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EFFECT OF MOISTURE CONTENT ON MECHANICAL AND DIMENSIONAL PROPERTIES OF NEW ZEALAND PARTICLE BOARDS AND FIBRE BOARDS

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ABSTRACT

The effect of moisture content induced by relative humidity on some mechanical and dimensional properties of New Zealand flooring particle board, medium density fibre board and hardboard is investigated. Some results of engineering consequence when the moisture content increases from about 10% to 20% are as follows: the modulus of elasticity of flooring particle board is reduced by at least one third, the linear expansion (in the plane of the board) of flooring particle board is at least 0.3% and the internal bond strength of standard medium density fibre board is reduced by two thirds. Some implications of this study for New Zealand building practice are discussed. In particular, flooring particle board may reach a moisture content of 20% when the floor is exposed to a damp subfloor and shielded from the indoor environment by floor coatings.

INTRODUCTION

It is a common observation that wetting by liquid water causes thickness swelling in uncoated wood-based composites and a reduction in their strength. However, the moisture content (MC) induced by the relative humidity of the surrounding air alone has important effects on the dimensional and mechanical properties of these composites. Even though the maximum MC induced by humidity (about 30%) is lower than the maximum induced by wetting, humidity-induced changes in dimensional and mechanical properties are important. The thickness swelling of wood-based composites caused by increasing the humidity from 65% to 90%, ranges from 4% to 12% (Dinwoodie 1979). A number of overseas workers (Halligan & Schniewind 1974, McNatt 1974a, McNatt 1974b, McNatt 1975, Saito et al 1978) have found that the modulus of elasticity and modulus of rupture of wood-based composites at high humidities (near 90%) range from about 60 to 90% of those at medium humidities (near 50 to 65%). However, these studies do not use composites made from Pinus radiata which is the main wood used for composites in New Zealand.

New Zealand has one of the largest production capacities in the world for medium density fibre board (MDF), being about 400,000 m^3/year in 1988 (Edwards 1988). Particle board production capacity was about 300,000 m^3/year in 1988 (Edwards 1988) and a high proportion (75% in 1981) of new flooring in New Zealand buildings is particle board (McLaughlan 1983). Hardboard production capacity was about 30,000 m^3/year in 1988 (Edwards 1988).

The atmosphere in New Zealand population centres, particularly by the coast, is humid, being near 80% (N.Z. Meteorological Service 1983). Subfloor air spaces are typically more humid than the outside air even with subfloor ventilation (which is mandatory for suspended floors). Many existing particle board floors are exposed directly to this damp air and can attain a high MC. However, newer dwellings have perforated foil insulation separating the floor from the subfloor air which markedly reduces the humidity next to the underside of the floor.

In view of the significant production capacity, and the unique combination of species of wood used and the humid environments found for some New Zealand buildings, a study on the effect of humidity on the dimensional changes and basic mechanical properties of New Zealand wood composites was started. The aim is to find what implications in engineering properties follow from MC-induced property changes in New Zealand composites. Data comes from laboratory tests and the property changes are discussed with an emphasis on the implications for New Zealand buildings.

MATERIALS

A range of seven types of established New Zealand wood-based composites, designated as boards A to D were obtained direct from the manufacturers. One large sheet only was used to represent each type of board in these tests to reduce variability and more clearly establish relationships between MC and board properties. All boards contained, predominantly, the timber species Pinus radiata. The adhesive for boards A, B, and C was urea formaldehyde, while the moisture resistant versions A1 and C1 contained melamine urea formaldehyde.

Three brands of flooring particle board were used: Boards A, A1 and B, all nominally 20mm in thickness, with a density of 690 or 730 kg/m^3 and with faces of long, thin flakes and a core of more coarse flakes.

The MDFs, boards C and C1, were nominally 18mm and 19mm in thickness, respectively, with densities of 725 and 740 kg/m^3 and essentially homogeneous. Board C is commonly used for furniture and board C1 is used for window reveals.

The hardboards, board D and the moisture resistant version (oil-tempered), board D1, were manufactured by the wet process, nominally 6mm in thickness, with a density of 980 and 1020 kg/m^3, respectively. Board D is used for wall linings, ceiling linings and floor underlays and board D1 is commonly used for wall linings in wet areas.

METHODS

A summary only is given. Details have been presented elsewhere (Watkinson and van Gosliga 1989).

