This is to certify that the

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MOISTURE ABSORPTION CHARACTERISTICS OF 100% RECYCLED CORRUGATED BOARD

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By

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ABSTRACT

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OF 100% RECYCLED CORRUGATED BOARD

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The equilibrium moisture sorption isotherm was used for 100% recycled corrugated board to predict its strength performances which were strongly affected by its moisture content. An Oswin equation was successfully applied to the equilibrium moisture sorption isotherm of 100% recycled corrugated board. The results of this study further demonstrated the utility of the linear regression model for describing the Oswin equation and the relationship between strength performances and equilibrium moisture content. The moisture content of 100% recycled corrugated board was found to have an inverse effect on edge crush strength, flat crush resistance and bursting strength. From the resulting linear regression equations, the edge crush strength and flat crush resistance can be successfully predicted under any relative humidity (between 0% and 100%) and at three temperatures (5, 20, and 40 °C).

DEDICATION

This thesis is dedicated to my mother, whose patience and support made this accomplishment possible.

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INTRODUCTION

It is generally recognized that corrugated board is affected by both moisture (or relative humidity) and temperature in the atmosphere. Since corrugated board is made of cellulose fiber, which is highly hygroscopic, it will readily absorb or desorb moisture within its environment. The rate of water vapor gained or lost by corrugated board is proportional to the difference of water vapor pressure existing inside the corrugated board and in the atmosphere to which the corrugated board is exposed. The absorption or desorption of water vapor by the corrugated board can be described by the equilibrium vapor sorption isotherm (or simply called moisture sorption isotherm). Plotting equilibrium moisture content (EMC) versus equilibrium relative humidity (or water activity) at a fixed temperature results in a sigmoidal curve, which is the moisture sorption isotherm.

The moisture sorption isotherm is an extremely valuable tool for the food scientist because it can be used to predict potential changes in food stability; it can be used for packaging selection and for ingredient selection. Similarly, it is also very valuable to apply the concept of moisture sorption isotherm to corrugated boards, because it can be used to predict potential change in strength performances (such as edgewise compressive (or edge crush) strength, bursting strength, flat crush resistance, and so on); it can be referred to for corrugated board selection. It is necessary to use a proper mathematical equation to describe the moisture sorption isotherm of corrugated boards. Some mathematical expressions which have been developed for the moisture sorption isotherm of foods may properly be chosen and applied to the moisture sorption isotherm of corrugated boards. In this study, the linear regression was used to describe the moisture sorption isotherm of corrugated board.

It is well known that the corrugated container plays an important role in such things as protection, transportation, distribution, communication, and warehouse storage. Since the corrugated container often suffers various environmental and handling hazards, it should meet the minimum requirements of railroads' Uniform Freight Classification Rule 41 and motor carriers' National Motor Freight Classification Item 222 so that the quality of its strength performance remains stable and therefore reduces damage to the product inside. Rule 41 and Item 222 require that singlewall corrugated fiberboard boxes have a minimum edge crush strength ranging from 23 to 55 pounds per inch and a minimum bursting strength ranging from 125 to 350 pounds per square inch, with a required minimum combined weight of facings ranging from 52 to 180 pounds per 1000 square feet allowing for a maximum weight of box and contents of 20 to 120 pounds (Fibre box handbook, 1992). Therefore, the standardization of the corrugated shipping container is largely governed by the railroad and motor carrier industry of the United States. The bursting strength, edge crush strength, basis weight, box size, and product's weight are all considered when designing a corrugated box for a given product.

Due to the solid waste disposal problem, the use of recycled corrugated board is gradually being supported by the freight industries. In general, the use of recycled fiber from recycled corrugated board lowers the strength properties of the resulting recycled corrugated container. Although recycled fiber is not as strong as virgin fiber, it has been improved and thus overcomes some of the loss in strength properties (Lumiainen, 1992). Therefore, even though 100% recycled corrugated board generally has lower performance in strength properties, it is very important to construct the moisture sorption isotherm of 100% recycled corrugated board in order to (1) understand the relationships between relative humidity and paperboard moisture content under different temperatures and (2) analyze the relationships between paperboard moisture content and physical properties of paperboard.

Therefore, the purpose of this study is: (1) to build up the moisture absorption characteristics of 100% recycled corrugated board by using moisture sorption isotherm, (2) to analyze the moisture sorption isotherm of 100% recycled corrugated board in terms of a mathematical equation, and (3) to compare and analyze the edge crush, flat crush, and bursting strength when the boards have different equilibrium moisture contents at different relative humidities or temperatures.

LITERATURE REVIEW

1. Corrugated Board:

A corrugated board is composed of a fluted or corrugated medium layer sandwiched between layers of linerboard. The corrugated (or fluted) medium is usually manufactured from virgin hardwoods and recycled corrugated containers by a semi-chemical process. Most linerboard is produced from softwoods by the kraft or sulfate process. The hardwoods and the recycling process provide shorter fibers than the softwoods. The longer fibers produced from softwoods result in stronger linerboard. Corrugated medium, because of its short, stiff fibers and good formation, has three functions : (1) to space and stabilize the linerboard materials, (2) to provide resistance to crushing of the combined board, and (3) to contribute compressive strength and flat-crush strength to the corrugated container made from the combined board (Kellicutt, 1972). Corrugated board may be formed into singlewall, doublewall, or triplewall combined board.

Old corrugated containers (OCC) can be recycled, composted, incinerated, or landfilled (Miller, 1992). Recycling corrugated boards can reduce disposal costs, help alleviate solid waste by saving space in landfills, and diminish the need for virgin fiber. (Edwards, 1990; Kishbaugh, 1990; Wray & Mulligan, 1992). Corrugated boards provide a high per-pound heating value of 7047 BTU (British thermal unit), thereby serving as clean fuel to help burn other products (Miller, 1992 and Fibre box handbook, 1992). OCC can be composted or landfilled because they are biodegradable and environmentally friendly.

2. The Effect Of Recycled Fiber On Paperboard Properties:

The recycling process tends to shorten the long fibers in linerboard as old boxes are re-pulped (Fibre box handbook, 1992). The swelling and bonding ability of fibers is reduced every time they pass through the papermaking process (Lumiainen, 1992). Because of shorter and reduced bonding-ability fibers, recycled fibers provide less flexibility and lower strength than virgin fibers. In general, the use of recycled materials lowers the strength properties of the resulting recycled paperboard and corrugated containers. These reductions in strength properties can, to a large extent, be avoided by further refining of the recycled fibers (Koning and Godshall, 1975). Because refining creates fibrils needed for good fiber bonding, the recycled fibers have improved natural bonding ability and thus overcome some of the loss in strength properties of the recycled paperboard and corrugated containers (Lumiainen, 1992).

Due to the production of shorter fibers and debris, increased refining can decrease the drainage rate on the paper machine and thus reduce the production rate (Kroeschell, 1992). Koning and Godshall also concluded that recycled fiber from corrugated fiberboard drains more slowly on the paper machine. Furthermore, due to the creation of less flexible and shorter fibers after repeated recycling, the medium becomes more susceptible to cracking on the corrugator (Koning and Godshall, 1975). This grade of OCC is yellowish in color and weaker than other forms of corrugated board

(Miller, 1992). The greatest loss in strength occurs with the first recycling of virgin material, rather than during subsequent recycling (Koning and Godshall, 1975).

Using Recycled clean corrugated fiberboard reduces such properties as flat crush, burst, and compressive strength -- reductions which generally increase as the percentage of recycled fiber increases (Fahey and Bormett, 1982). The best quality of recycled board is achieved when the recycled material is old corrugated containers (OCC) and the ratio of virgin kraft to recycled materials is in the neighborhood of 80:20 (Huck, 1991). Today, most corrugated board manufacturers use 100% OCC to produce 100% recycled medium and use a mixture of OCC and double-lined kraft (DLK) cuttings to manufacture linerboard. In general, corrugated paperboard made of 100% recycled fibers has lower performance in strength properties.

3. The Effect Of Moisture Content On Corrugated Board:

The main ingredient of paper or paperboard is cellulose, which is highly hydroscopic and is affected by the moisture in the atmosphere. Normally, the physical properties of a substance vary greatly, depending on its precise moisture content. Therefore, the relationship between paper's physical properties and its moisture content is of primary importance.

The moisture content of paperboard is strongly related to the humidity and temperature of the atmosphere. Variations in humidity and temperature cause the paperboard to vary in moisture content. There is also a direct relationship between the vapor pressure surrounding the paperboard and the paperboard's moisture content : "When the vapor pressure outside the paperboard is greater than that inside the paperboard, water vapor tends to be driven inside and the paperboard is likely to absorb the excess moisture. When the vapor pressure inside is greater than that outside, water vapor tends to be driven out and the paperboard is likely to lose moisture. When there is no further exchange of moisture between paperboard and its environment, the paperboard and its environment are said to be in equilibrium." (Singh, winter 1992).

Since the water vapor pressure at a given temperature is determined by

$$P = Psat \times RH\% \qquad (1)$$

where P : vapor pressure

Psat : saturated vapor pressure at a given temperature

RH % : relative humidity

and Psat is directly affected by temperature changes, a relationship also can be found between relative humidity and moisture content. The graph of moisture content versus relative humidity under equilibrium conditions at a fixed temperature is the Equilibrium Vapor Sorption Isotherm.

Benson (1971) carried out a study of the "effects of relative humidity and temperature on tensile stress-strain properties of kraft linerboard". He used the specimen equilibrium moisture content (EMC) instead of relative humidity to show the relationship with tensile properties. His results showed that when the EMC increased, the tensile properties decreased and when the temperature increased, the EMC decreased and thus the tensile properties increased. He also concluded that the effects of temperature on tensile properties consist of two factors: (1) At any given level of RH, temperature change causes a change in the level of absolute water vapor available to the paper, a change in the absolute vapor pressure acting on the paper, and a resulting change in the paper EMC. (2) Temperature changes directly affected the behavior of paper subject to an external stress through changes in thermal energy levels.

Ievans (1977) indicated that the corrugated board equilibrium moisture content is directly related to the ambient % RH and affects the stacking strength of palletized corrugated boxes. Kellicutt (1959) also showed that as the moisture content decreases, the paperboard box's compressive strength increases. He developed the equation below:

$$CS = CS_0 \ X \ 10^{-3.01M} \qquad (2)$$

where CS : compressive strength of box (lbs)

CS_0 : compressive strength at 0 percent moisture content

M : moisture content (grams H_2O/100 grams dry board)

Normally, the moisture content existing in paperboard is in the neighborhood of 6%. Increasing moisture content lowers the compressive strength of paperboard boxes and weakens the paperboard.

Because the moisture content in the paperboard box affects the compressive or stacking strength of paperboard box, it also can influence the box life span. The moisture content is dependent on the fluctuations in humidity and temperature in the real world. According to Boonyasarn's study (1990), he demonstrated even though two types of corrugated fiberboard containers perform similarly in a non-cyclic environment, one may fail before the other in a cyclic environment. That means one box type may lose its compression strength greater or faster than the other under the cyclic environment. Leake and Wojcik (1993) demonstrated that boxes subjected to changing humidity while under load have a shorter life span than those exposed to a constant environment and that the greater the moisture change, the shorter the life span. They also pointed out that the shortening of a box's life span caused by a fluctuating environment is not simply a laboratory-induced phenomenon, but occurs in the real world of warehousing and transportation.

4. Equilibrium Vapor Sorption Isotherm:

In describing an equilibrium vapor sorption isotherm, the concepts of water activity (or equilibrium relative humidity), equilibrium moisture content (EMC), and temperature are very important. Plotting EMC versus equilibrium relative humidity (or water activity) at a fixed temperature results in a sigmoidal curve, which is the equilibrium vapor sorption isotherm.

4.1 Water activity:

The water activity, Aw, is defined as:

$$Aw = \%ERH / 100 = P / Psat \qquad (3)$$

where ERH : equilibrium relative humidity

P : vapor pressure

Psat : saturated vapor pressure at a given temperature

The water activity of a moisture-sensitive product at various moisture contents and temperatures will determine whether this product will gain or lose moisture when exposed to a surrounding environment. In general, at a constant moisture content in the moisture-sensitive product, Aw increases with increasing temperature (Labuza, 1984). Both chemical reaction rate and microbial activity are directly controlled by Aw (Labuza, 1970). An increase in Aw can result in an increase in reaction rate, which leads to the quality loss of a product. The degree of binding of water also has an effect on the quality of a product. The more tightly water is bound, the lower its Aw (Labuza, 1984).

4.2 Equilibrium moisture content:

The EMC is defined as the moisture content of a product has come to equilibrium with the moisture of the surrounding environment. Water directly interacts with a product through dipole-dipole forces, ionic bonds (H_3O^+ or OH^-), Van Der Walls forces (hydrophobic bond), or the hydrogen bond (Labuza, 1984). These water molecules, if tightly bound to the product, require extra energy to be transferred from the liquid into the vapor state and thus are less free to the vapor, resulting in reduced Aw (equation 3). When the vapor pressure inside the product is equal to that outside the product, it is said to be in equilibrium and the EMC of the product is therefore reached.

4.3 Temperature effect:

Because of the nature of water bonding, at constant Aw, moisture-sensitive products hold less water at higher temperatures than at lower ones. The effect of temperature follows the Clausius-Clapeyron equation (Labuza, 1984):

$$\ln Aw2/Aw1 = Qs \times (1/T1 - 1/T2) / R \qquad (4)$$

where Aw1 : water activity at temperature T1 ^{o}K

Aw2 : water activity at temperature T2 ^{o}K

Qs : heat of sorption in cal/mole (function of moisture content)

R : gas constant (1.987 cal/mole^{o}K)

If the corresponding heat of sorption is known at constant moisture content, the Clausius-Claypeyron equation can be used to predict the isotherm Aw value at any temperature. To determine Qs, the sorption isotherm must be measured for at least two temperatures. The Qs does not change with temperature. Generally, Qs increases with decreasing moisture content, indicating a stronger interaction energy.

4.4 Mathematical models for the equilibrium vapor sorption isotherm:

It is necessary to develop a mathematical expression model of the equilibrium vapor sorption isotherm. As with any mathematical model, care should be taken in giving it any physical meaning, and one should understand the limitations of the data. Several commonly used mathematical expressions are showed below:

The B.E.T. (Brunauer-Emmett-Teller) equation (Labuza, 1984; Giacin and Downes, spring 1993) is:

$$Aw / [(1-Aw)M] = 1 / (M_0C) + [(C-1)Aw] / (M_0C) \qquad (5)$$

where Aw : water activity

M : moisture content (dry weight basis) at Aw and temperature T

C : constant

M_0 : monolayer value

The monolayer value, which is usually around an Aw of 0.2-0.4, has the lowest rate of most deteriorative reactions in food systems (Salwin, 1959). An increase in Aw beyond this region (0.2-0.4) can result in an increase rate by a factor of 50-100% for each 0.1 Aw change (Labuza, Kaanane, and Chen, 1985). For most dry foods, an increase in Aw by 0.1 unit in this region decreases shelf life two to three times. Below this range, the quality loss happens (Lauza, 1984). Therefore, this monolayer value can be viewed as critical Aw value, which is related to the quality control of a product.

The GAB (Guggenheim-Anderson-de Boer) equation (Labuza, 1984) was found to fit many hundreds of food isotherms. The equation has the form:

$$M / M_0 = C1KAw / [(1-KAw)(1-KAw+C1KAw)] \quad (6)$$

where M : moisture content

M_0 : monolayer value

C1, K : constants

Aw : water activity

The Hailwood and Horrobin equation (Labuza, 1984) is :

$$Aw / M = C1 + C2Aw + C3Aw^2 \quad (7)$$

where Aw : water activity

M : moisture content

C1, C2, C3 : constants

The linear equation (Chirife & Iglesias, 1978; Giacin & Downes, Spring 1993) is:

$$M = Aw \times a + b \quad (8)$$

where M : moisture content

Aw : water activity

a : slope

b : intercept

The Oswin equation (Oswin, 1946) is:

$$M = C\,[Aw/(1-Aw)]^n \quad (9)$$

where M : moisture content

C : constant

Aw : water activity

n : exponent

The Mizrahi equation (Mizrahi & Labuza, 1970) is:

$$Aw = (C1 + M) / (C2 + M) \quad (10)$$

where Aw : water activity

C1, C2 : constants

M : moisture content

The Henderson equation (Henderson, 1952) is:

$$1 - Aw = \exp\,[-CM^n] \quad (11)$$

where Aw : water activity

C : constant

M : moisture content

n : exponent

The Kuhn equation (Giacin & Downes, spring 1993) is:

$$M = C1 / (\ln Aw)^n + C2 \qquad (12)$$

where M : moisture content

C1, C2 : constants

Aw : water activity

n : exponent

5. Development Of A Theoretical Model For The Compressive Strength Of Corrugated Fiberboards:

Compression strength is a very important indicator of final box performance. In order to design a box which performs well, it is necessary to develop a theory to predict the expected compressive strength. The theory developed by McKee, Gander, and Wachuta (1963) accounts for top-load compression strength of corrugated boxes. Their theory is based on the theory for the buckling of thin plates modified empirically to match experimental data. Finally, an equation was developed to predict compression strength. The equation is as follows:

$$P = 2.028 \times P_m^{0.746} \times ((D_x D_y)^{1/2})^{0.254} \times Z^{0.492} \qquad (13)$$

where P : container compressive strength, lb

P_m : edgewise compressive strength, lb/in.

D_x : flexural stiffness per unit width of combined board (machine direction), lb-in.

D_y : flexural stiffness per unit width of combined board (cross-machine direction), lb-in.

Z : container perimeter, in.

Because the flexural stiffness, which is a measure of the bending strength of the combined board, is not easy to measure and can be simplified by finding the correlation of composite flexural stiffness, edgewise compression strength, and combined board caliper:

$$(D_x D_y)^{1/2} = 66.1 \text{ X } P_m \text{ X } H^2 \qquad (14)$$

where H : board caliper, in.

Equation (13) can be modified as:

$$P = 5.87 \text{ X } P_m \text{ X } (ZH)^{1/2} \qquad (15)$$

where P : container compressive strength, lb

P_m : edgewise compressive strength, lb/in.

Z : container perimeter, in.

H : board caliper, in.

According to Nordkvist's study on optimizing fluting and liner proportions (1988), the simplified equation (15) can be used with results as good as equation (13). He also mentioned that due to the lack of reliable methods to measure flexural stiffness, flexural stiffness can be substituted by the thickness (or caliper) of corrugated board and thus equation (13) can be modified as equation (15).

