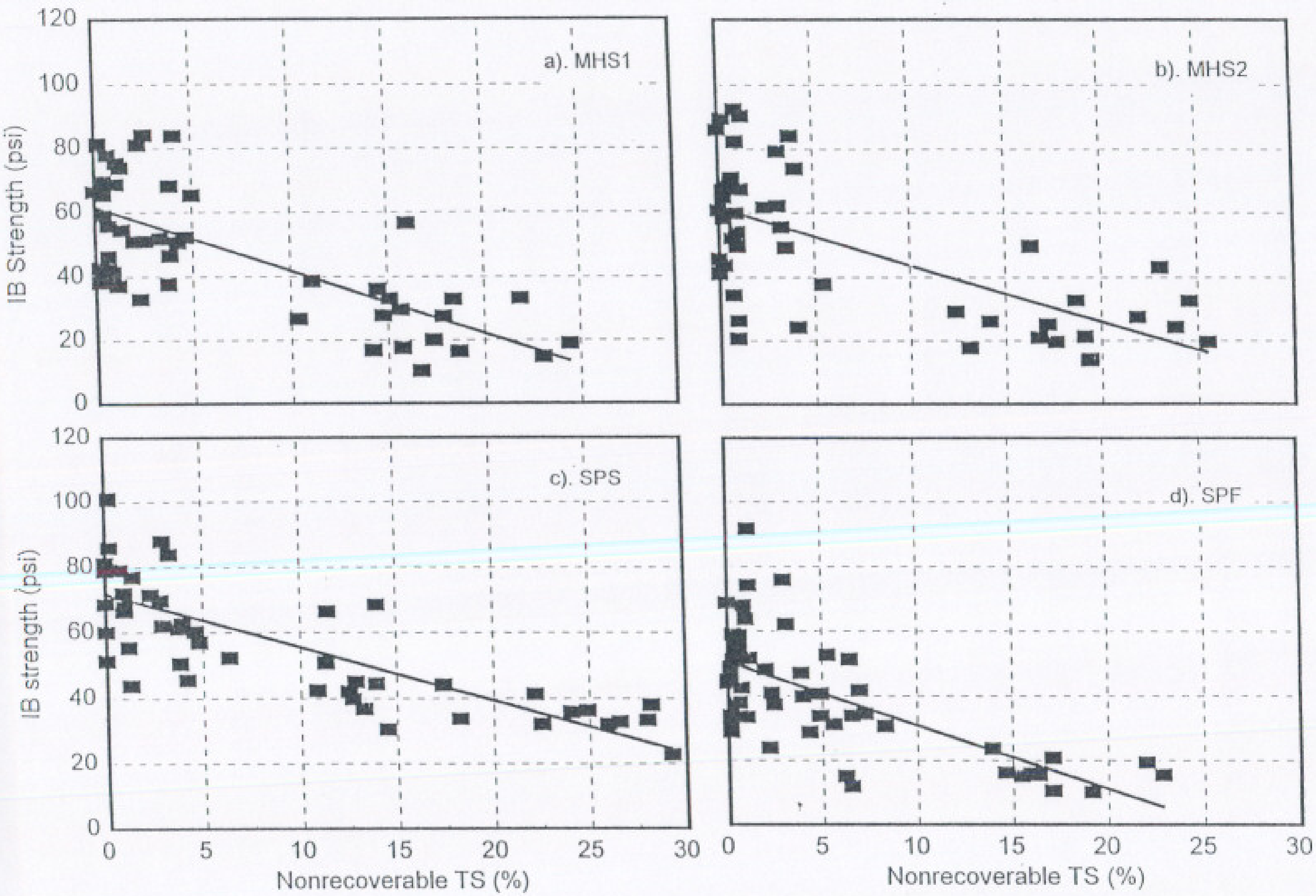

a) MHS1
RTTS
RNTS
b) SPS
RTTS
RNTS
TS Rate (%TS/%MC)
TS Rate (%TS/%MC)
Moisture Content (%)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25
30



a) MHS1
b) SPS
Thickness Swelling (%)
Thickness Swelling (%)
Water Absorption (%)
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80



0.5
0.4
0.3
0.2
0.1
0
TS Rate (%TS/%WA)
Swelling rate = -0.137+0.65 SG r2=0.41
0.55
0.6
0.65
0.7
0.75
0.8
0.85
Specific Gravity



a). MHS1
b). MHS2
c). SPS
d). SPF
IB Strength (psi)
IB strength (psi)
0
20
40
60
80
100
120
0
5
10
15
20
25
30
Nonrecoverable TS (%)
Nonrecoverable TS (%)