All samples were first conditioned to 65% humidity so that dimensions at this control condition could be found for all samples. They were then randomly assigned to one of the four exposure conditions of nominally 25%, 65%, 85% and 95% humidity at 22°C, and MC equilibrium at these humidities was established.

The source of test methods for finding MC, the dimensional changes of thickness swelling and linear expansion, and the mechanical properties of modulus of elasticity, modulus of rupture, internal bond strength and compressibility (perpendicular to the plane of a sheet) was BS 5669:1979 (British Standards Institution 1979) with minor modifications. However, the source of the test methods was BS 1142:Part 1:1971 (British Standards Institution 1985) for hardboard when determining modulus of elasticity, modulus of rupture, and internal bond strength. All properties were determined at the MC resulting from equilibration at the final humidity.

Samples were examined visually for fungi after completion of these tests.

RESULTS AND DISCUSSION

Statistical Analyses

A standard analysis of variance was performed to assess the effect of humidity on MC, dimensional changes and mechanical properties. The analyses were significant at the 1% level for every property. In addition, analyses contrasting properties at the control environment (65% humidity) with other environments pooled were significant at the 1% level for every property with the following exceptions: linear expansion for board D and board D1, modulus of elasticity for board D and all mechanical properties for board D1. However, the analyses contrasting properties were significant at the 5% level with linear expansion for board D and with compressibility and modulus of elasticity (using dimensions at the time of test) for board D1. Thus, in general, the properties of these composites are significantly different when the humidity is changed.

Moisture Content

The MC data, obtained after first preconditioning at 65% humidity and then conditioning at the final humidity, are presented in Figure 1. MC changes much more from 65%RH to 95% RH (increases typically 7-11%) than from 65%RH to 25%RH (decreases typically 4%). Therefore, moisture-induced changes in dimension and mechanical properties are likely to be greater when changing to humidities above 65% than for equal changes in humidity below 65%. At high humidities, MCs of up to about 20% are obtained for particle boards and MDFs and about 15% for hardboards. Equilibrium MC values are on or within the hysteresis loops found by other workers (Cunningham and Sprott 1984) on similar composites.

The hardboards attained a lower MC (3.6% - 16%) at a given humidity than the particle boards and MDFs (5.9% - 23%). This can be explained by the presence of hydrophobic oils and the less hydrophilic nature of the processed timber constituents of the hardboards compared with the other composites. The moisture resistant variety of particle board attained a slightly lower MC for a given humidity than the standard particle boards.

Hereafter, the following approximations are used for the equilibrium MC attained in this work at the control environment of 65 ± 5 % humidity: particle boards and MDFs attained 10% MC and hardboards attained 7% MC.

Dimensional Changes

MC-induced dimensional changes in the thickness (thickness swelling) of these composites are presented in Figure 2 and changes parallel to the plane of a sheet (linear expansion) are in Figure 3. These data were obtained after preconditioning at 65% humidity and conditioning at the final humidity. Dimensions at the equilibrium MC of the control samples (65% humidity) have been taken as the zero, or reference point.

Thickness swelling is typically 20 to 30 fold larger than linear expansion over the MC range tested. The maximum thickness swelling of about 15% , and the maximum linear expansion of about 0.5% were both in standard flooring particle board. Thickness swelling is approximately linear with MC for the entire MC range (3 - 16%) for hardboards and above 10% MC for the other composites. Plots of linear expansion versus MC are approximately linear for standard particle boards above 10% MC.

The changes in thickness and linear expansion with MC are in general similar to other work on analogous wood composites (McNatt 1974a, N.Z. Forest Products Ltd 1977, United States Dept. Agric., Forest Service 1981).

Dimensional Changes: Implications for New Zealand buildings

These dimensional changes are relevant to coated composites installed in buildings at medium humidities (near 65%) and used at high humidities. Water vapour from the air can penetrate all coatings and acrylic- and polyvinyl acetate-based paints offer little resistance. The exact changes depend on the change in humidity and the total time of exposure. Although humidity-induced dimensional changes may not, in practice, prove to be a major problem, the following worst cases may be inferred:

Moisture resistant MDF window-reveals initially at 10% MC (65% humidity) and 19mm thick would swell by as much as 2.5mm if they were kept at 20% MC (95% humidity). However, this level of humidity-induced swelling is very unlikely to occur in a typical house since the humidity by the window is unlikely to remain near 95%. Another possible source of significant MC increases in the sill is prolonged high humidity from a damp wall cavity beneath the sill.