Because McKee's equation (equation (15)) does not include the influence of moisture content and is inadequate in the case of wrap-around boxes, Kawanishi (1989) derived a statistical formula useful for estimating the compression strength of a box based on its specifications. The specifications are grade of corrugated fiberboard, size of box, type of box, printed area and moisture content. The formula is:

$$F = 3.79 \times 10^{-8} \times K^{0.379} \times W^{0.650} \times w^{1.20} \times d^{-4.15} \times y^{2.45} \times t^{3.34} \times Z^{0.565} \times k^{-0.315} \times P^{0.0602} \times S^{-1.10} \quad (16)$$

where F: compression strength of box (kgf)

K : liner type (3 for K liner, 2.5 for K' liner, 2 for B liner; linerboard average)

W : total basis weight of linerboard (g/m^2)

w : total basis weight of corrugating medium (g/m^2)

d : total corrugation ratio (1.59 for A-flute, 1.36 for B-flute, 1.27 for E-flute, 2.59 for AB-flute)

y : average corrugation count (34 for A-flute, 50 for B-flute, 90 for E-flute, 42 for AB-flute)

t : thickness of corrugated fiberboard sheet (mm)

Z : box perimeter (cm)

k : type of box (1 for A-1 type = a regular slotted container, 2 for wrap-around type)

P : printed ratio of box (1 for no print, 0.01 for solid print)

S : moisture content of side wall

Equation (16) seems a little more complicated than equation (15). Furthermore, equation (16) derived from its specifications can only be used for a limited range--- A, B, E, and AB-flutes. However, equation (16) gives better agreement with experimental results than equation (15) or (13).

6. Papermaking Factors Affecting Box Properties:

6.1 Liner/medium weight relationships:

According to Rule 41, the corrugating medium must not weigh less than 26 pounds per 1000 square feet. The main function of the corrugated medium is to space the facings and to provide stability to prevent buckling or crushing. Kellicutt (1972) indicated that 26 pounds per 1000 square feet corrugating medium provides the stability necessary to develop all of the inherent strength of the facings in double-faced corrugated board. Also the weight of the corrugating medium required to develop all the inherent strength of the facing material in double-faced corrugated is dependent on the weight of that facing material. He also showed that compressive strength values were higher when the combined board had (1) heavier facings, (2) heavier mediums, or (3) both heavier facings and heavier mediums. That means the higher the basis weight, the higher the compression strength.

6.2 Fluting process:

Fluting is a forming operation. The corrugating medium is formed into the flute (or sinusoidal) contour when it is drawn into a nip created by two gearlike corrugating rolls under certain stress, temperature, and moisture conditions. During fluting, the corrugated medium is exposed to relatively high tensile, bending, shearing, and transverse compressive stresses to enhance the fiber-to-fiber bonding and thus lower 40% of the machine direction (MD) and 20% of the cross direction (CD) edgewise compressive strength of the corrugating medium (Whitsitt and Sprague, 1987). In this case, the reduction of compressive strength of the corrugated medium in MD and CD also will reduce the combined board's performance in compressive strength and flat crush strength.

In order to minimize the strength losses during fluting, there are two approaches (Whitsitt and Baum, 1987) : One approach is to make more effective use of preconditioning heat and steam, because preconditioning alters the properties of the corrugating medium resulting in a medium which has sustained less damage. The second approach is to alter the properties of the base medium during its manufacture. This can be expressed as the formula:

$$RR = 1 - (K/R)\,(E_x/E_z)^{1/4}\,(W/d) \qquad (17)$$

where RR : retention ratio, or the ratio of compressive strengths of fluted to uncorrugated medium

E_x : MD Young's modulus

E_z : out-of-plane Young's modulus

W : basis weight

d : density

R : radius of curvature of the fluting rolls

K : constant

It is clear that increasing the density of the corrugated medium increases the retention ratio and thus improves both its edgewise crush strength and its flat crush strength. Whitsitt and Baum also indicated that densification of the corrugated medium by wet pressing pressure makes substantial increases in the flat crush and edgewise crush strength of combined board made from that corrugated medium.

6.3 Glueability at the corrugator:

The proper gluing of medium to linerboard is essential to box performance. During the fluting process, medium and liner are combined to form single-faced board in the single facer of the corrugator by first applying adhesive to the flute tips and then immediately pressing the flute tips against a preheated linerboard. Then, the single-faced board travels along a bridge to the double backer, where adhesive is again applied to the flute tips and a second preheated linerboard is pressed against the flute tips, thus producing a combined board.

Due to the combination of thermal gelatinization and dehydration, the starch adhesive develops a very strong bond between the medium and linerboard (Lepoutre and Inoue, 1989). The gelatinization of the starch adhesive, created by heating it over a temperature range, contributes to increased viscosity and the development of strong bond strength. The viscosity increases when the starch granules absorb water from the surrounding gelatinized starch solution and swell enough to intensify the inter-granular friction strength. Leaving a layer of raw starch granules separated at the surface of the board, the aqueous phase (gelatinized starch) is absorbed by the board, and then provides the bond to hold fibers together. When water molecules diffuse out of the wet adhesive into the board and finally into the atmosphere, a strong permanent bond is formed between board and adhesive.

Lorenz and Whitsitt (1990) concluded that the liner and medium properties which may be expected to influence adhesion include wettability, porosity, roughness, and density, in addition to the internal fiber bonding strength of the sheet. They also indicated four properties which are important for good bonding : (1) A porous surface which has many uniformly distributed pore openings. (2) A rough surface which provides a greater surface area for bonding than a smooth surface. (3) A surface which is easily wet by an aqueous adhesive. (4) The strongest fiber-to-fiber bond consistent with other properties.

6.4 Press drying:

Press drying is a papermaking technique used for drying paperboard webs simultaneously with heat and pressure. Because heat and pressure increase the fiber conformability and fiber bonding ability by promoting natural polymer flow on the fiber surface (Horn, Bormett, and Setterholm, 1988), press drying can provide more support for fiber-to-fiber bonding and produce a much stronger linerboard and corrugating medium than conventional drying (Horn and Bormett, 1985). Therefore, some physical properties of paperboard will be improved after the press drying process. Horn and Bormett (1985) in their study, conventional and press dry of high-yield paper birch for use in linerboard and corrugating medium, concluded that press drying eliminated scoreline fracturing and increased burst strength, flat crush, edge crush, compressive strength, and flexural stiffness, but decreased impact resistance. The reason for decreased impact resistance is the shorter fiber length and increased stiffness associated with these high yield pulps. Also, the tear strength in birch linerboards also was found by them to be lower than commercial pine linerboard. The reason is the increased fiber-to-fiber bonding and the shorter fiber length of the birch fiber.

Horn (1989) studied the factors affecting wet strength of press-dried paperboard, and concluded that four press-drying variables were related to the moisture resistance of handsheets made from high-yield hardwood kraft pulp: (1) Pulp yield : Dry tensile strength was higher in sheets made from lower-yield (59%) pulp, and wet tensile strength was higher in sheets made from higher-yield (69%) pulp. The higher tensile strength can be attributed to both the greater availability for bonding of hemicellulose on the fiber surface and the lower lignin content for sealing the hemicellulose bonds. The increase in wet strength is due primarily to lignin flow. (2) Pressing pressure : Dry tensile strength increased 25% if pressing pressure increased from 0.35 Mpa to 2.76 Mpa, and wet tensile strength was doubled if pressing pressure increased from 0.35 Mpa to 5.52 Mpa. (3) Drying temperature : Drying at 204 ^{0}C produced stronger sheets in dry and wet strength than at 94 ^{0}C. (4) Drying time : At 204 ^{0}C, pressing for 10 minutes produced over 300% higher wet strength than pressing for 30 seconds. Therefore, drying time (nip residence time) is an important factor in maximizing the wet tensile strength.

7. Edgewise Compressive Strength:

Edgewise compressive strength (ECT) is mainly dependent on the compressive properties of the components of the combined board. Kroeschell

(1992) showed that ECT must be largely determined by the strength of the component linerboard and corrugated medium, since all of these variables, adhesion, and combined board thickness have only minimal effect on ECT. There are two ways to approach the relationship between ECT and component characteristics (Whitsitt, 1988) : (1) To sum up the compressive strengths of the components and allow for the draw of the corrugated medium. (2) To treat combined board as a structure composed of (a) narrow flat plate elements of liners between flute tops and (b) flat or curved plates of medium. These miniature plate elements could become unstable, buckling in the same way that a box panel buckles in top-load compression. When such local buckling occurs, the combined board ECT is dependent on the edgewise compression and bending properties of the liners and medium.

McKee et al. (1963) indicated that edgewise compressive strength (ECT) and flexural stiffness affect the top-load compressive strength performance of a box (equation (13)). Therefore, the ECT is directly related to the box compression strength. Generally, the higher the edgewise compression resistance, the better the stacking properties of the box (Thielert, 1986). Using ECT values, shippers can more accurately determine stacking strength, optimizing warehouse and shipping performance at a lower cost (Santelli, 1991). Whitsitt (1988) concluded that reducing the ratio of the machine direction to the cross-machine direction of linerboard increased the cross-machine direction compressive strength of liners and, hence, ECT. He also showed that increasing the density of the linerboard and medium by wet pressing increased the combined board ECT, though increased wet pressing decreased the thickness and bending stiffness of the liners.

In the ECT test, according to ASTM D 2808-69, the samples are cut into 2" X 1 1/4" sizes and the edges of the samples are reinforced by impregnating them with paraffin wax to prevent edge failure. The rectangular sample of corrugated board is placed between the platens of the crush tester and makes use of the two supporting blocks to hold the sample (or flute direction) upright. The load is applied perpendicular to the flutes. The greatest force that sample can bear without failure is the edge crush value. Uneven sample cuts, samples which slip during testing, and compression speed will affect the ECT values.

8. Bursting Strength:

The bursting strength is directly related to the combination of tensile strength and stretch of sheet material. Therefore, burst strength is related to the manner and rate of sheet formation and drying, sheet thickness, and basis weight (McGee, 1985). In the burst test, the material is secured between platens and is ruptured by an expanding rubber diaphragm which the pressure rises from. The clamp pressure is the main variable that affects the test results and reproducibility. A low clamp pressure causes corrugated samples to slip and higher results will be read. A high pressure causes the flutes of corrugated board to be crushed and lower values are produced. The test yields a reproducibility that may vary from 10 to 25 percent. McGee (1985) also showed that bursting strength tests are subject to more variation than many other physical tests. The causes of variation are the differences in fiber size, shape, and orientation, and interfiber bonding within the sheet, as well as the complex stresses and strains created during testing.

9. Flat Crush Resistance:

Flat crush resistance is the ability of corrugated board to resist being crushed when applying the crush force perpendicular to the surface of the board. This crushing may occur in the printing operation, bundling machines, and so on. The flat crush test value is most affected by the thickness of the board and the strength and density of the medium.

MATERIALS AND METHODS

TEST MATERIALS:

There were three kinds of 100% recycled, C-flute (42 flutes/ft), and single-wall corrugated fiberboards supplied by a commercial manufacturer of corrugated packaging used in this study. The calipers of the three kinds of fiberboards were all the same, 5/32 inches. Three different basis weights (linerboard/medium/linerboard) (lb/1000 ft^2) were used as described below:

Board 1: 34/26/34

Board 2: 50/26/50

Board 3: 67/26/67

Prior to conditioning and testing all test fiberboard materials were preconditioned at 10 to 35% relative humidity and 22 to 40°C (American Society for Testing and Materials (ASTM) D685-87) for a week. After that, they were used to make test specimens for moisture content determination, edge crush test, bursting strength test, and flat crush test. The number and size of the samples were as follows:

1. Ten samples per temperature under each relative humidity of each saturated salt solution condition (Table 1) were cut into 3" x 3" for each type of board to determine their equilibrium moisture content. The total number of samples was : 10 replications x 15 saturated salt solutions' conditions x 3 board types = 450 samples.

2. Ten samples per temperature under each relative humidity condition were cut into 1.25" wide x 2" long for each type of board for the edge crush test. The flutes were parallel to the long axis of the test sample. The total number of samples was : 10 replications x (3 ASTM conditions + 15 saturated salt solutions' conditions) x 3 board types = 540 samples.

3. Five board samples per temperature under each relative humidity condition (except for saturated salt solutions' conditions) were cut into 12" x 12" for each type of board for the bursting strength test. The total number of samples was : 5 replications x 3 ASTM conditions x 3 board types = 45 samples.

4. Ten circular samples per temperature under each relative humidity condition were cut by circular sample cutter (TMI) into about a 10 square inch area for each type of board for the flat crush test. The total number of samples was : 10 replications x (3 ASTM conditions + 15 saturated salt solutions' conditions) x 3 board types = 540 samples.

CONDITIONING:

After making test specimens, the test samples of each board type were brought to the following standardized conditions:

A. ASTM conditions:

1. Refrigerated storage condition: 5±2 °C and 85±5 %RH
2. Temperate high humidity condition: 20±2 °C and 85±5 %RH

3. Tropical condition: 40±2 °C and 85±5 %RH

B. Saturated salt solutions' conditions: see Table 1

Table 1. Equilibrium relative humidities (RH) for saturated salt solutions at different temperatures

Saturated Salt Solutions	5°C	20°C	40°C
	(%RH)	(%RH)	(%RH)
Lithium Chloride ($LiCl.H_2O$)	14.0	12.4	11.6
Magnesium Chloride ($MgCl_2.6H_2O$)	34.6	33.6	32.1
Magnesium Nitrate ($Mg(NO_3)_2.6H_2O$)	59.2	54.9	49.2
Sodium Chloride (NaCl)	75.1	75.5	75.4
Potassium Nitrate (KNO_3)	96.6	93.2	87.9

The temperatures and humidities for the refrigerated storage, temperate high humidity, and tropical conditions follow the recommendations of ASTM 4332-89. Environmental Chambers (Nor-Lake Scientific No.3 and Chrysler Koppin refrigerator) were used to maintain those conditions. Under those conditions, the corrugated boards will reach equilibrium with the atmospheres such that subsequent measurements of physical properties can be done.

The values of the temperatures and humidities for the saturated salt solutions' conditions follow Wexler and Hasegawa's study on the "Relative

Humidity-Temperature Relationships of Some Saturated Salt Solutions in the Temperature Range 0 to 50 °C" (1954). Under the saturated salt solutions' conditions, the corrugated boards should be placed and kept in those specific atmospheres until they reach equilibrium with those atmospheres in order to determine the equilibrium moisture content of the corrugated boards, construct the moisture sorption isotherms of the corrugated boards, and measure the physical properties of the corrugated boards which can then be compared to those measured under the refrigerated storage, temperate high humidity, and tropical conditions.

In order to create the saturated salt solutions' conditions, a series of tightly closed 5 gallon plastic buckets was used. Those buckets were too small to contain the 12" x 12" samples for bursting strength test. Therefore, those samples could only be conditioned at refrigerated storage condition, temperate high humidity condition, and tropical condition.

Two coolers, which also were conditioned at 5, 20, and 40 °C, were used to protect the conditioned samples during the transfer from environmental chambers to test equipment.

TEST METHODS:

Equilibrium Moisture Content (EMC) Determination:

The equilibrium moisture contents of the conditioned board samples were determined in accordance with ASTM D644-89. The EMC determined on a dry weight basis was calculated from the loss of weight of the sample after oven drying. The specimens were dried in a Precision Scientific P/S

Model 524 oven. The expression used to calculate the EMC is shown below:

$$EMC = [(W1 - W2) / W2] \times 100 \qquad (18)$$

where EMC : equilibrium moisture content (g water/100 g dry weight of the corrugated board)

W1 : equilibrium weight before oven drying (g), or final weight of corrugated board after equilibrium is reached in the conditioned atmosphere

W2 : weight after oven drying or dry weight (g)

Moisture Sorption Isotherm:

In developing moisture sorption isotherm data, care was taken to insure that the relative humidity buckets employed were maintained at constant temperature and relative humidity. Sorption isotherms for each board type were desired at 5, 20, and 40 °C. Three different temperatures could be obtained by the Environmental Chambers (Nor-Lake Scientific No.3 and Chrysler Koppin refrigerator). Different humidities at each temperature were obtained by using saturated salt solutions (Table 1) in contact with an excess of the solids (salt) phase. The moisture sorption isotherms constructed in this study were determined by placing corrugated board samples over the saturated salt solutions in a series of tightly closed 5 gallon plastic humidity buckets, maintained at the three constant testing temperatures. These samples were weighed every three or four days until no change (gain or loss) in weight was observed. Since no weight change was observed, it was assumed equilibrium had been reached.

With stirring, a saturated salt solution was prepared by adding distilled water to the salt in a clean container which was put into a closed bucket. The actual solution should be a slurry with excess crystals present. The relative humidity within each bucket was occasionally monitored by a hygrometer to assure constant relative humidity values were maintained. Moisture sorption isotherms were obtained by plotting the average equilibrium moisture content of the ten replicates versus relative humidity at each of the testing temperatures.

Edge Crush Testing:

The edge crush values for the conditioned specimens were determined in accordance with ASTM D2808-69. The specimens were tested on a Crush Tester (Model No. 17-36) manufactured by Test Machines Incorporated (TMI).

Bursting Strength Testing:

The bursting strength testing of the conditioned board specimens was performed for each group of test samples in accordance with TAPPI 810om-80. There were four readings taken on each of the 5 specimens. The specimens were tested on a Mullen Tester manufactured by Perkins Holyoke.

Flat Crush Testing:

The flat crush values for the conditioned board specimens were determined in accordance with TAPPI 808om-86. The specimens were tested on a Crush Tester (Model No. 17-36) manufactured by TMI.

RESULTS AND DISCUSSION

Equilibrium Moisture Content (EMC):

The saturated salt solutions and oven drying method were utilized for determination of the equilibrium moisture content of the corrugated board. The saturated salt solutions were very useful in producing known relative humidities. A drying temperature of 105 ^{o}C and a drying time of 2 hours was used to provide a drying condition for the corrugated board. Tables A-1 to A-45 (see appendix A) present the EMC determinations of three different boards under different conditions. The EMC provides an important component for the moisture sorption isotherm.

Moisture Sorption Isotherm:

The sorption isotherms were obtained by plotting the equilibrium moisture content (g water/100 g dry weight) on the Y axis vs. the corresponding relative humidity (or water activity) on the X axis. Tables 2 to 4 show the data of equilibrium moisture content (EMC) vs. relative humidity (RH) and water activity (Aw) for three different boards (board 1, board 2, and board 3) under three different temperatures (5, 20, and 40 ^{o}C). Figures 1 to 3 present graphically the moisture sorption data for board 1, board 2, and board 3.

From figures 1 to 3, the moisture sorption isotherms are dependent on temperature. It is clearly evident from those moisture sorption isotherms that for a given moisture content an increase in temperature results in an increase in the relative humidity (or water activity). Of concern to the

Table 2. EMC vs. RH and Aw for Board 1

Temperature = 40 °C :					
EMC	3.44	5.36	6.80	9.70	14.17
RH (%)	11.6	32.1	49.2	75.4	87.9
Aw	0.116	0.321	0.492	0.754	0.879
Temperature = 20 °C :					
EMC	4.72	7.12	8.65	11.96	19.64
RH (%)	12.4	33.6	54.9	75.5	93.2
Aw	0.124	0.336	0.549	0.755	0.932
Temperature = 5 °C :					
EMC	6.72	9.11	10.65	14.23	23.79
RH (%)	14.0	34.6	59.2	75.1	96.6
Aw	0.14	0.346	0.592	0.751	0.966

Table 3. EMC vs. RH and Aw for Board 2

Temperature = 40 °C :					
EMC	3.60	5.52	7.05	9.78	13.65
RH (%)	11.6	32.1	49.2	75.4	87.9
Aw	0.116	0.321	0.492	0.754	0.879
Temperature = 20 °C :					
EMC	4.98	7.28	9.13	11.57	19.22
RH (%)	12.4	33.6	54.9	75.5	93.2
Aw	0.124	0.336	0.549	0.755	0.932
Temperature = 5 °C :					
EMC	7.53	9.15	11.31	14.31	23.84
RH (%)	14.0	34.6	59.2	75.1	96.6
Aw	0.14	0.346	0.592	0.751	0.966

Table 4. EMC vs. RH and Aw for Board 3

Temperature = 40 °C :					
EMC	3.18	5.14	6.89	9.96	13.69
RH (%)	11.6	32.1	49.2	75.4	87.9
Aw	0.116	0.321	0.492	0.754	0.879
Temperature = 20 °C :					
EMC	4.86	7.16	9.13	11.50	19.34
RH (%)	12.4	33.6	54.9	75.7	93.2
Aw	0.124	0.336	0.549	0.757	0.932
Temperature = 5 °C :					
EMC	7.61	9.26	11.75	14.70	23.83
RH (%)	14.0	34.6	59.2	75.1	96.6
Aw	0.14	0.346	0.592	0.751	0.966

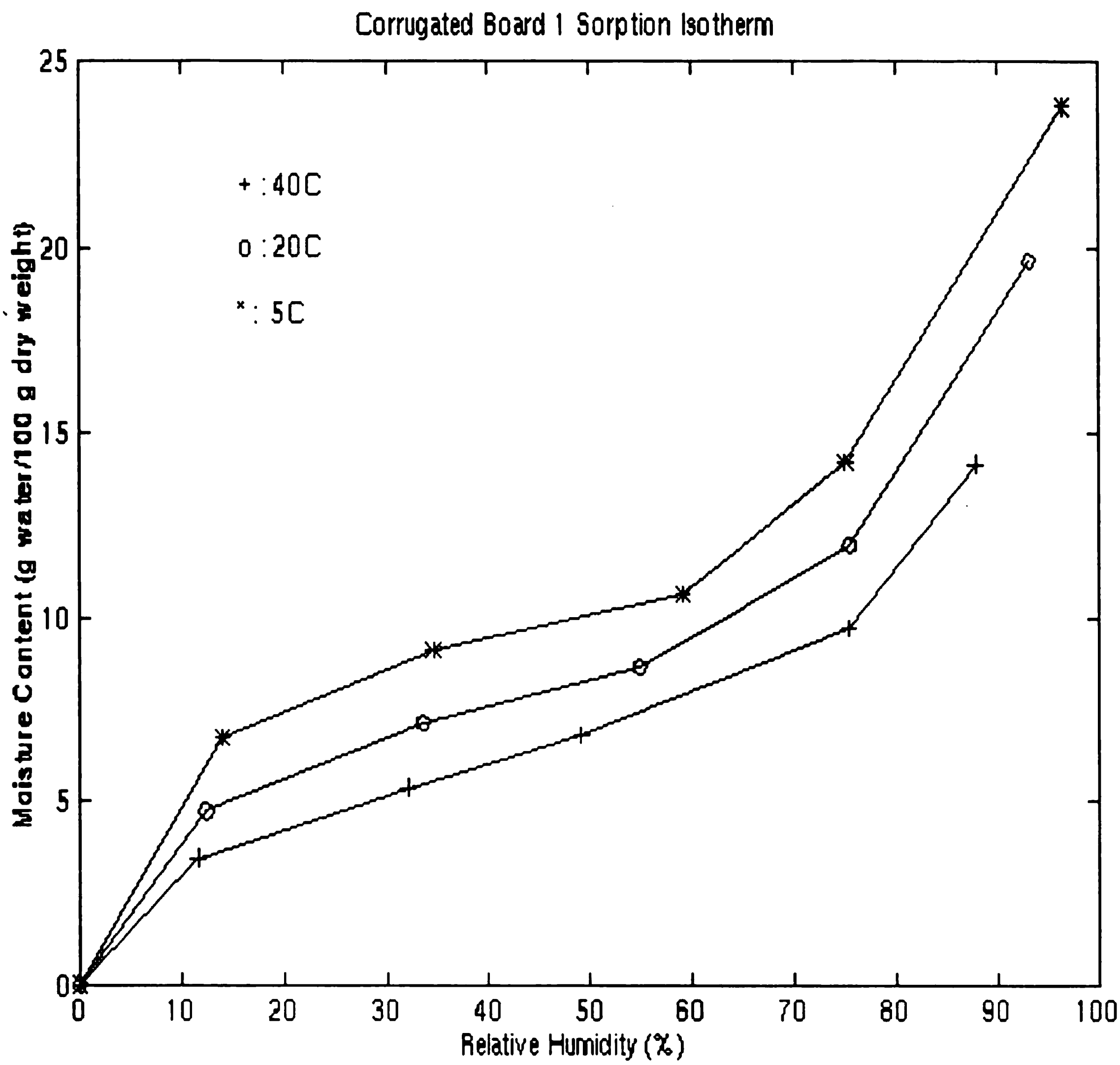
Corrugated Board 1 Sorption Isotherm
+ : 40C
o : 20C
* : 5C
Moisture Content (g water/100 g dry weight)
Relative Humidity (%)
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90
100

Figure 1

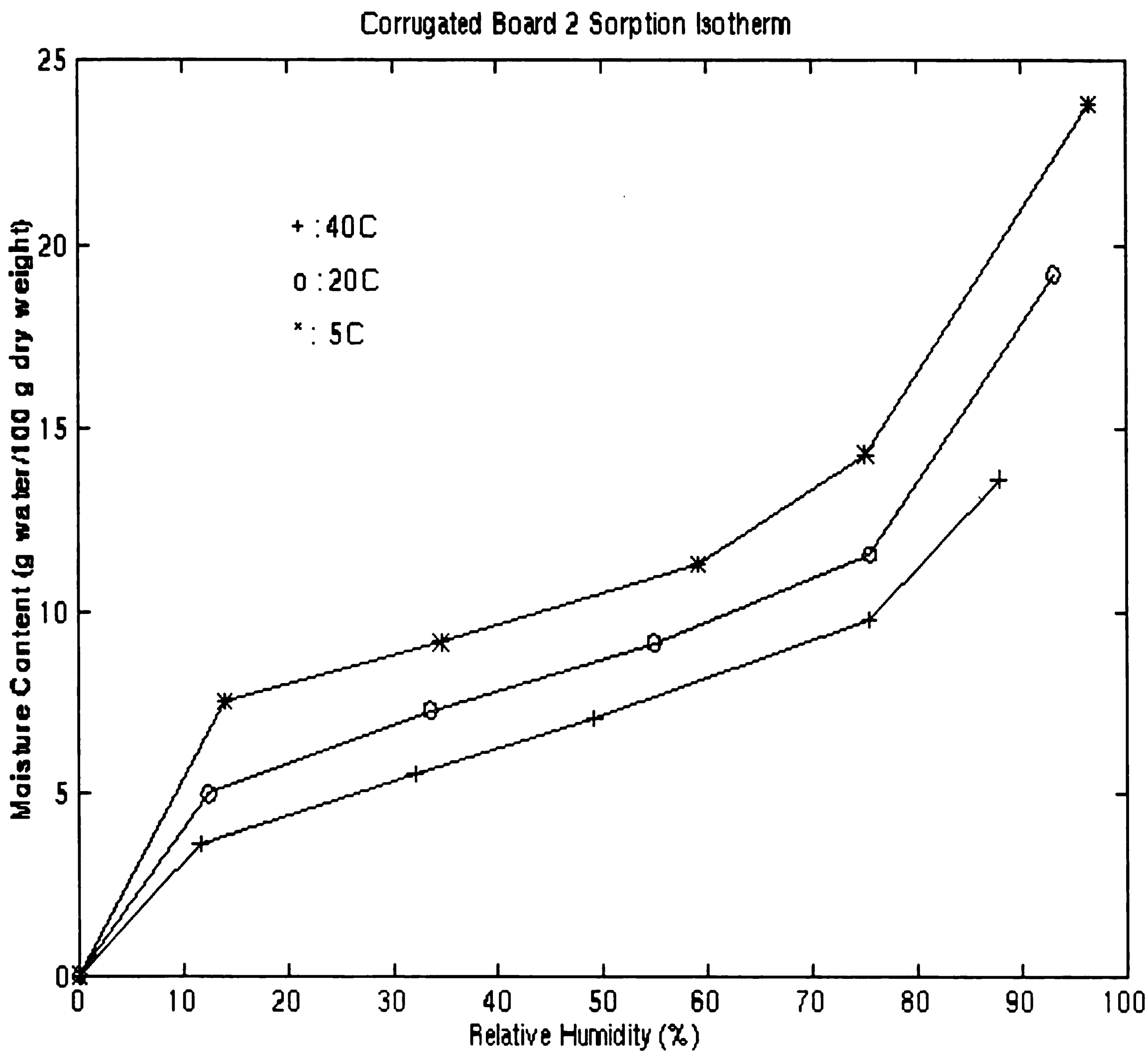
Corrugated Board 2 Sorption Isotherm
+ : 40C
o : 20C
* : 5C
Moisture Content (g water/100 g dry weight)
Relative Humidity (%)
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90
100

Figure 2

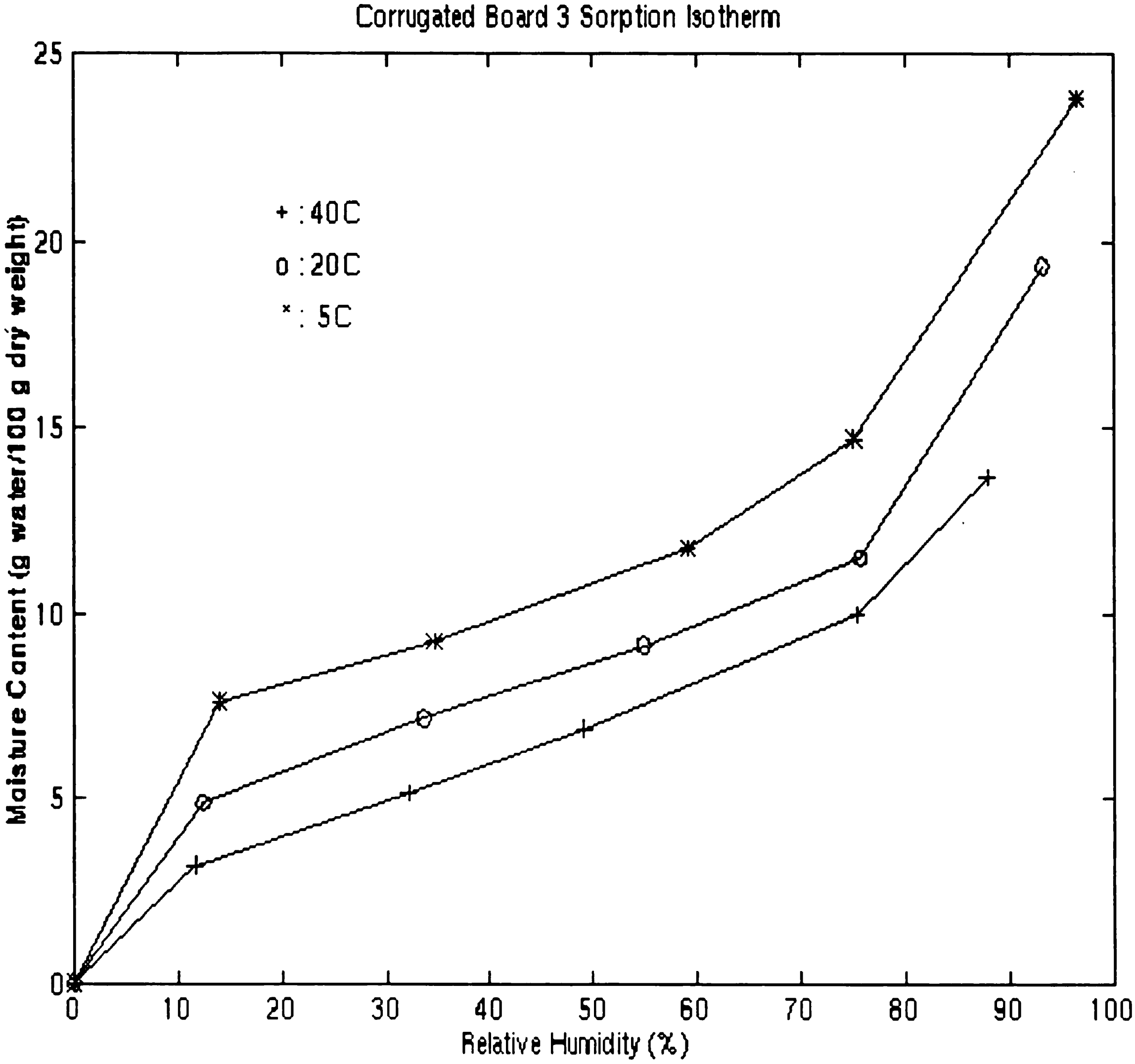
Corrugated Board 3 Sorption Isotherm
+ : 40C
o : 20C
* : 5C
Moisture Content (g water/100 g dry weight)
Relative Humidity (%)
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90
100

Figure 3

corrugated board manufacturers is the fact that, during storage, a 100 % recycled corrugated board may be exposed to long periods at a temperature lower or higher than the temperature at which it was manufactured. Thus, if the EMC remains the same, the 100% recycled corrugated board will increase to a higher RH (or Aw) or decrease to a lower RH (or Aw) (figures 1 to 3). Consequently, in an atmosphere of constant relative humidity the 100 % recycled corrugated boards will absorb higher moisture level at lower temperatures than at higher temperatures.

In order to describe the sorption isotherm by using a mathematical expression, the Oswin equation (equation (9)) can properly be chosen and applied. But the Oswin equation should be converted to the equation (19) below:

$$\text{Ln } M = K1 + K2 \times \text{Ln } (Aw / 1\text{-}Aw) \tag{19}$$

where M : equilibrium moisture content (EMC)

K1, K2 : constant

Aw : water activity

Tables 5 to 7 and figures 4 to 6 show the linear relationships between Ln EMC and Ln (Aw / 1-Aw). The linear regression was applied to the data in figures 4 to 6 and the results are given in Table 8. All of the correlation coefficients (r) were very close to 1, which means the linear correlation was good.

Any change in either RH (or Aw) or temperature can lead to a change in the EMC and thus may affect the strength performances (such as edge crush strength, flat crush resistance, and bursting strength) of boards. Therefore, it is imperative to do moisture sorption isotherms for 100 % recycled

Table 5. Ln EMC vs. Ln (Aw / 1-Aw) for Board 1

Temperature = 40 °C :					
EMC	3.44	5.36	6.80	9.70	14.17
Ln EMC	1.235	1.679	1.917	2.272	2.651
Aw	0.116	0.321	0.492	0.754	0.879
Ln (Aw / 1-Aw)	-2.031	-0.749	-0.032	1.120	1.983
Temperature = 20 °C :					
EMC	4.72	7.12	8.65	11.96	19.64
Ln EMC	1.552	1.963	2.158	2.482	2.978
Aw	0.124	0.336	0.549	0.755	0.932
Ln (Aw / 1-Aw)	-1.955	-0.681	0.197	1.125	2.168
Temperature = 5 °C :					
EMC	6.72	9.11	10.65	14.23	23.79
Ln EMC	1.905	2.209	2.366	2.655	3.169
Aw	0.14	0.346	0.592	0.751	0.966
Ln (Aw / 1-Aw)	-1.815	-0.637	0.372	1.104	3.347

Table 6. Ln EMC vs. Ln (Aw / 1-Aw) for Board 2

Temperature = 40 °C :					
EMC	3.60	5.52	7.05	9.78	13.65
Ln EMC	1.281	1.708	1.953	2.280	2.614
Aw	0.116	0.321	0.492	0.754	0.879
Ln (Aw / 1-Aw)	-2.031	-0.749	-0.032	1.120	1.983
Temperature = 20 °C :					
EMC	4.98	7.28	9.13	11.57	19.22
Ln EMC	1.605	1.985	2.212	2.448	2.956
Aw	0.124	0.336	0.549	0.755	0.932
Ln (Aw / 1-Aw)	-1.955	-0.681	0.197	1.125	2.168
Temperature = 5 °C :					
EMC	7.53	9.15	11.31	14.31	23.84
Ln EMC	2.019	2.214	2.426	2.661	3.171
Aw	0.14	0.346	0.592	0.751	0.966
Ln (Aw / 1-Aw)	-1.815	-0.637	0.372	1.104	3.347

Table 7. Ln EMC vs. Ln (Aw / 1-Aw) for Board 3

Temperature = 40 °C :					
EMC	3.18	5.14	6.89	9.96	13.69
Ln EMC	1.157	1.637	1.930	2.299	2.617
Aw	0.116	0.321	0.492	0.754	0.879
Ln (Aw / 1-Aw)	-2.031	-0.749	-0.032	1.120	1.983
Temperature = 20 °C :					
EMC	4.86	7.16	9.13	11.50	19.34
Ln EMC	1.581	1.969	2.212	2.442	2.962
Aw	0.124	0.336	0.549	0.755	0.932
Ln (Aw / 1-Aw)	-1.955	-0.681	0.197	1.125	2.168
Temperature = 5 °C :					
EMC	7.61	9.26	11.75	14.70	23.83
Ln EMC	2.029	2.226	2.464	2.688	3.171
Aw	0.14	0.346	0.592	0.751	0.966
Ln (Aw / 1-Aw)	-1.815	-0.637	0.372	1.104	3.347