MDF of 18mm thickness installed at 10% MC as a washbasin unit and left in a damp bathroom may swell as much as 2mm if it reaches 20% MC. Oil-tempered hardboard installed at 7% MC as a shower lining may expand as much as 1.7mm per metre width if it reaches 14% MC. This expansion may need to be accomodated by jointers, or buckling of the sheet will occur. In both these cases, the MC increase could be caused by an increase in humidity from 65% to 95% alone, but it is unlikely in a typical building that such a high humidity would be sustained long enough to attain such high MCs. Indoor humidities can be highly variable, but mean general values near 85% humidity (MCs are now 10 to 12%) in unheated and solar-shaded buildings are more likely than mean values of 95%.

MC-induced linear expansion of a number of adjacent flooring particleboard sheets can cause rotation of an adjacent rigid wall system (or possibly out-of-plane buckling of the floor). To stop movement of the rigid wall (eg. concrete or masonry), a 10mm gap is normally left between it and the floor perimeter. Although the largest MC increase will be induced by rain rather than humidity, the MC increase from humidity is still significant. Standard flooring particle board will expand up to 5.4mm per metre width when humidity increases from 65% (about 10% MC) and is maintained at 95% (about 20% MC). Later discussions on bending stiffness will show that high MCs may be attained in floors. Fortunately, in practice, the floor movement is restrained by the nailing to a timber framework. About 62% of the movement can be restrained by nails (Kasper and Carroll 1979) yielding restrained expansion of about 2mm per metre width. Thus, proper nailing of large areas of composite sheets before they increase in MC is important.

Mechanical Properties

The mechanical properties are bending moment capacity (Figure 4), bending stiffness (Figure 5), internal bond strength (Figure 6) and compressibility (Figure 7). Following the example of other workers (McNatt 1974a, McNatt 1974b, McNatt 1975, Saito et al 1975) the modulus of rupture and modulus of elasticity are expressed as a percentage of values at the control environment (65% humidity). These ratios derived from the modulus of rupture and modulus of elasticity are called bending moment capacity and bending stiffness, respectively, and they both use dimensions at the control environment. Thus any change in these properties with MC is due to a change in the maximum load or the slope of the load / deformation curve rather than a change in thickness or width. Bending moment capacity and bending stiffness are properties of a component rather than properties of a material.

Actual values at the control environment of 65% humidity and the variability are recorded for all mechanical properties in Table 1. Manufacturers generally only advertise mechanical properties at a MC induced by humidities near 50% to 65%. Since inter-batch variability has not been included in this work, the mean values in Table 1 are generally similar to, but not the same as manufacturers' mean values. In addition, differences between manufacturers' mean values and Table 1 arise because of slight differences in test method (e.g., test machine crosshead speed).

No wood decay fungi were found in the composites at the highest MC. Thus the reduction in particle board modulus of rupture, modulus of elasticity and internal bond strength at high MC is probably due mainly to a mechanical breaking of adhesive to wood component bonds (Irle and Bolton 1988). It is possible that similar mechanisms apply to the MDFs, which have essentially the same adhesive as found in the particle boards. Similarly, reductions in these properties for the hardboards can be attributed to softening of the amorphous cellulose (Back and Ostman 1983).

It is important to note that the strength and stiffness of wood-based composites will be reduced not only by MC but also eventually by wood decay fungi and wood eating insects if the composites remain for long periods of time at very high MCs (above 20%). In the current work, composites were left at high humidities only long enough (up to several months) to approach equilibrium MC.

In general, bending moment capacity and bending stiffness decrease with increasing MC. For particle boards and MDFs, values at 20% MC are 50% to 70% of those at 10% MC. For hardboards, a MC increase from 10% to 20% must be based on an extrapolation of the existing lines and values at 20% MC are about 65 to 80% of the original ones.

Internal bond strength generally decreases with increasing MC but several boards have statistically significant maxima. Moisture resistant flooring particle board (A1) and MDF (C1) both have a maximum between 7 to 12% MC, and standard hardboard has a maximum between 5 to 9% MC. For particle boards and MDFs, values at 20% MC are 45% to 65% of those at 10% MC. For hardboards, a MC increase from 10% to 20% must use an extrapolation of the existing lines and values at 20% MC are about 50% to 90% of the original ones.

The retention of modulus of rupture, modulus of elasticity and internal bond strength in this work is, in general, similar (or slightly higher than) retentions of properties for commercial Japanese particle boards (Saito et al 1978) and commercial and experimental United States particle boards and hardboards (Halligan and Schniewind 1974, McNatt 1974a, McNatt 1974b, McNatt 1975). In all these comparisons; the same initial and final MC are used. No literature could be found to compare with the retention of the same mechanical properties studied in the current work for MDF.

Compressibility is generally constant over the MC range 6% to 12% and for particle boards and MDFs increases quickly above a MC of 12% to 14%. For hardboards, the compressibility does not increase markedly above 12% MC.

Mechanical Properties: Implications for New Zealand buildings

Perhaps the most important practical implication of this study for current New Zealand building practices is the reduction in bending stiffness of flooring particle board at high MCs (near 20%). At about 20% MC all three particle boards have a bending stiffness of about 65% compared to standard conditions of about 10% MC. If the modulus of elasticity using dimensions at the time of test is measured, its retention is only 53% for a MC increase from 10% to 20%. Thus a floor near 20%MC may have noticeably larger deflections than one with a MC near 10%.

High MCs near 20% might be found when the bottom of the floor is directly exposed to a damp subfloor and the top of the floor is shielded from the lower indoor humidity by a vapour-impermeable material. This material could commonly include polyurethane floor coatings or sheet PVC floor coverings. Damp subfloor air will often have a higher humidity than the outside air which itself has a yearly average of near 80% for New Zealand population centres (N.Z. Meteorological Service 1983). The likely MC of particle board floors in New Zealand houses with relatively damp subfloors can be estimated as 14% to 24%. These MCs were based on a survey which included the MC of timber strip flooring over damp subfloors (Trethowen and Middlemass 1988) and conversion to the probable MC if particle board were placed in the same effective humidity (Cunningham and Sprott 1984). Field studies of the MC of flooring particle board would indicate how important this effect is.

This analysis excludes the additional degradation found in most particle board floors from short term natural weathering. A past study (Fry and Whitney 1980) on New Zealand flooring particle board showed modulus of elasticity retention of about 80% after the standard maximum exposure period of 2 months and sanding. There were also reductions in modulus of rupture and internal bond strength.

Flooring particle board is reduced in thickness by as much as 1.7mm under 1.4MPa pressure at high MCs (20%). At the control environment near 10% MC the thickness reduction is only 0.3mm. The pressure exerted by gravity from two storeys of a standard residential building via the bottom plate onto the floor will normally be less than the compressibility test pressure of 1.4 MPa if the timber bottom plate resting on the floor is perfectly flat. But the pressure on the floor can become similar to the test pressure if the plate is bowed. To find the actual pressure on the particle board from load bearing walls, collection of field data would be necessary.

Internal bond strength retentions were as little as 47% for particle boards and MDFs (MC increases from 10% to 20%) and as little as 69% for hardboards (MC increases from 7% to 15%). Internal bond strength correlates with compression shear tests (Hall and Haygreen 1983) and thus is probably also an indicator of interlaminar shear strength. Interlaminar shear strength duplicates shear stresses for glued structural assemblies like I beams and box beams. Thus the effectiveness of these particle boards, MDFs and hardboards for webs in I beams or in box beams is likely to be reduced at high MCs (15 to 20%) (eg. in subfloor spaces). Although wood-based composite I beams are not used in large quantities in New Zealand, hardboard webbed beams have been used for many years in Europe (McNatt 1980). In addition there is an anticipation of significant future use of other wood composites for this application (Lee and Stephens 1988).

The assumption that internal bond strength trends can be an indicator of interlaminar shear changes is shown to be at least a reasonable first approximation when comparing this work with a 1988 study (Lee and Stephens 1988). The retention in interlaminar shear of oil-tempered hardboard increasing from 6% to 14% MC was 66% in that study, being similar to the retention in internal bond strength for oil-tempered hardboard over the same MC range of 68% for the present work. The retention in interlaminar shear of urea formaldehyde bonded particle board increasing from 8% to 15% MC was 93% in the same study. This retention is similar or higher than the retention in internal bond strength of 90% to 71% for urea formaldehyde bonded particle board increasing from 8% to 15% MC for the present work.