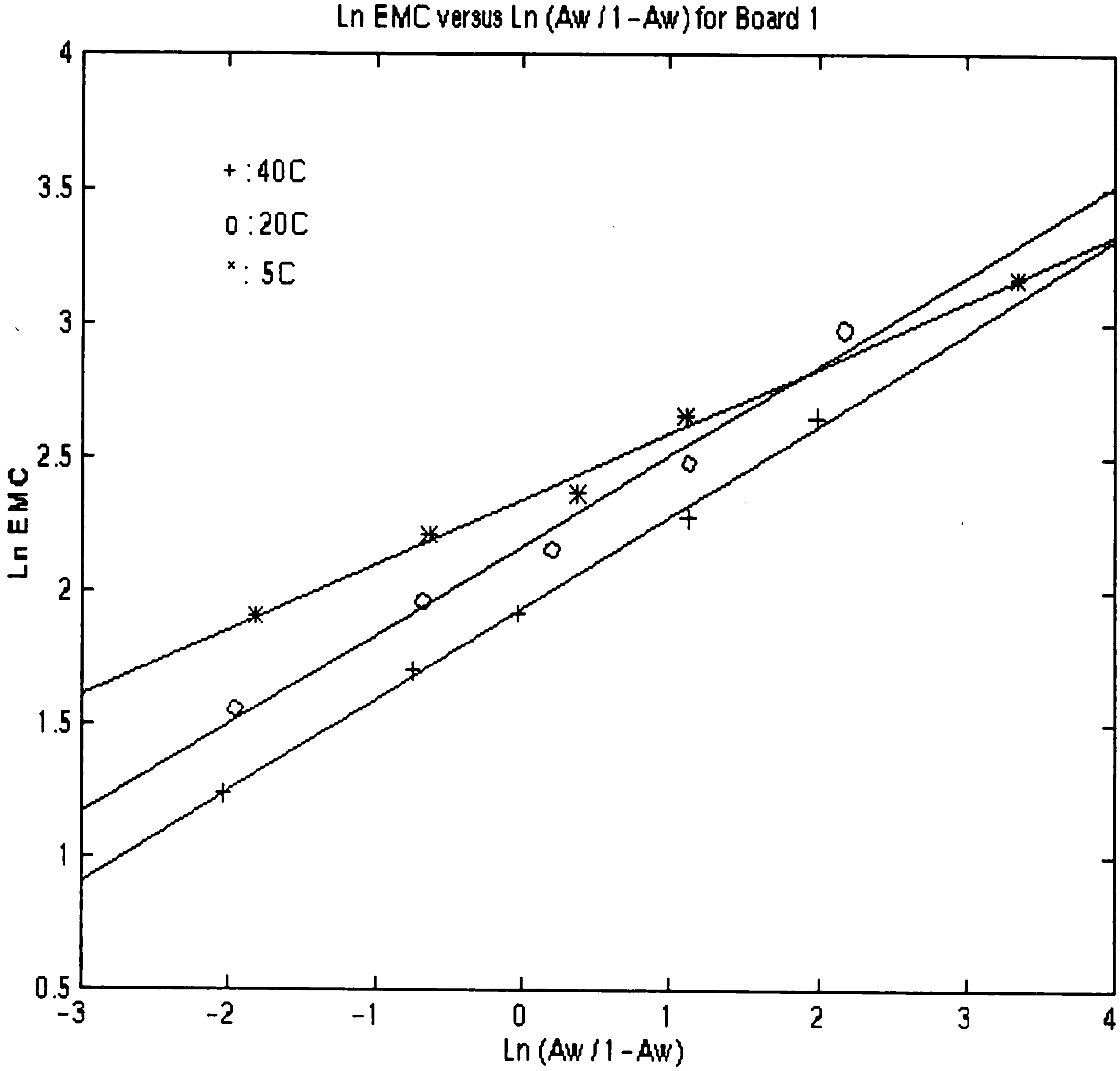
Ln EMC versus Ln (Aw / 1 - Aw) for Board 1
+ : 40C
o : 20C
* : 5C
Ln EMC
Ln (Aw / 1 - Aw)
4
3.5
3
2.5
2
1.5
1
0.5
-3
-2
-1
0
1
2
3
4

Figure 4

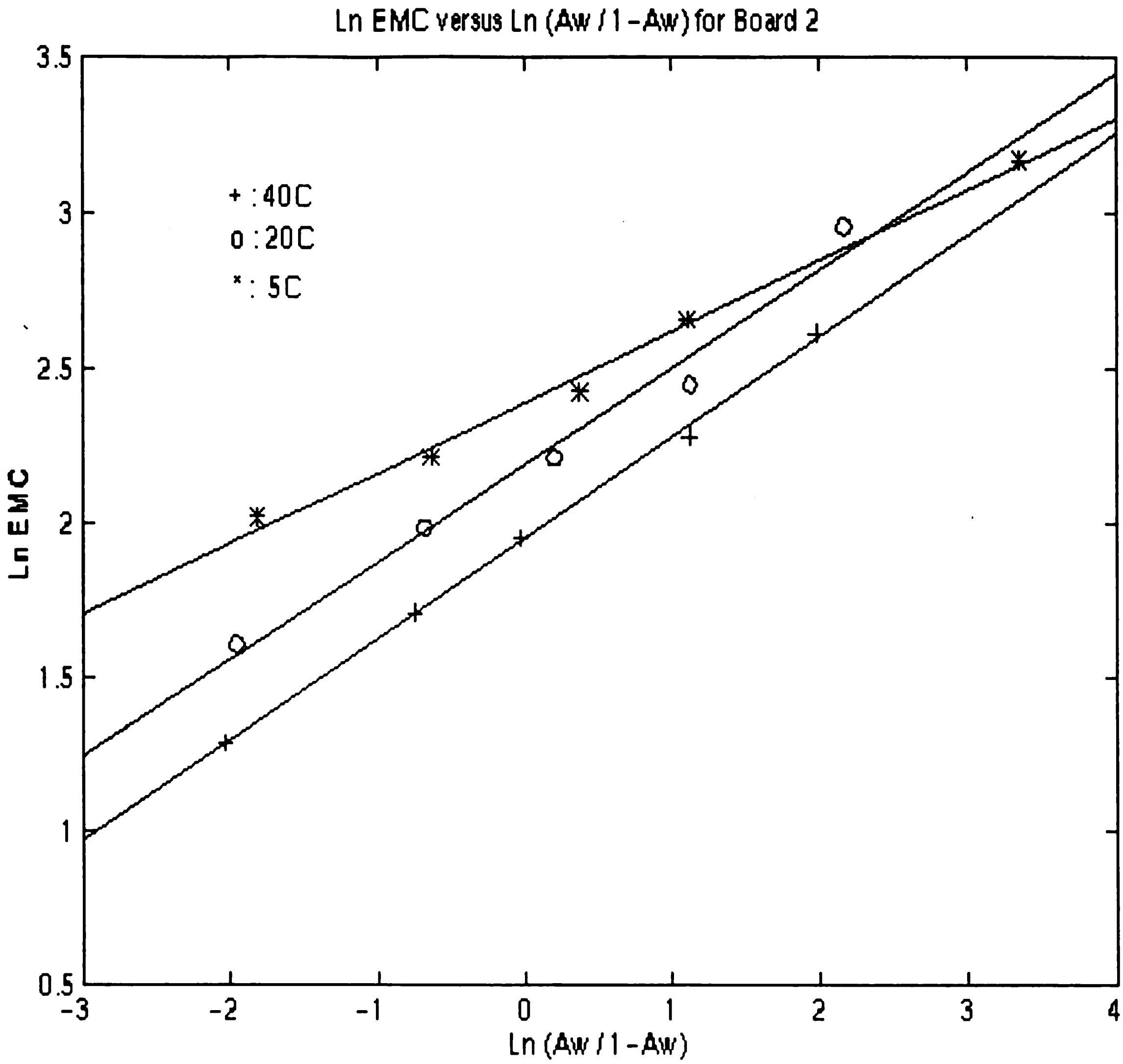
Ln EMC versus Ln (Aw / 1 - Aw) for Board 2
+ : 40C
o : 20C
* : 5C
Ln EMC
Ln (Aw / 1 - Aw)
3.5
3
2.5
2
1.5
1
0.5
-3
-2
-1
0
1
2
3
4

Figure 5

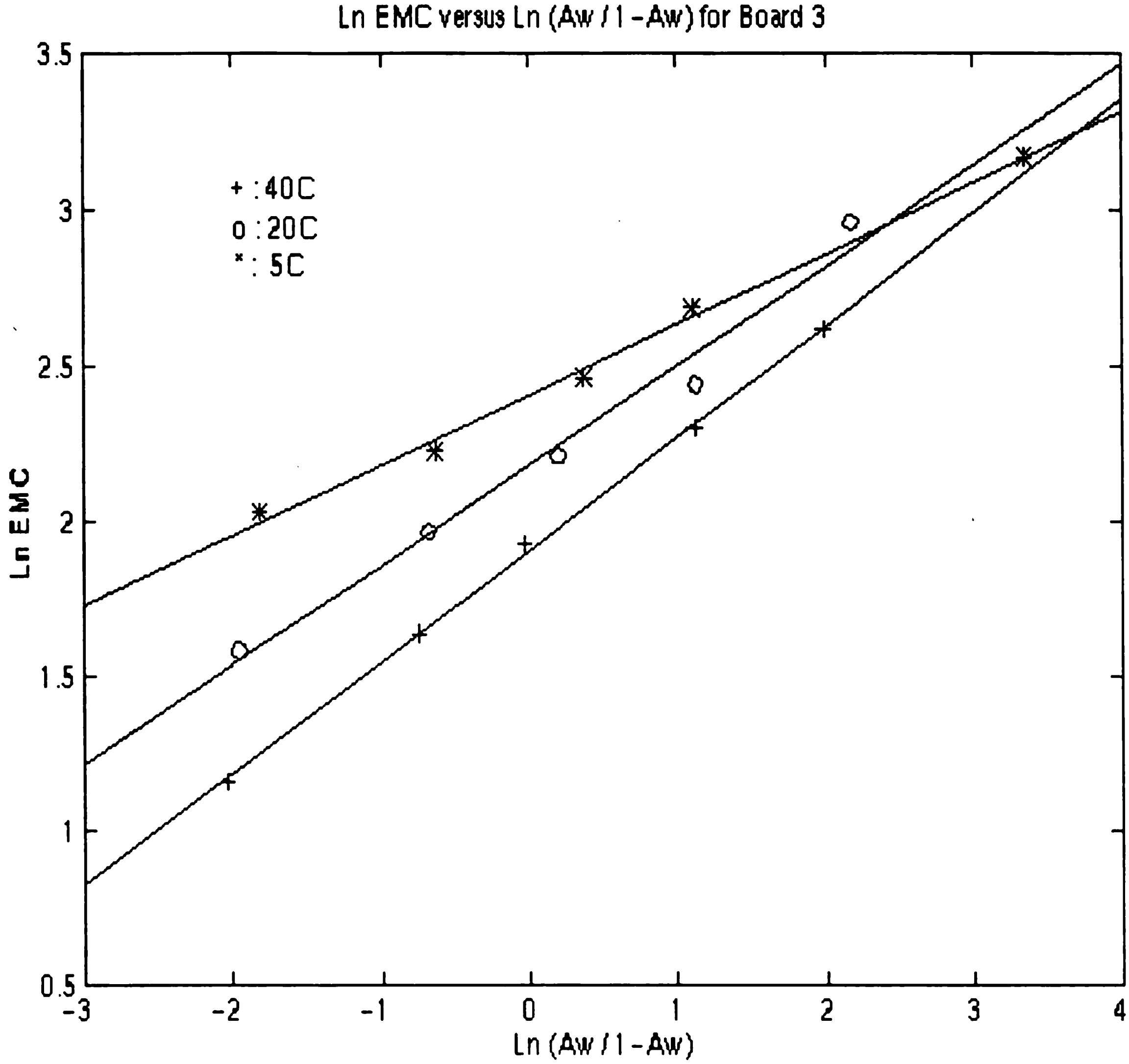
Ln EMC versus Ln (Aw / 1 - Aw) for Board 3
+ : 40C
o : 20C
* : 5C
Ln EMC
Ln (Aw / 1 - Aw)
3.5
3
2.5
2
1.5
1
0.5
-3
-2
-1
0
1
2
3
4

Figure 6

Table 8. Linear Regression for Ln EMC vs. Ln (Aw / 1-Aw)

Board 1 :

Temperature	Linear Regression	r
40 °C	Ln EMC = 1.931 + 0.3456 x Ln (Aw / 1-Aw)	0.9985
20 °C	Ln EMC = 2.146 + 0.3089 x Ln (Aw / 1-Aw)	0.9919
5 °C	Ln EMC = 2.344 + 0.2457 x Ln (Aw / 1-Aw)	0.9970

Board 2 :

Temperature	Linear Regression	r
40 °C	Ln EMC = 1.948 + 0.3268 x Ln (Aw / 1-Aw)	0.9992
20 °C	Ln EMC = 2.187 + 0.3149 x Ln (Aw / 1-Aw)	0.9908
5 °C	Ln EMC = 2.390 + 0.2283 x Ln (Aw / 1-Aw)	0.9963

Board 3 :

Temperature	Linear Regression	r
40 °C	Ln EMC = 1.907 + 0.3617 x Ln (Aw / 1-Aw)	0.9994
20 °C	Ln EMC = 2.156 + 0.2969 x Ln (Aw / 1-Aw)	0.9911
5 °C	Ln EMC = 2.408 + 0.2268 x Ln (Aw / 1-Aw)	0.9755

r = correlation coefficient

corrugated boards at a minimum of two different temperatures to determine the magnitude of the change of the strength performances of 100 % recycled corrugated boards.

Edge Crush Strength (Under Saturated Salt Solutions' Conditions) Versus Equilibrium Moisture Content:

Appendix B and figures 7 to 9 show the relationships between edge crush strength and relative humidity at the three different temperatures for the three boards. In general, as relative humidity increased at any temperature, edge crush strength decreased. As the temperature change from high to low under a fixed relative humidity, edge crush strength also decreased. The reason for this is that the condition at higher relative humidity and lower temperature tended to increase the solubility of water in the board. The more moisture in the board, the lower the edge crush strength of the board.

Because the relationship between the equilibrium moisture content (EMC) and the relative humidity (RH) has been constructed by moisture sorption isotherm, the relationship between the edge crush strength and the EMC can be found by substituting EMC for RH. Tables 9 to 11 and figures 10 to 12 present the relationships between the edge crush strength and the EMC at three different temperatures for three boards. According to figures 10 to 12, the curves show that the more the EMC, the less the edge crush strength. Table 12 gives the results of the linear regression between edge crush strength and EMC. All of the correlation coefficients were close to 1, which means that linear correlation was good.

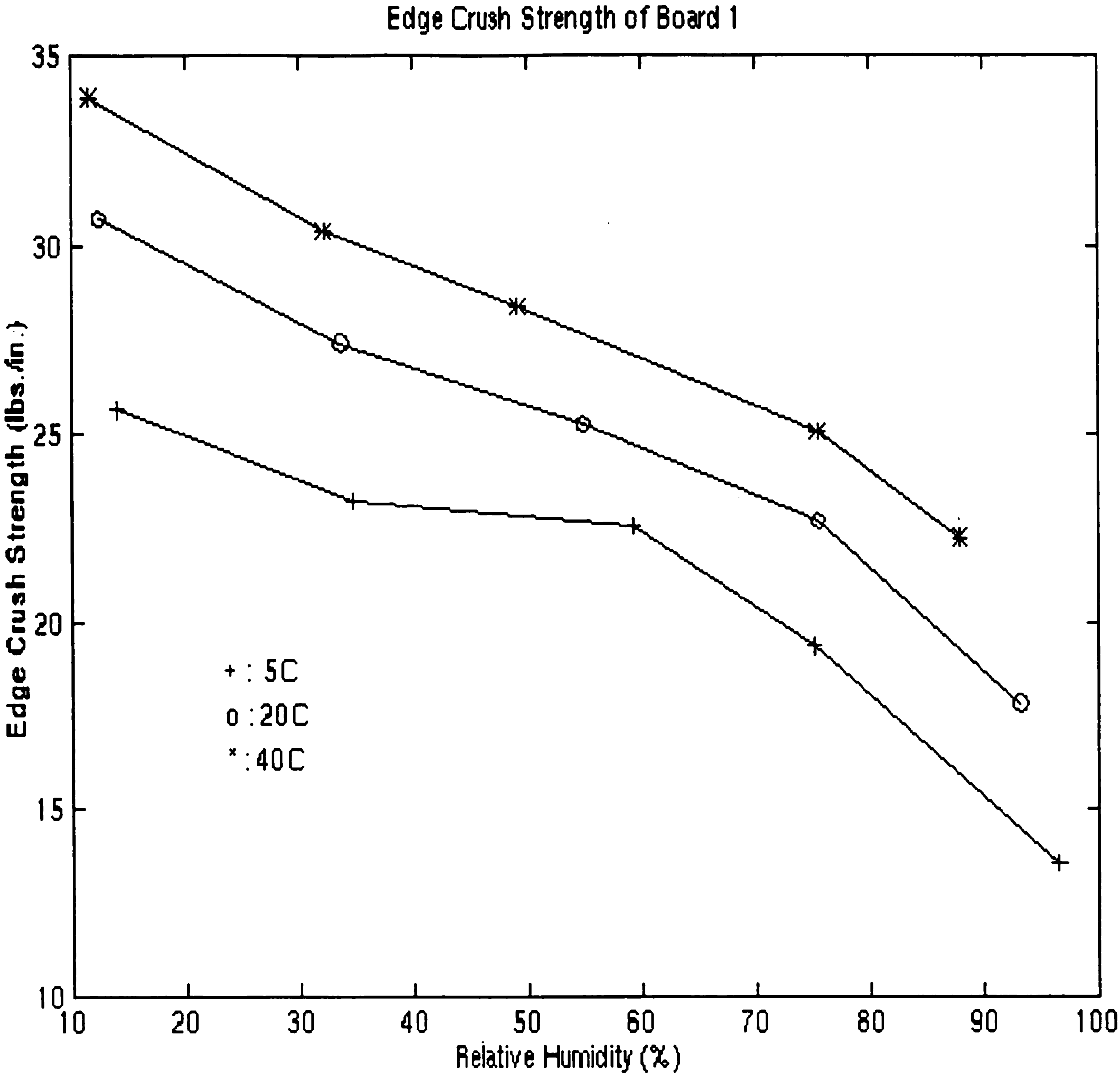
Edge Crush Strength of Board 1
Edge Crush Strength (lbs./in.)
Relative Humidity (%)
35
30
25
20
15
10
10
20
30
40
50
60
70
80
90
100
+ : 5C
o : 20C
* : 40C