Considering the significant changes in selected mechanical properties (and dimensional changes) caused by MC changes in wood composites, MC needs to be accounted for when structural integrity is important. The present results indicate several areas where MC needs to be considered for design purposes. To get more accurate property values for design purposes there is a need to include representative production batches within each type of board.

CONCLUSIONS

The effect of moisture content induced by humidity on selected dimensional and mechanical properties of seven wood-based composites commercially available in New Zealand has been shown to be significant.

If wood composites are used in engineering applications, then in-service moisture content needs to be accounted for. However, to get more accurate property values for design purposes and address inter-batch variability, tests ought to include representative production batches within each type of board.

Indications of areas where moisture content is an important variable are found in some "worst case" practical implications for New Zealand buildings. Cases have been deduced from dimensional and basic mechanical property changes caused by increases in moisture content from about 10% (7% for hardboards) at standard indoor humidities to about 20% (15% for hardboards) at high humidities. Some examples follow using these increases in moisture content:

The bending stiffness of flooring particle board is reduced by about 35%. A moisture content of about 20% may be obtained when the floor is directly exposed to a damp subfloor and it is shielded from the dry indoor air by a vapour-impermeable floor coating or covering.

Standard flooring particle board when unrestrained by nails can expand, parallel to the sheet face, up to 5.4mm per metre width. Fortunately, most expansion is probably restrained by nailing to a timber framework.

Internal bond strength, while not directly related to the shear stresses in glued assemblies like I beams or box beams, gives some indication of the more relevant parameter, interlaminar shear strength. Thus the large reductions (of up to 58%) in internal bond strength indicate that the effectiveness of these particle boards, medium density fibre boards and hardboards for webs in I beams or in box beams is likely to be reduced at high moisture contents.

Window sills of 19mm moisture resistant medium density fibre board can swell as much as 2.5mm. However, moisture contents near 20% are very unlikely to be caused by humidity alone in typical use in New Zealand buildings.

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TABLE 1. - Mechanical properties and moisture content of Wood based composites at the control environment of 65% humidity.

BOARD CODE	MOISTURE CONTENT (%) (a)	MODULUS OF RUPTURE (MPa)	MODULUS OF ELASTICITY (MPa)	INTERNAL BOND STRENGTH (MPa)	COMPRESS-IBILITY (mm)
A	11.14 (0.06)	25.3 (0.8)	3610 (120)	0.68 (0.03)	0.264 (0.005)
A1	10.17 (0.04)	28.9 (0.5)	3630 (70)	0.91 (0.03)	0.32 (0.02)
B	10.33 (0.06)	23.4 (0.7)	3170 (60)	0.38 (0.03)	0.270 (0.003)
C	9.61 (0.06)	41.4 (0.7)	3080 (60)	0.70 (0.03)	0.204 (0.006)
C1	9.81 (0.03)	34.8 (0.5)	2790 (30)	0.59 (0.02)	0.266 (0.002)
D	7.47 (0.08)	46.8 (2.0)	7080 (270)	2.75 (0.1)	0.102 (0.004)
D1	7.09 (0.09)	38.2 (1.2)	5560 (210)	1.60 (0.07)	0.146 (0.005)

(a)
Standard errors of the means are given in parentheses.