Figure 7

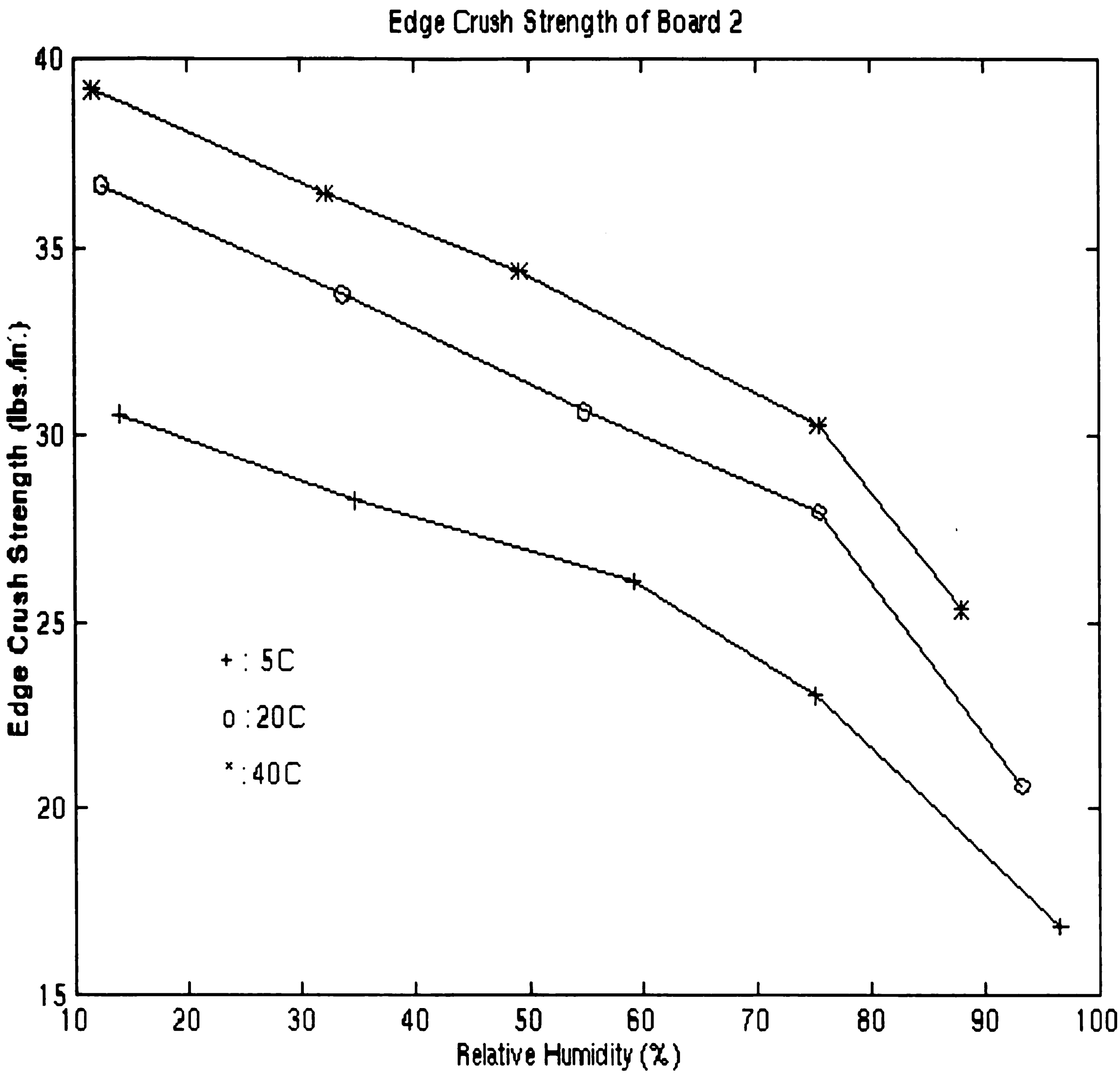
Edge Crush Strength of Board 2
Edge Crush Strength (lbs./in.)
Relative Humidity (%)
40
35
30
25
20
15
10
20
30
40
50
60
70
80
90
100
+ : 5C
o : 20C
* : 40C

Figure 8

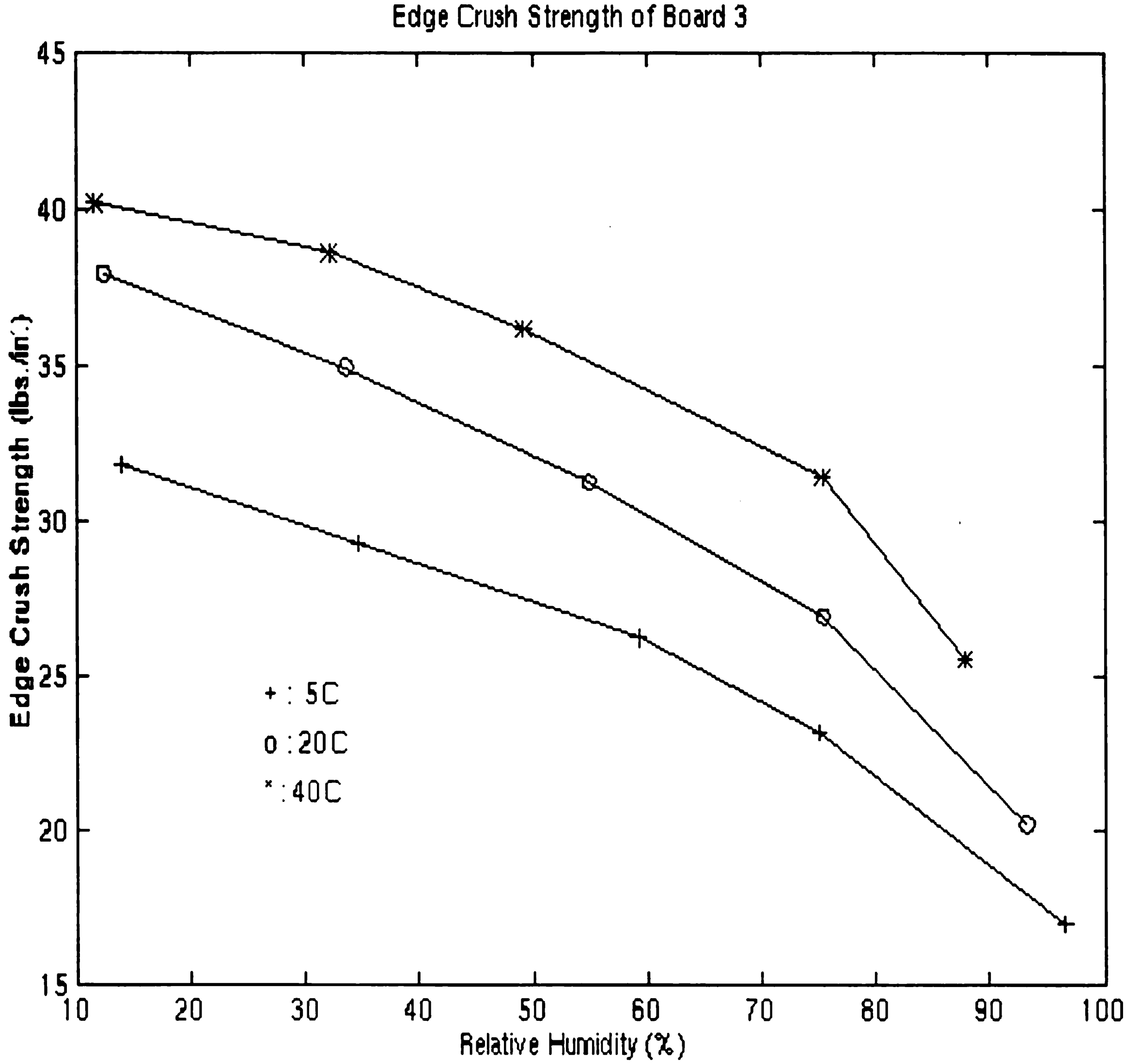
Edge Crush Strength of Board 3
Edge Crush Strength (lbs./in.)
45
40
35
30
25
20
15
10
20
30
40
50
60
70
80
90
100
Relative Humidity (%)
+ : 5C
o : 20C
* : 40C

Figure 9

Table 9. Edge Crush Strength vs. EMC and RH for Board 1

Temperature = 5 °C :					
Strength (lbs./in.)	25.64	23.24	22.56	19.36	13.56
EMC	6.72	9.11	10.65	14.23	23.79
RH (%)	14.0	34.6	59.2	75.1	96.6
Temperature = 20 °C :					
Strength (lbs./in.)	30.70	27.42	25.28	22.68	17.82
EMC	4.72	7.12	8.65	11.96	19.64
RH (%)	12.4	33.6	54.9	75.5	93.2
Temperature = 40 °C :					
Strength (lbs./in.)	33.92	30.36	28.40	25.09	22.25
EMC	3.44	5.36	6.80	9.70	14.17
RH (%)	11.6	32.1	49.2	75.4	87.9

Table 10. Edge Crush Strength vs. EMC and RH for Board 2

Temperature = 5 °C :					
Strength (lbs./in.)	30.56	28.26	26.10	23.02	16.81
EMC	7.53	9.15	11.31	14.31	23.84
RH (%)	14.0	34.6	59.2	75.1	96.6
Temperature = 20 °C :					
Strength (lbs./in.)	36.67	33.76	30.64	27.95	20.60
EMC	4.98	7.28	9.13	11.57	19.22
RH (%)	12.4	33.6	54.9	75.5	93.2
Temperature = 40 °C :					
Strength (lbs./in.)	39.20	36.45	34.37	30.27	25.34
EMC	3.60	5.52	7.05	9.78	13.65
RH (%)	11.6	32.1	49.2	75.4	87.9

Table 11. Edge Crush Strength vs. EMC and RH for Board 3

Temperature = 5 °C :

Strength (lbs./in.)	31.81	29.29	26.23	23.13	16.93
EMC	7.61	9.26	11.75	14.70	23.83
RH (%)	14.0	34.6	59.2	75.1	96.6

Temperature = 20 °C :

Strength (lbs./in.)	37.96	34.95	31.27	26.91	20.18
EMC	4.86	7.16	9.13	11.50	19.34
RH (%)	12.4	33.6	54.9	75.5	93.2

Temperature = 40 °C :

Strength (lbs./in.)	40.22	38.62	36.20	31.44	25.52
EMC	3.18	5.14	6.89	9.96	13.69
RH (%)	11.6	32.1	49.2	75.4	87.9

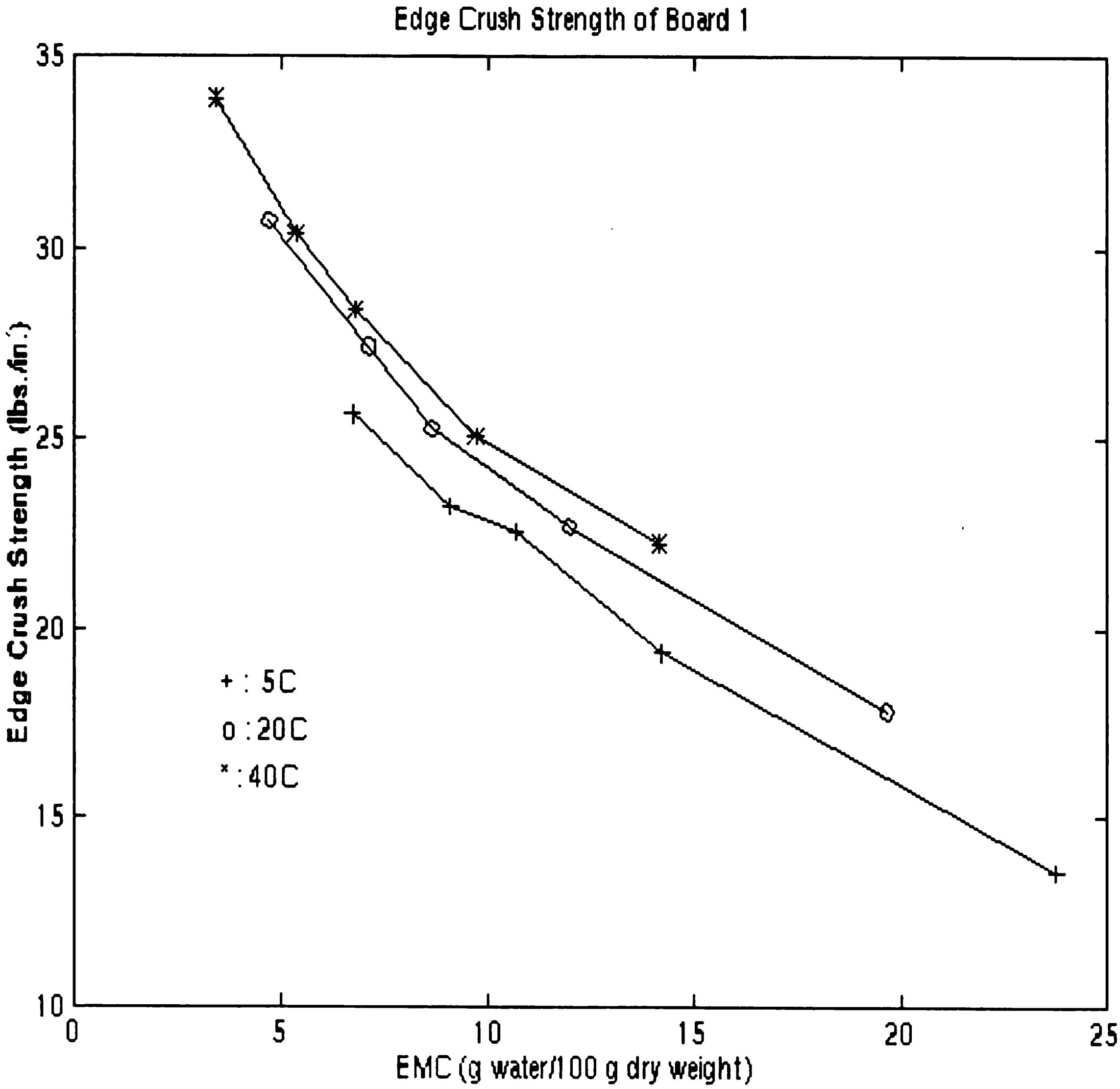
Edge Crush Strength of Board 1
Edge Crush Strength (lbs./in.)
EMC (g water/100 g dry weight)
35
30
25
20
15
10
0
5
10
15
20
25
+ : 5C
o :20C
* :40C

Figure 10

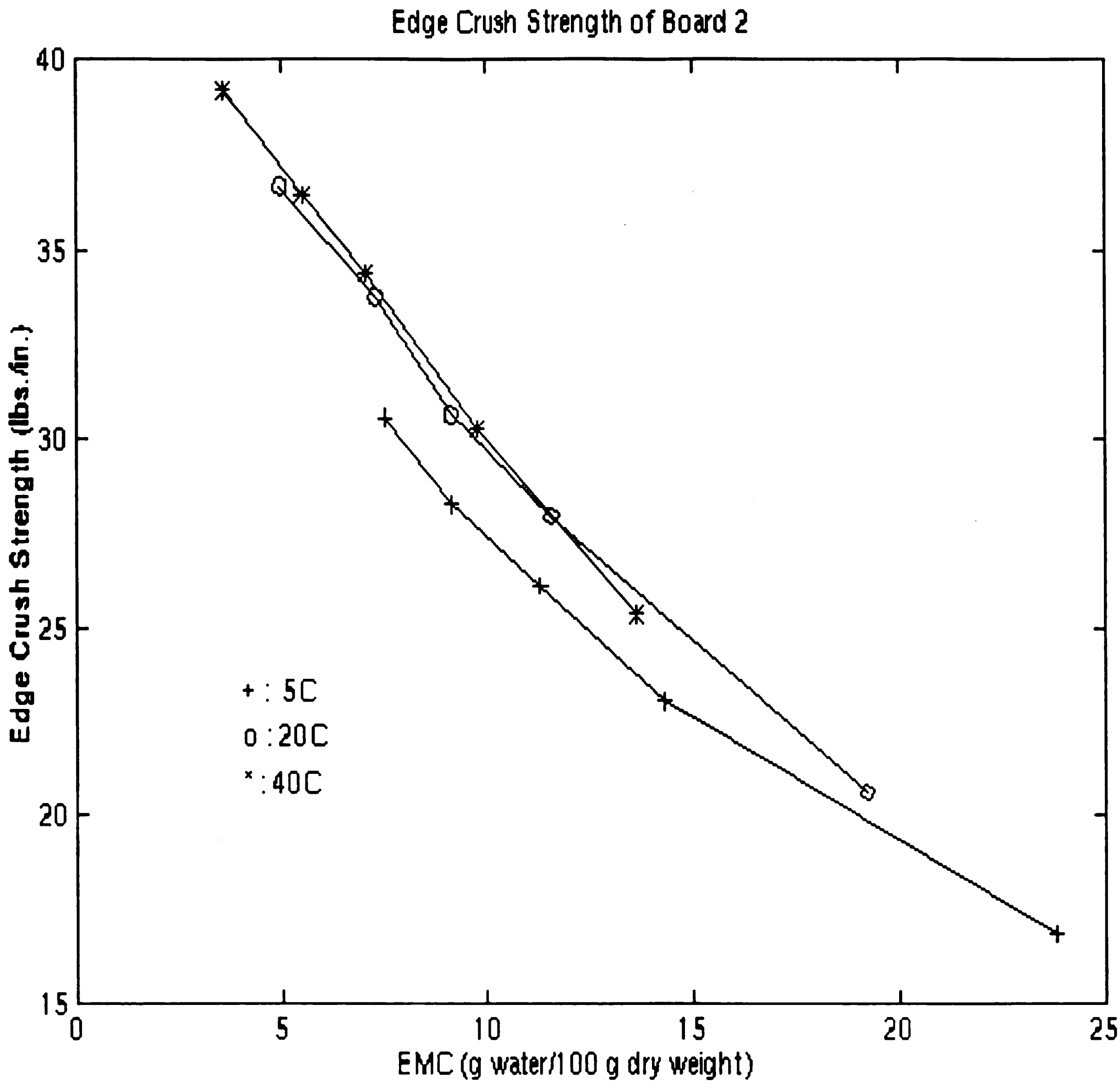
Edge Crush Strength of Board 2
Edge Crush Strength (lbs./in.)
EMC (g water/100 g dry weight)
+ : 5C
o : 20C
* : 40C
40
35
30
25
20
15
0
5
10
15
20
25

Figure 11

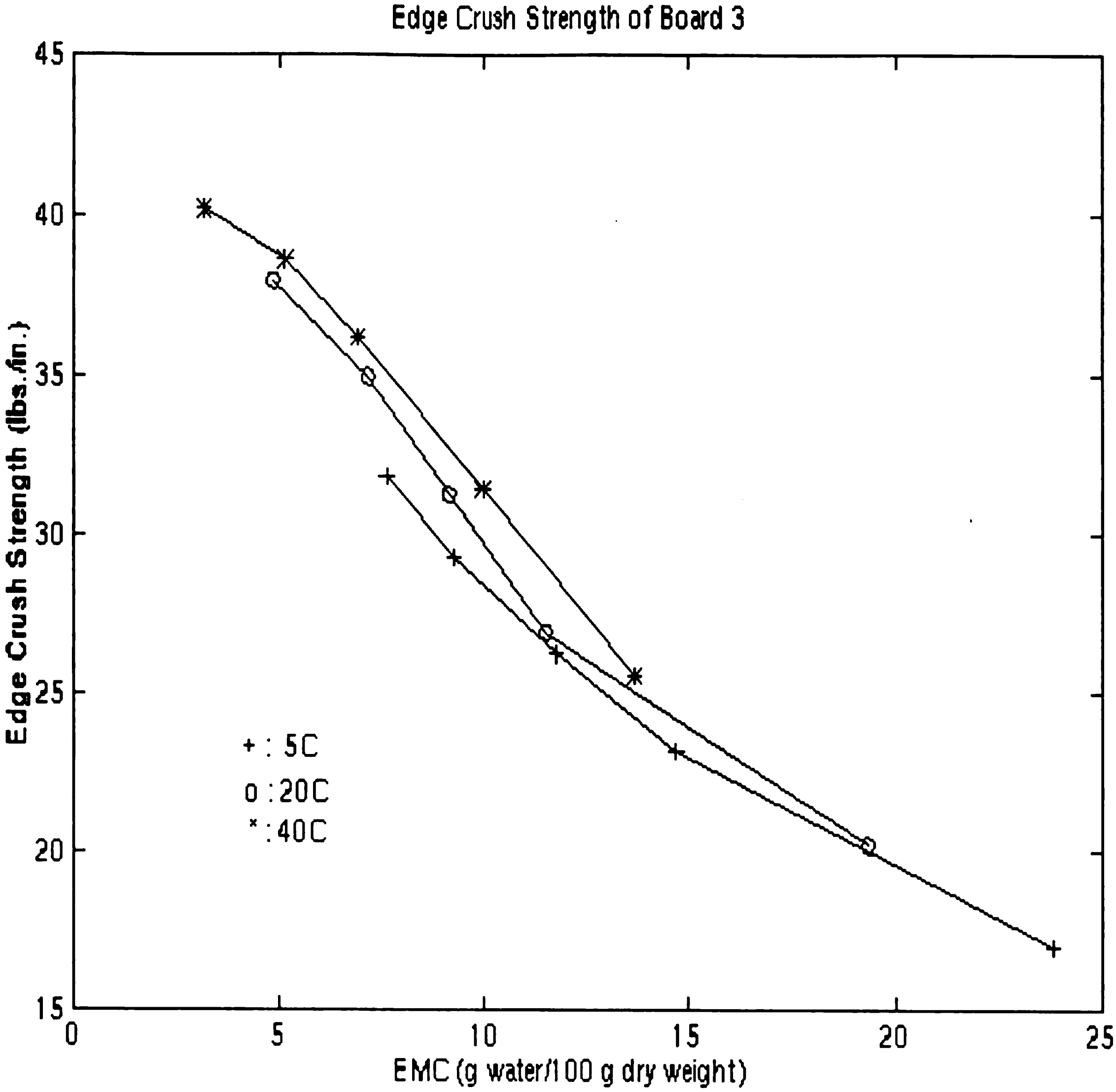
Edge Crush Strength of Board 3
Edge Crush Strength (lbs./in.)
EMC (g water/100 g dry weight)
+ : 5C
o : 20C
* : 40C
45
40
35
30
25
20
15
0
5
10
15
20
25

Figure 12

Table 12. Linear Regression for Edge Crush Strength vs. EMC

Board 1 :

Temperature	Linear Regression	r
40 °C	ECT = 36.35 - 1.0570 x EMC	0.9759
20 °C	ECT = 33.40 - 0.8271 x EMC	0.9813
5 °C	ECT = 29.85 - 0.6960 x EMC	0.9958

Board 2 :

Temperature	Linear Regression	r
40 °C	ECT = 44.11 - 1.3860 x EMC	0.9995
20 °C	ECT = 41.59 - 1.1180 x EMC	0.9940
5 °C	ECT = 35.76 - 0.8174 x EMC	0.9891

Board 3 :

Temperature	Linear Regression	r
40 °C	ECT = 45.55 - 1.4350 x EMC	0.9956
20 °C	ECT = 43.09 - 1.2340 x EMC	0.9834
5 °C	ECT = 37.44 - 0.8904 x EMC	0.9854

r = correlation coefficient
ECT = edge crush strength
EMC = equilibrium moisture content

Flat Crush Resistance (Under Saturated Salt Solutions' Conditions) Versus Equilibrium Moisture Content:

Appendix C and figures 13 to 15 show the relationships between the flat crush resistance and the relative humidity at the three different temperatures for three boards. In general, as the relative humidity increased, the flat crush resistance decreased. As the temperature shifted from high to low under a fixed relative humidity, the flat crush resistance also decreased. The reason for this is the same as for that of edge crush strength. By substituting EMC for RH from the sorption isotherm, tables 13 to 15 and figures 16 to 18 present the relationships between flat crush resistance and EMC at three different temperatures for three boards. Table 16 shows the results of the linear regression between flat crush resistance and EMC. All of the correlation coefficients were close to 1, which means that linear correlation was good.

Strength Performances Under Recommended ASTM Conditions:

Table 17 shows the edge crush strength (Appendix B), flat crush resistance (Appendix C), and bursting strength (Appendix D) for three different boards under three recommended ASTM conditions. Figures 19 to 21 also present graphically the relationships between strength properties and temperature. In general, under a fixed relative humidity (85%), any board conditioned at lower temperature has lower strength performances. This result is consistent with that found under saturated salt solutions' conditions (figures 7 to 9 and figures 13 to 15). The values of strength found under recommended ASTM conditions are also consistent with those found under saturated salt solutions' conditions. Because, under the same temperature condition, the values of strength (edge crush and flat crush) conditioned at relative humidity 85 % are always in between those (higher values of strength) conditioned at less than 85 % relative humidity and those (lower values of strength) conditioned at greater than 85 % relative humidity. The reason is that because less moisture is absorbed by the board when exposed to lower than 85 % relative humidity, the board is stronger; and because more moisture is absorbed by the board when exposed to greater than 85 % relative humidity, the board is weaker.

The bursting strength of test samples could be tested only under the recommended ASTM conditions, because the test samples were too big to fit into the buckets used for creating the saturated salt solutions' conditions. Under a constant relative humidity (85%), the lower the temperature, the lower the bursting strength. The reason is that the more moisture absorbed by the board under the lower temperature, the lower bursting strength of the board.

Linear Regression Equations To Re-build The Data:

Use linear regression equations from table 8, table 12, and table 16 to re-build the data of RH, Aw, EMC, ECT, and FCR. The results are presented in Appendix E. For each type of board under any condition, An increase in RH (or Aw) by 10% (or 0.1 unit) decreases less ECT and FCR in the 10-70% RH (or 0.1-0.7 Aw) range than the 70-90% RH (or 0.7-0.9 Aw) range. The reason can be found from the EMC column, which shows that the three types of boards absorbed less moisture in the 10-70% RH range than the 70-90% RH range. Moreover, under the same RH, a change in temperature from high to low decreased ECT and FCR, because of increased moisture content. Therefore, moisture content is the main cause of reduced strength performances.

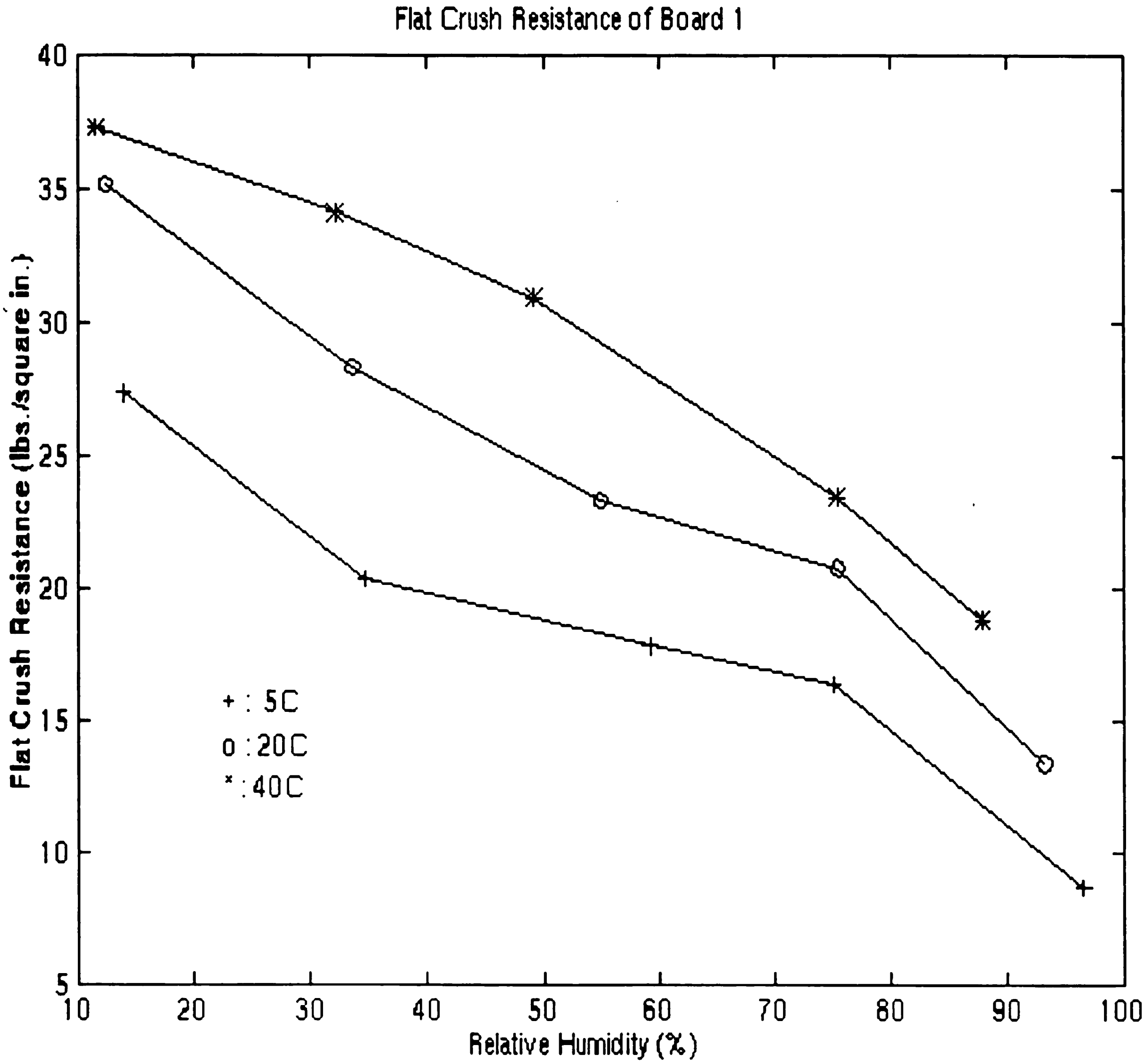
Flat Crush Resistance of Board 1
Flat Crush Resistance (lbs./square in.)
Relative Humidity (%)
40
35
30
25
20
15
10
5
10
20
30
40
50
60
70
80
90
100
+ : 5C
o : 20C
* : 40C

Figure 13

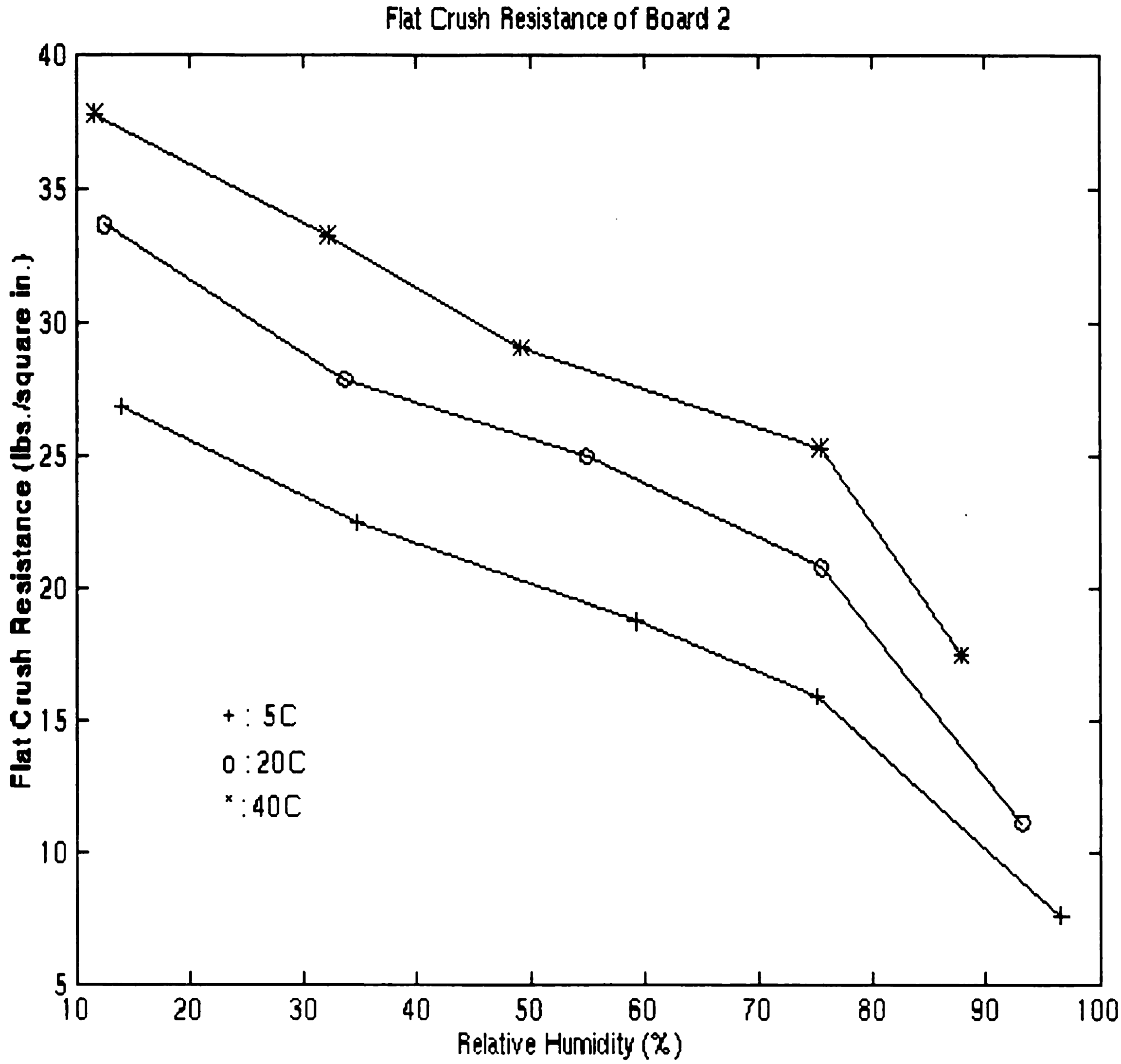
Flat Crush Resistance of Board 2
Flat Crush Resistance (lbs./square in.)
Relative Humidity (%)
+ : 5C
o : 20C
* : 40C
40
35
30
25
20
15
10
5
10
20
30
40
50
60
70
80
90
100

Figure 14

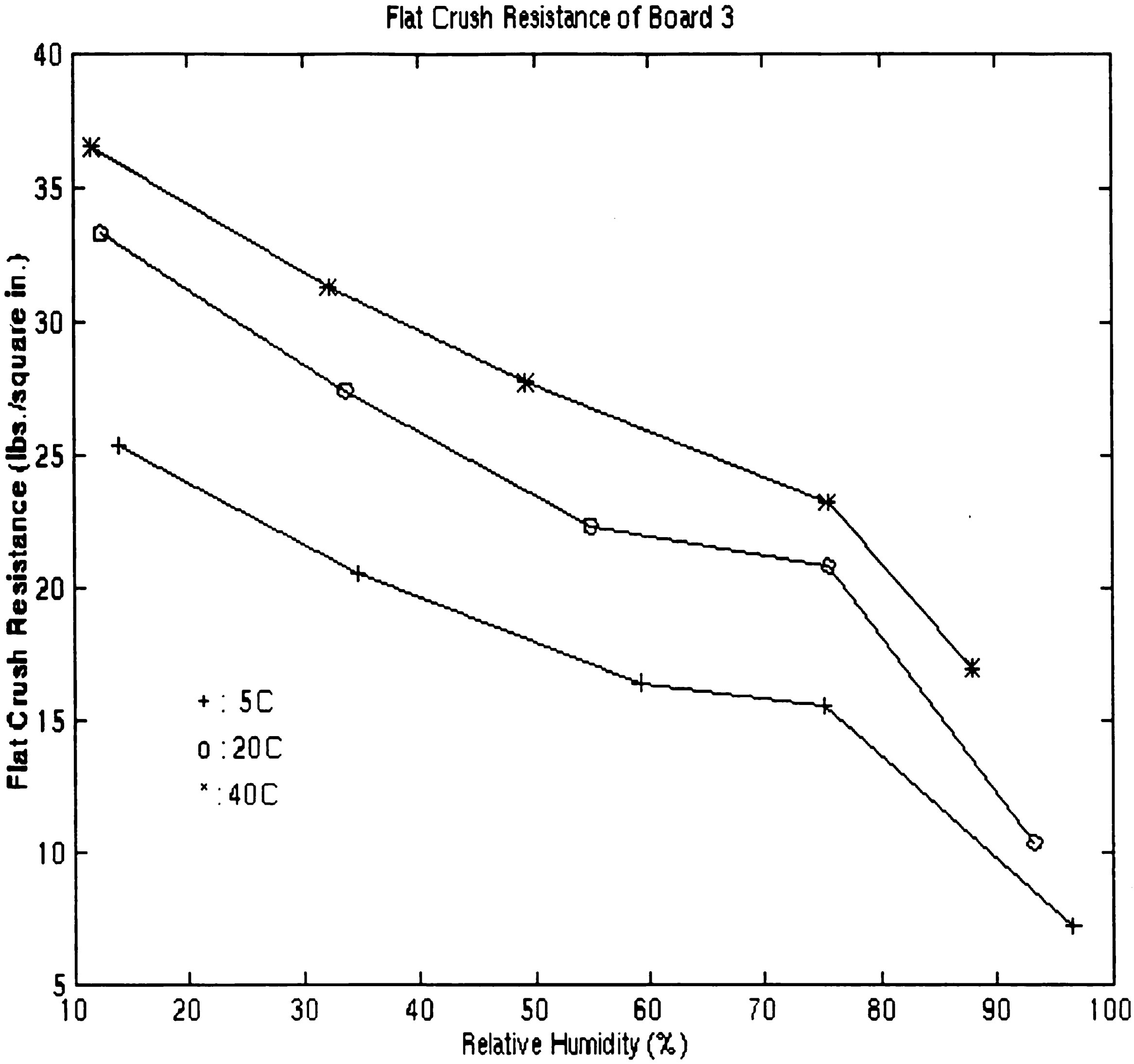
Flat Crush Resistance of Board 3
Flat Crush Resistance (lbs./square in.)
Relative Humidity (%)
+ : 5C
o : 20C
* : 40C
40
35
30
25
20
15
10
5
10
20
30
40
50
60
70
80
90
100

Figure 15

Table 13 Flat Crush Resistance vs. EMC and RH for Board 1

Temperature = 5 °C :					
Strength (lbs./in^2.)	27.37	20.38	17.81	16.37	8.69
EMC	6.72	9.11	10.65	14.23	23.79
RH (%)	14.0	34.6	59.2	75.1	96.6
Temperature = 20 °C :					
Strength (lbs./in^2.)	35.21	28.33	23.31	20.77	13.35
EMC	4.72	7.12	8.65	11.96	19.64
RH (%)	12.4	33.6	54.9	75.5	93.2
Temperature = 40 °C :					
Strength (lbs./in^2.)	37.32	34.13	30.97	23.45	18.81
EMC	3.44	5.36	6.80	9.70	14.17
RH (%)	11.6	32.1	49.2	75.4	87.9