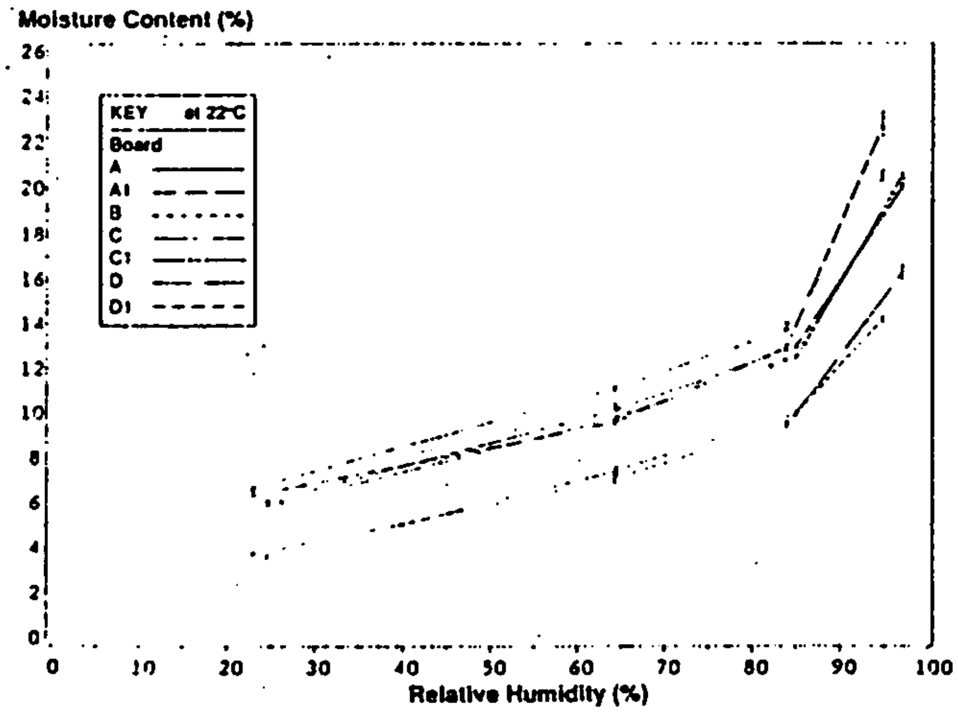

Figure 1. -. The effect of Relative Humidity on Moisture Content. The 95% confidence limits are given for the mean values.

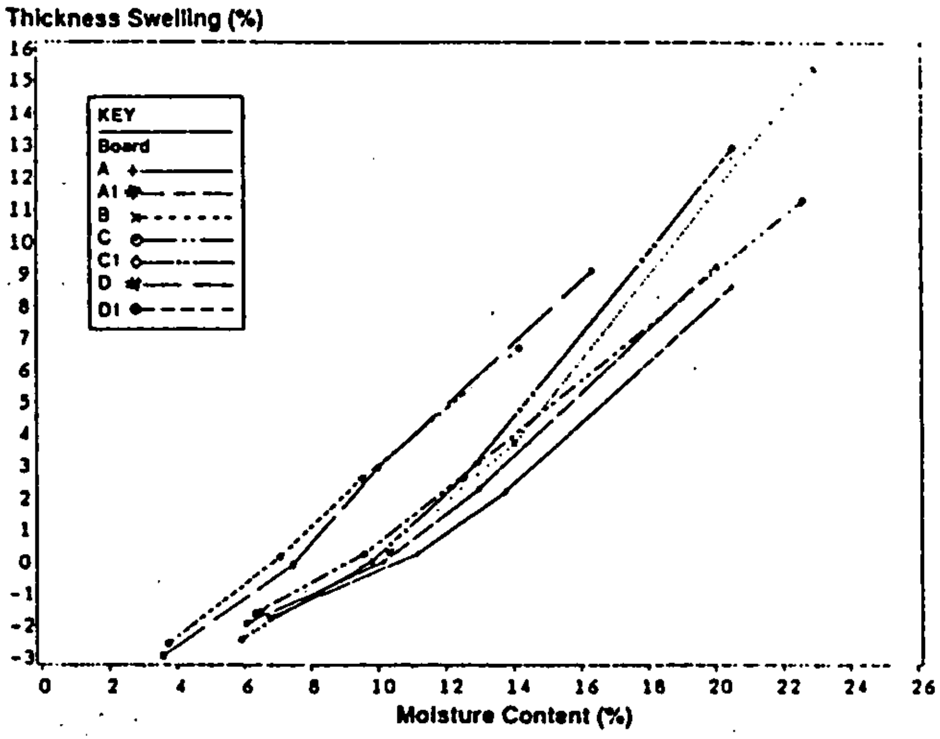

Figure 2. - The effect of Moisture Content on Thickness Swelling (percent of controls).