Table 14. Flat Crush Resistance vs. EMC and RH for Board 2

Temperature = 5 °C :					
Strength (lbs./in^2.)	26.87	22.51	18.75	15.91	7.59
EMC	7.53	9.15	11.31	14.31	23.84
RH (%)	14.0	34.6	59.2	75.1	96.6
Temperature = 20 °C :					
Strength (lbs./in^2.)	33.69	27.87	24.98	20.78	11.10
EMC	4.98	7.28	9.13	11.57	19.22
RH (%)	12.4	33.6	54.9	75.5	93.2
Temperature = 40 °C :					
Strength (lbs./in^2.)	37.84	33.28	29.07	25.30	17.49
EMC	3.60	5.52	7.05	9.78	13.65
RH (%)	11.6	32.1	49.2	75.4	87.9

Table 15. Flat Crush Resistance vs. EMC and RH for Board 3

Temperature = 5 °C :					
Strength (lbs./in^2.)	25.35	20.56	16.39	15.54	7.17
EMC	7.61	9.26	11.75	14.70	23.83
RH (%)	14.0	34.6	59.2	75.1	96.6
Temperature = 20 °C :					
Strength (lbs./in^2.)	33.32	27.43	22.33	20.82	10.35
EMC	4.86	7.16	9.13	11.50	19.34
RH (%)	12.4	33.6	54.9	75.5	93.2
Temperature = 40 °C :					
Strength (lbs./in^2.)	36.56	31.29	27.74	23.25	16.96
EMC	3.18	5.14	6.89	9.96	13.69
RH (%)	11.6	32.1	49.2	75.4	87.9

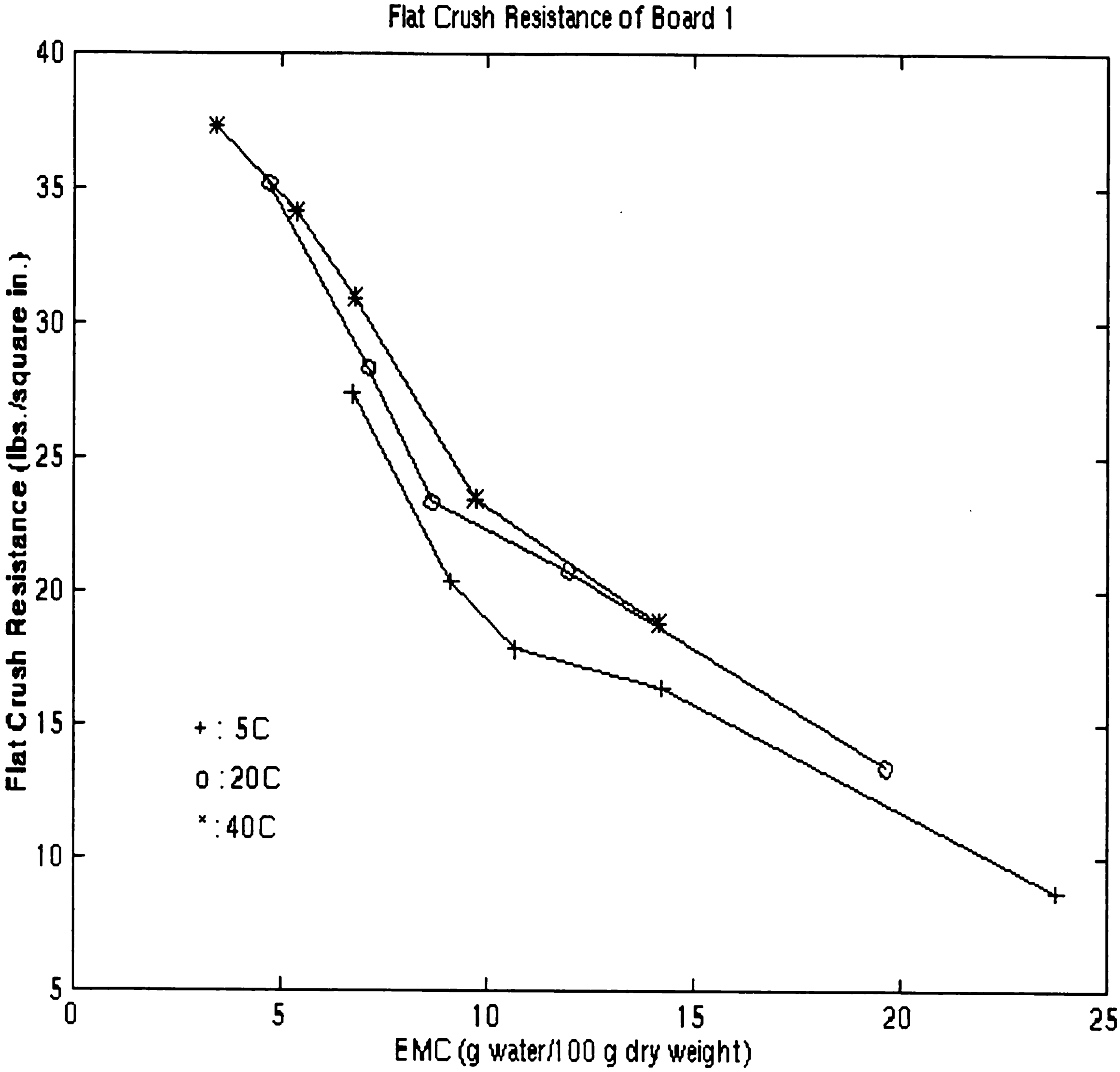
Flat Crush Resistance of Board 1
Flat Crush Resistance (lbs./square in.)
40
35
30
25
20
15
10
5
0
5
10
15
20
25
EMC (g water/100 g dry weight)
+ : 5C
o : 20C
* : 40C

Figure 16

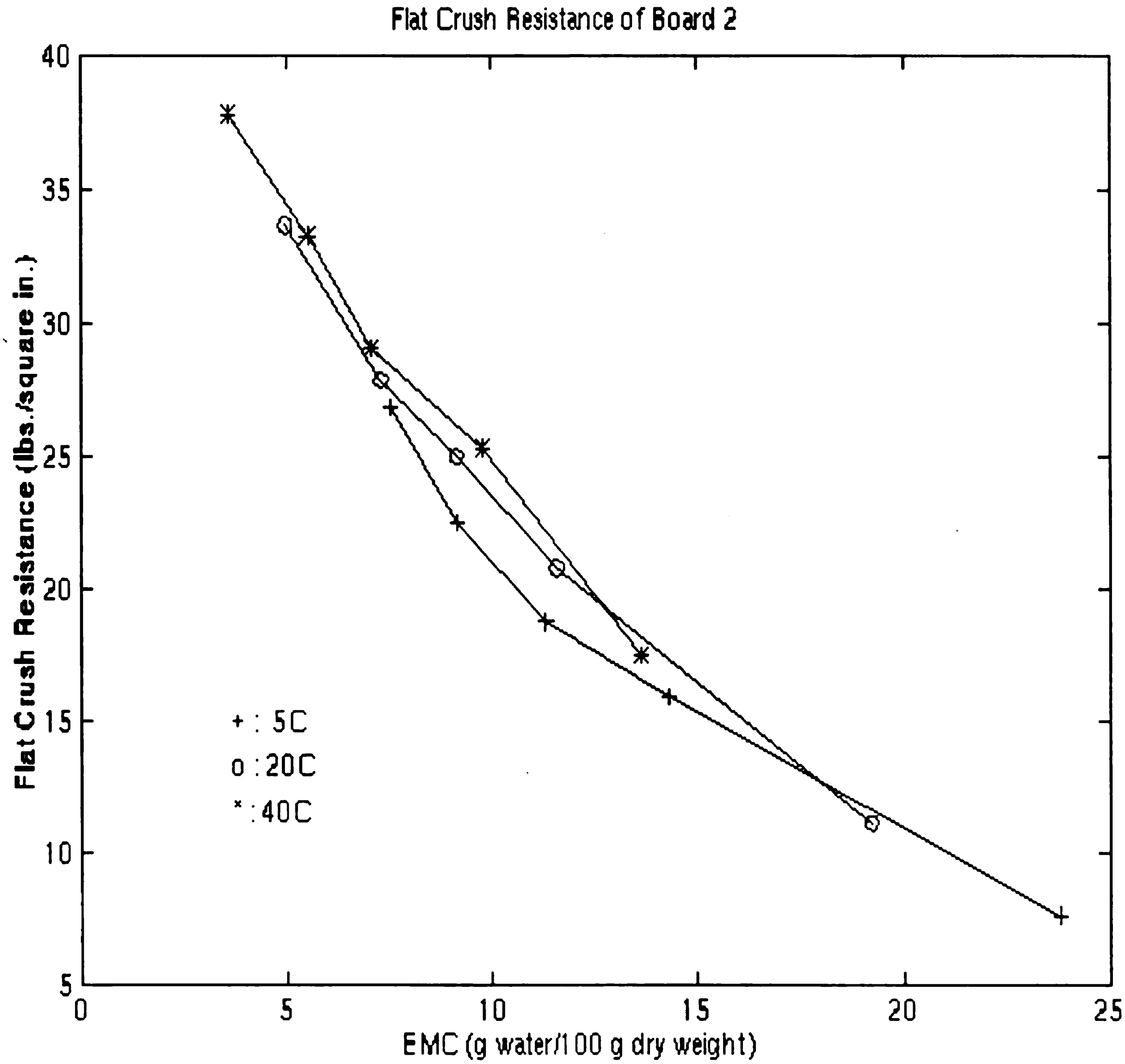
Flat Crush Resistance of Board 2
Flat Crush Resistance (lbs./square in.)
EMC (g water/100 g dry weight)
+ : 5C
o : 20C
* : 40C
0
5
10
15
20
25
30
35
40

Figure 17

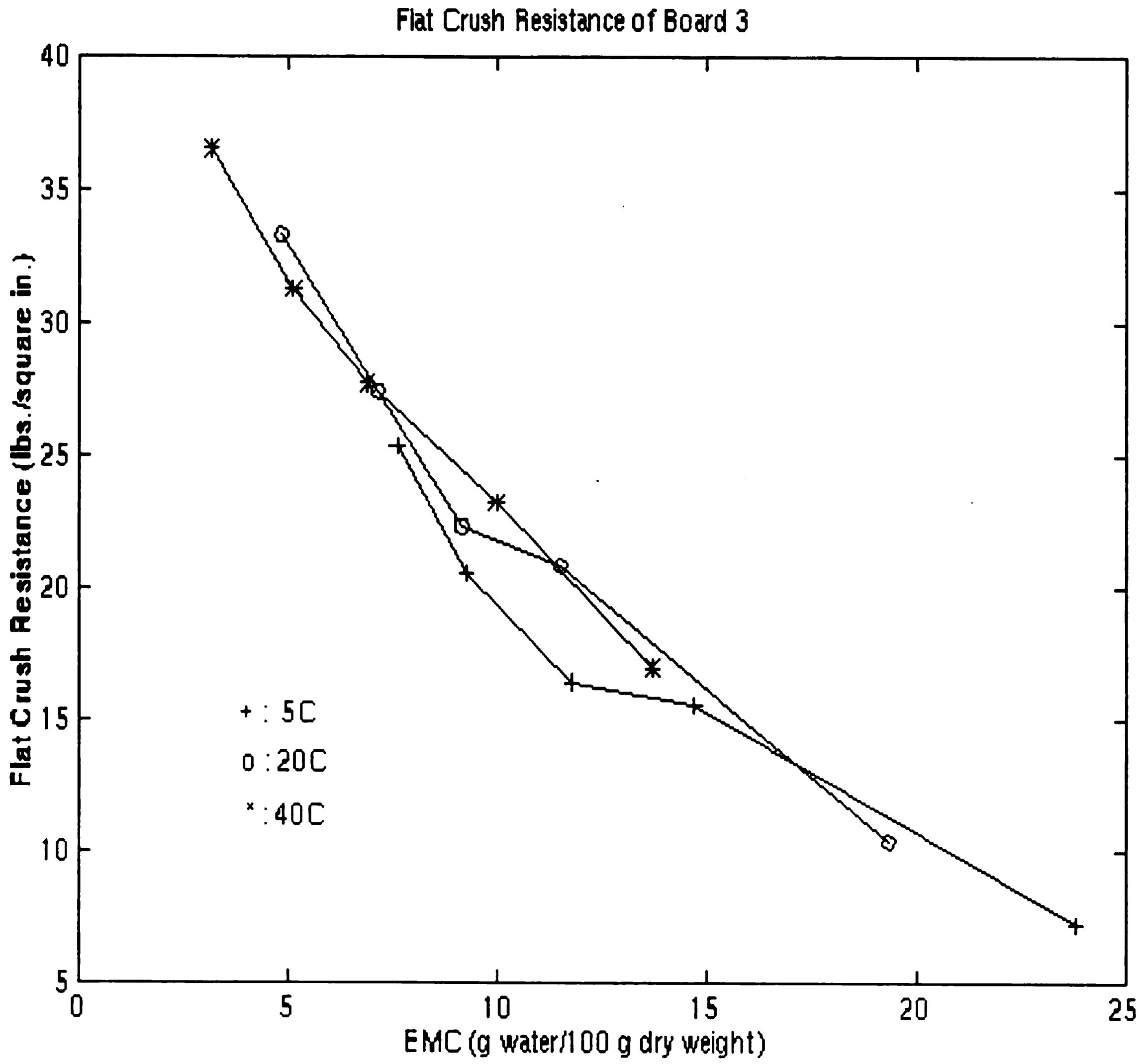
Flat Crush Resistance of Board 3
Flat Crush Resistance (lbs./square in.)
EMC (g water/100 g dry weight)
+ : 5C
o : 20C
* : 40C
40
35
30
25
20
15
10
5
0
5
10
15
20
25

Figure 18

Table 16. Linear Regression for Flat Crush Resistance vs. EMC

Board 1 :

Temperature	Linear Regression	r
40 °C	FCR = 43.14 - 1.8000 x EMC	0.9851
20 °C	FCR = 38.21 - 1.3450 x EMC	0.9499
5 °C	FCR = 30.45 - 0.9555 x EMC	0.9429

Board 2 :

Temperature	Linear Regression	r
40 °C	FCR = 44.23 - 1.9740 x EMC	0.9953
20 °C	FCR = 39.64 - 1.5290 x EMC	0.9899
5 °C	FCR = 32.87 - 1.0990 x EMC	0.9749

Board 3 :

Temperature	Linear Regression	r
40 °C	FCR = 41.15 - 1.8000 x EMC	0.9936
20 °C	FCR = 38.47 - 1.5020 x EMC	0.9799
5 °C	FCR = 30.65 - 1.0160 x EMC	0.9654

r = correlation coefficient
FCR = flat crush resistance
EMC = equilibrium moisture content

Table 17. Strength under Recommended ASTM Conditions

Board 1 :			
Temperature (°C)	5	20	40
RH (%)	85.0	85.0	85.0
Edge Crush (lbs./in.)	18.63	20.74	22.15
Flat Crush (lbs./in^2.)	12.64	17.22	18.65
Bursting (lbs./in^2.)	94	116	119
Board 2 :			
Temperature (°C)	5	20	40
RH (%)	85.0	85.0	85.0
Edge Crush (lbs./in.)	21.32	24.29	25.49
Flat Crush (lbs./in^2.)	11.42	16.47	17.15
Bursting (lbs./in^2.)	178	241	250
Board 3 :			
Temperature (°C)	5	20	40
RH (%)	85.0	85.0	85.0
Edge Crush (lbs./in.)	22.31	25.44	26.26
Flat Crush (lbs./in^2.)	10.97	15.33	16.30
Bursting (lbs./in^2.)	216	256	259

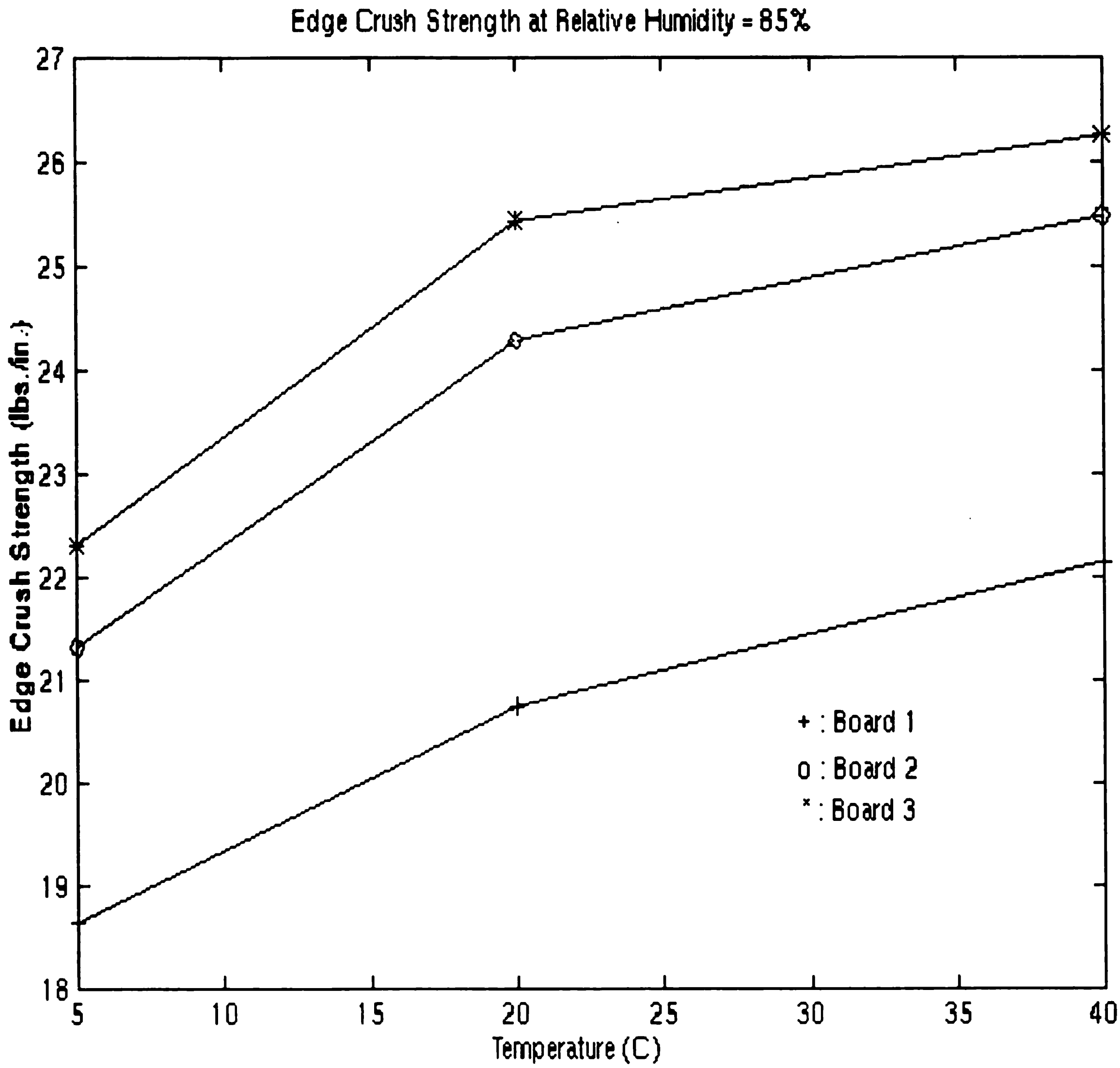
Edge Crush Strength at Relative Humidity = 85%
Edge Crush Strength (lbs./in.)
27
26
25
24
23
22
21
20
19
18
5
10
15
20
25
30
35
40
Temperature (C)
+ : Board 1
o : Board 2
* : Board 3