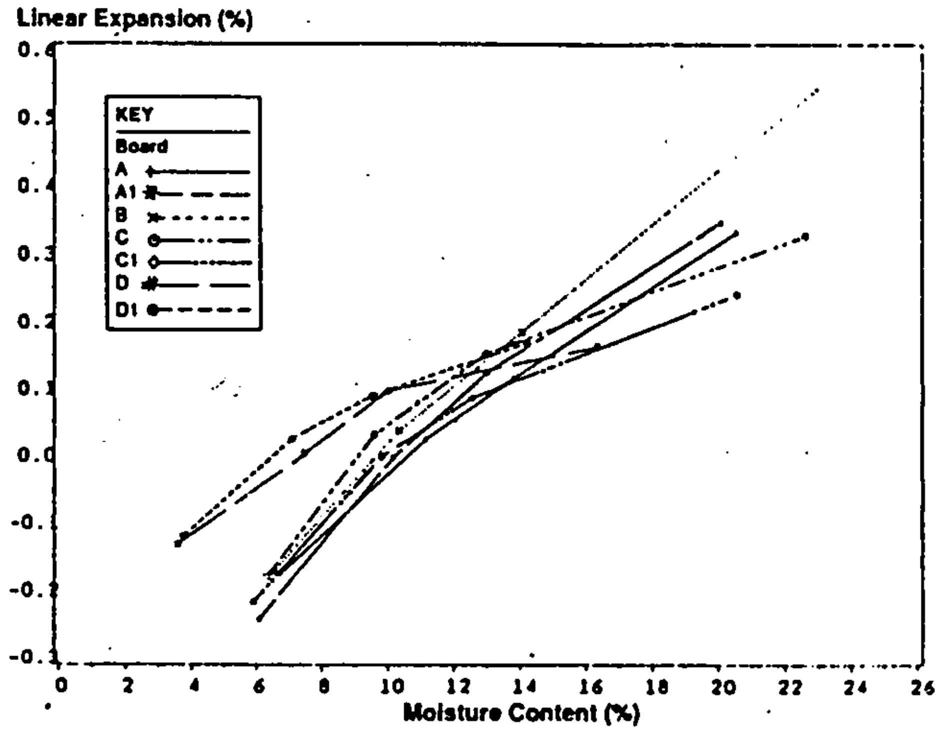

Figure 3. - The effect of Moisture Content on Linear Expansion (percent of controls).

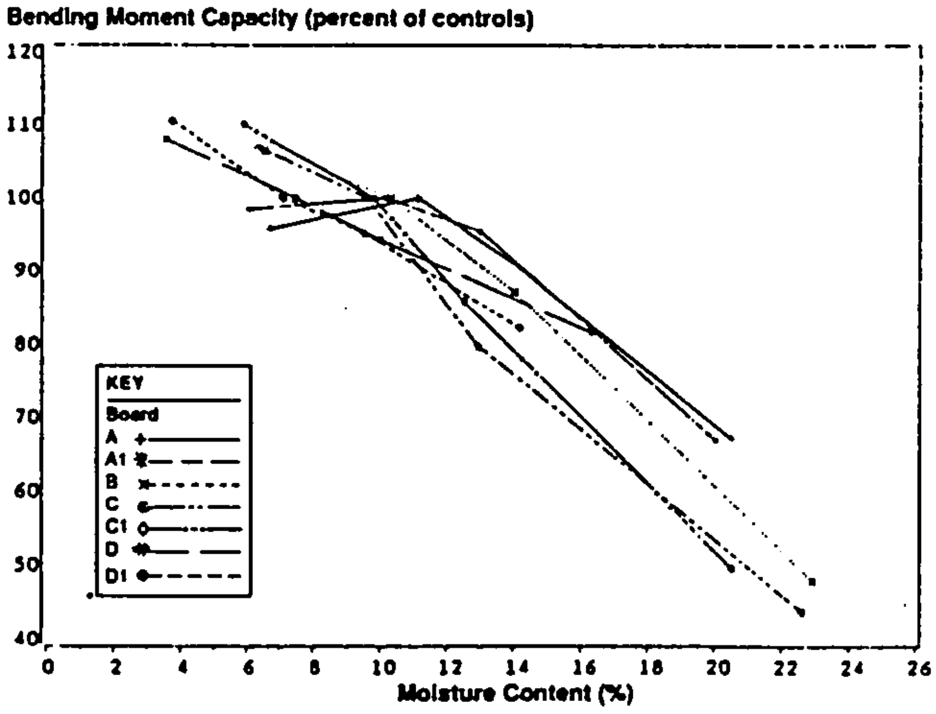

Figure 4. - The effect of Moisture Content on Bending Moment Capacity (percent of controls using dimensions at the control environment. Thus the data are based on the maximum load.)

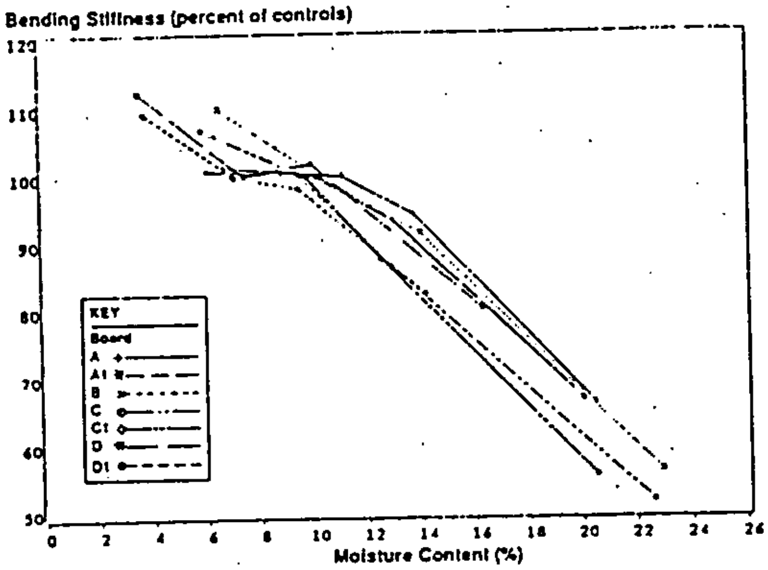

Figure 5. - The effect of Moisture Content on Bending Stiffness (percent of controls using dimensions at the control environment. Thus the data are based on the slope of the load/deformation curve.)

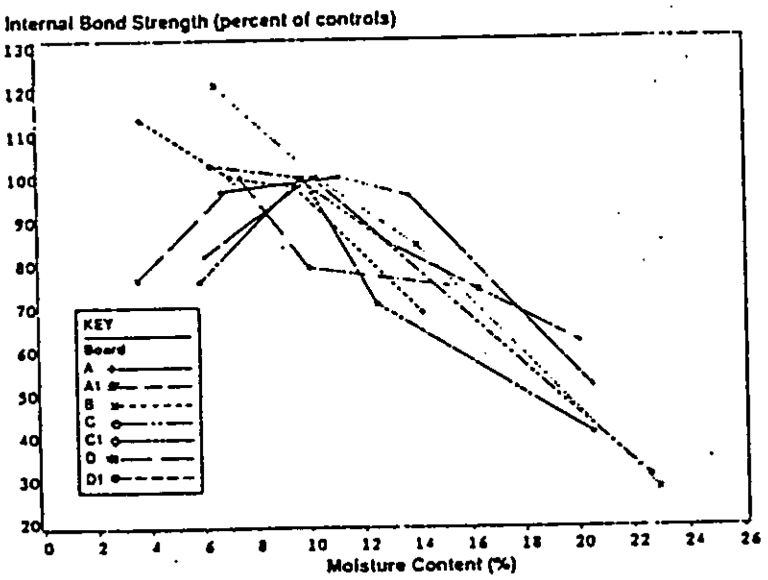

Figure 6. - The effect of Moisture Content on Internal Bond Strength (percent of controls).

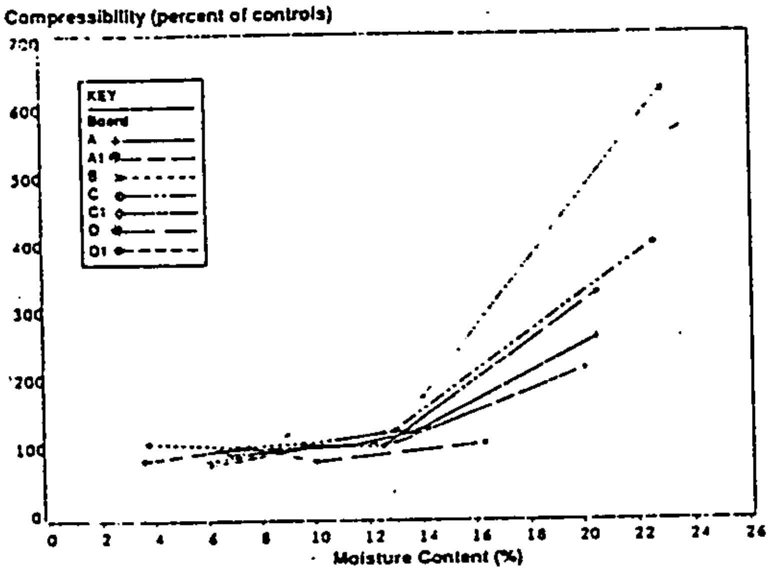

Figure 7. - The effect of Moisture Content on Compressibility (percent of controls).

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