Figure 19

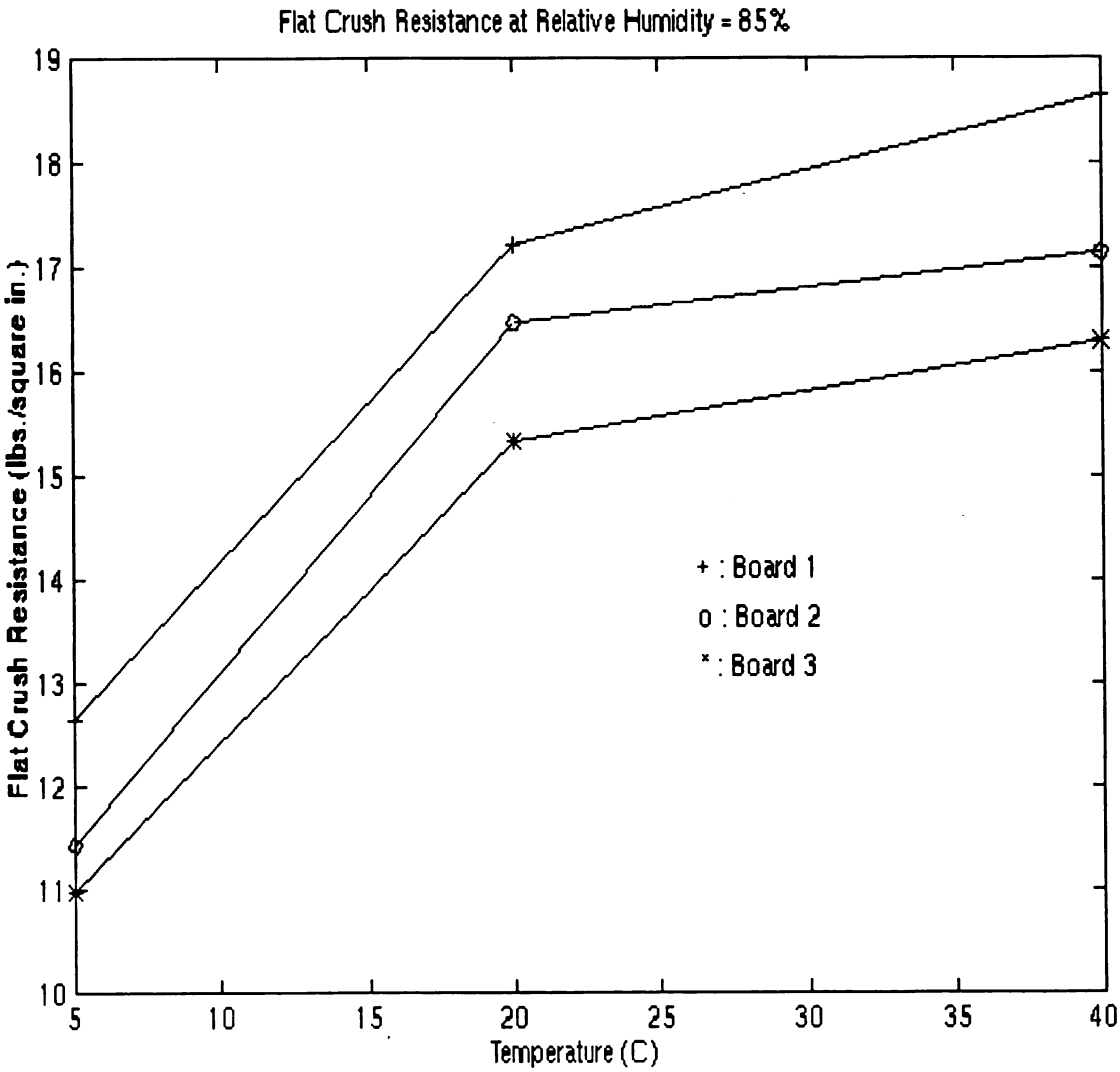
Flat Crush Resistance at Relative Humidity = 85%
Flat Crush Resistance (lbs./square in.)
Temperature (C)
+ : Board 1
o : Board 2
* : Board 3
19
18
17
16
15
14
13
12
11
10
5
10
15
20
25
30
35
40

Figure 20

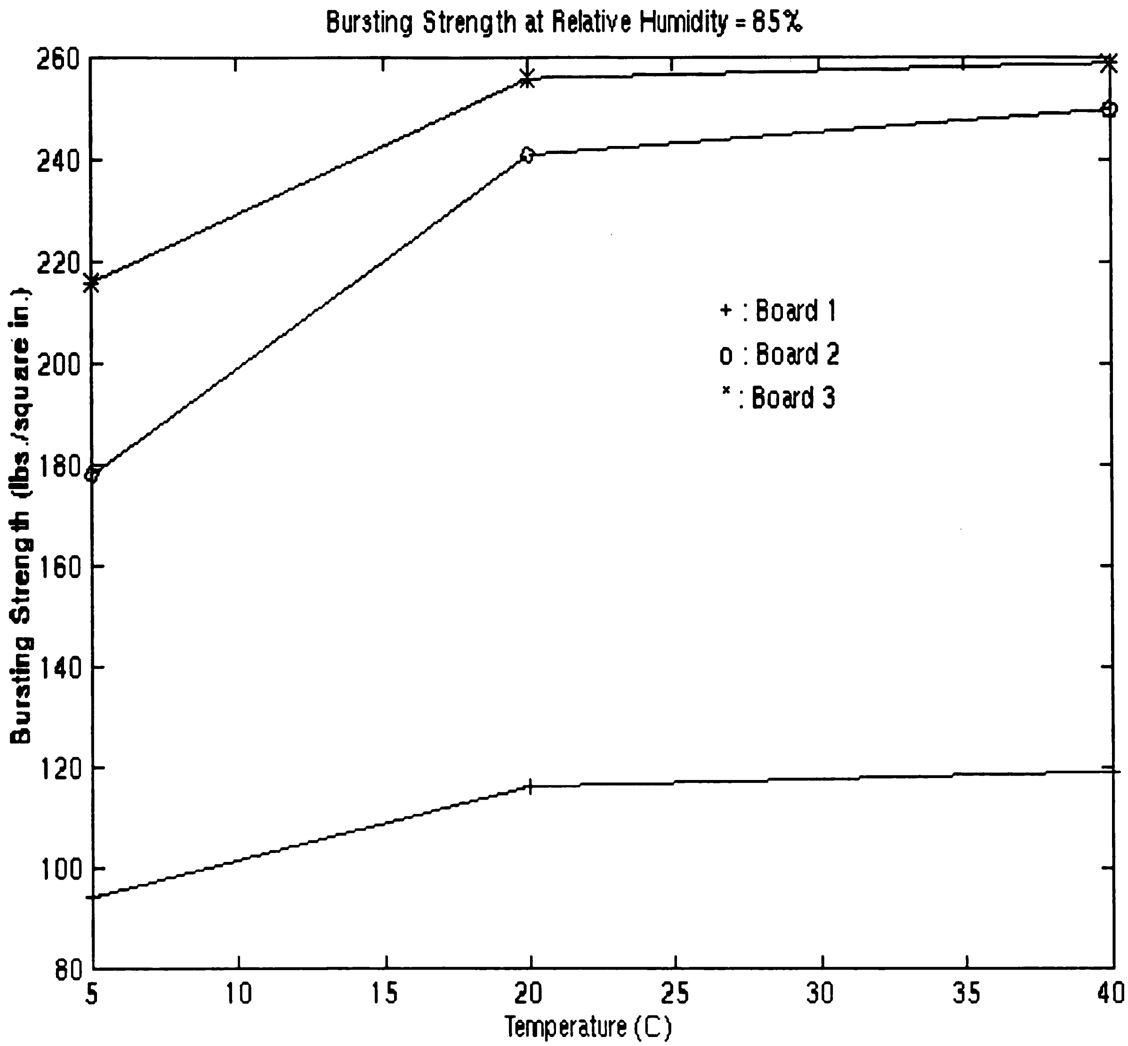
Bursting Strength at Relative Humidity = 85%
Bursting Strength (lbs./square in.)
260
240
220
200
180
160
140
120
100
80
5
10
15
20
25
30
35
40
Temperature (C)
+ : Board 1
o : Board 2
* : Board 3

Figure 21

CONCLUSIONS AND FUTURE RESEARCH

The conclusions of this study were:

1. The moisture sorption isotherm of 100% recycled corrugated board shows that for a given equilibrium moisture content an increase in temperature results in an increase in relative humidity (or water activity). The Oswin equation can be properly applied to describe this moisture sorption isotherm.

2. Edge crush strength and flat crush resistance are strongly affected by any change in either relative humidity or temperature. In general, a condition of higher relative humidity and lower temperature tends to increase the solubility of the board. The more water in the board, the lower the strength performances of the board. The high correlation coefficients (close to 1) indicate that these results are quite reliable. Bursting strength is also strongly affected by change in temperature under a constant 85% relative humidity. The lower the temperature, the lower the bursting strength. The reason is that the lower temperature causes the board to absorb more moisture thereby reducing its bursting strength.

3. The values of both edge crush and flat crush under the recommended ASTM conditions are consistent with those under the saturated salt solutions' conditions.

A more detailed study needs to be carried out to construct the moisture desorption isotherm, test the bursting strength under saturated salt solutions' conditions, and evaluate other physical properties under saturated salt solutions' conditions and recommended ASTM conditions. In this way, the effect of moisture on 100 % recycled corrugated board can be conclusively studied.

APPENDICES

Appendix A : Equilibrium Moisture Content

Table A-1. Equilibrium Moisture Content of Board 1 at T = 40 °C, RH = 11.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.8513	2.7632	3.19
2	2.7874	2.6972	3.34
3	2.8965	2.801	3.41
4	2.8006	2.714	3.19
5	2.88	2.7807	3.57
6	2.8224	2.7276	3.48
7	2.8027	2.7015	3.75
8	2.8676	2.7702	3.52
9	2.8462	2.7529	3.39
10	2.7754	2.6811	3.52
		Mean	3.44
		Std. Dev.	0.17

Table A-2. Equilibrium Moisture Content of Board 1 at T = 40 °C, RH = 32.1%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.8182	2.6767	5.29
2	2.9262	2.7755	5.43
3	2.9257	2.7769	5.36
4	2.9221	2.7673	5.59
5	2.9487	2.8036	5.18
6	2.9614	2.8049	5.58
7	2.8811	2.7305	5.52
8	2.7849	2.641	5.45
9	2.9505	2.8062	5.14
10	2.9091	2.7679	5.10
		Mean	5.36
		Std. Dev.	0.18

Table A-3. Equilibrium Moisture Content of Board 1 at T = 40 °C, RH = 49.2%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.9354	2.7433	7.00
2	2.96	2.7669	6.98
3	2.9197	2.7307	6.92
4	2.8153	2.6412	6.59
5	2.7854	2.6053	6.91
6	2.9615	2.7704	6.70
7	2.9448	2.7564	6.84
8	2.9218	2.7361	6.79
9	2.9773	2.7945	6.54
10	2.9686	2.7821	6.70
		Mean	6.80
		Std. Dev.	0.16

Table A-4. Equilibrium Moisture Content of Board 1 at T = 40 °C, RH = 75.4%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.0414	2.7829	9.29
2	2.9587	2.6987	9.63
3	2.9996	2.7379	9.56
4	2.9971	2.7271	9.90
5	2.8936	2.6371	9.73
6	3.0255	2.7595	9.64
7	2.9674	2.7004	9.89
8	2.9971	2.7308	9.75
9	2.9832	2.7131	9.96
10	3.0496	2.7825	9.60
		Mean	9.70
		Std. Dev.	0.20

Table A-5. Equilibrium Moisture Content of Board 1 at T = 40 °C, RH = 87.9%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.1334	2.7365	14.50
2	3.243	2.8337	14.44
3	3.2582	2.8519	14.25
4	3.1972	2.7952	14.38
5	2.995	2.6259	14.06
6	3.0444	2.6732	13.89
7	3.06	2.6813	14.12
8	3.096	2.7184	13.89
9	3.1859	2.7948	13.99
10	3.1553	2.764	14.15
		Mean	14.17
		Std. Dev.	0.22

Table A-6. Equilibrium Moisture Content of Board 2 at T = 40 °C, RH = 11.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.7702	3.6437	3.47
2	3.8237	3.6925	3.55
3	3.6134	3.4877	3.60
4	3.5471	3.4319	3.36
5	3.58	3.4588	3.50
6	3.7724	3.6446	3.51
7	3.6235	3.4896	3.84
8	3.6902	3.553	3.86
9	3.7289	3.5867	3.96
10	3.731	3.6115	3.31
		Mean	3.60
		Std. Dev.	0.22

Table A-7. Equilibrium Moisture Content of Board 2 at T = 40 °C, RH = 32.1%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.7787	3.5841	5.43
2	3.6875	3.4925	5.58
3	3.6521	3.4583	5.60
4	3.8164	3.614	5.60
5	3.8132	3.6172	5.42
6	3.7952	3.5946	5.58
7	3.7936	3.5927	5.59
8	3.7871	3.5934	5.39
9	3.6795	3.4854	5.57
10	3.7022	3.5115	5.43
		Mean	5.52
		Std. Dev.	0.09

Table A-8. Equilibrium Moisture Content of Board 2 at T = 40 °C, RH = 49.2%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.7465	3.5012	7.01
2	3.8385	3.5855	7.06
3	3.8035	3.552	7.08
4	3.6335	3.4011	6.83
5	3.833	3.5804	7.06
6	3.8793	3.6201	7.16
7	3.8041	3.5478	7.22
8	3.7805	3.5265	7.20
9	3.771	3.5279	6.89
10	3.8163	3.5679	6.96
		Mean	7.05
		Std. Dev.	0.13

Table A-9. Equilibrium Moisture Content of Board 2 at T = 40 °C, RH = 75.4%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.0328	3.6833	9.49
2	3.9631	3.6088	9.82
3	3.8323	3.4929	9.72
4	4.0348	3.6714	9.90
5	3.9169	3.57	9.72
6	3.96	3.6053	9.84
7	3.9183	3.5782	9.50
8	3.8717	3.5213	9.95
9	3.8799	3.5274	9.99
10	3.901	3.5498	9.89
		Mean	9.78
		Std. Dev.	0.17

Table A-10. Equilibrium Moisture Content of Board 2 at T = 40 °C, RH = 87.9%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.0292	3.5567	13.28
2	3.8784	3.4133	13.63
3	4.0594	3.568	13.77
4	4.0939	3.5967	13.82
5	4.0206	3.5303	13.89
6	4.1043	3.6159	13.51
7	4.1736	3.6789	13.45
8	4.0485	3.5617	13.67
9	4.1126	3.6196	13.62
10	4.1522	3.6454	13.90
		Mean	13.65
		Std. Dev.	0.20

Table A-11. Equilibrium Moisture Content of Board 3 at T = 40 °C, RH = 11.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.6857	4.5491	3.00
2	4.6134	4.4824	2.92
3	4.6981	4.5514	3.22
4	4.6024	4.4551	3.31
5	4.6361	4.4872	3.32
6	4.6977	4.5481	2.57
7	4.7173	4.5699	3.23
8	4.7391	4.5837	3.39
9	4.689	4.5343	3.41
10	4.5568	4.4067	3.40
		Mean	3.18
		Std. Dev.	0.27

Table A-12. Equilibrium Moisture Content of Board 3 at T = 40 °C, RH = 32.1%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.705	4.4797	5.03
2	4.686	4.4618	5.02
3	4.6961	4.4659	5.15
4	4.7812	4.5432	5.24
5	4.7116	4.4806	5.16
6	4.8923	4.6532	5.14
7	4.6771	4.4457	5.21
8	4.7172	4.4805	5.28
9	4.776	4.5465	5.05
10	4.7388	4.5068	5.15
		Mean	5.14
		Std. Dev.	0.09

Table A-13. Equilibrium Moisture Content of Board 3 at T = 40 °C, RH = 49.2%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.8697	4.5575	6.85
2	4.8695	4.5559	6.88
3	4.7225	4.4162	6.94
4	4.7735	4.4675	6.85
5	4.7897	4.4888	6.70
6	4.8909	4.5748	6.91
7	4.843	4.5302	6.90
8	4.7431	4.4338	6.98
9	4.7555	4.4503	6.86
10	4.7938	4.4807	6.99
		Mean	6.89
		Std. Dev.	0.08

Table A-14. Equilibrium Moisture Content of Board 3 at T = 40 °C, RH = 75.4%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	5.0249	4.5713	9.92
2	4.9092	4.4654	9.94
3	4.9674	4.5137	10.05
4	4.8743	4.4347	9.91
5	4.878	4.4433	9.78
6	5.0167	4.5643	9.91
7	4.8695	4.4268	10.00
8	5.02	4.5647	9.97
9	5.0324	4.5746	10.01
10	5.0317	4.5718	10.06
		Mean	9.96
		Std. Dev.	0.08

Table A-15. Equilibrium Moisture Content of Board 3 at T = 40 °C, RH = 87.9%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	5.4163	4.745	14.15
2	5.4414	4.767	14.15
3	5.2383	4.5967	13.96
4	5.1225	4.5094	13.60
5	5.0773	4.4748	13.46
6	5.3022	4.6618	13.74
7	5.1704	4.5522	13.58
8	5.0342	4.4391	13.41
9	4.976	4.3815	13.57
10	5.0516	4.4577	13.32
		Mean	13.69
		Std. Dev.	0.30

Table A-16. Equilibrium Moisture Content of Board 1 at T = 20 °C, RH = 12.4%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.5447	2.4366	4.44
2	2.6234	2.5069	4.65
3	2.4761	2.3607	4.89
4	2.6088	2.4917	4.70
5	2.5912	2.4717	4.83
6	2.5907	2.4713	4.83
7	2.6075	2.4912	4.67
8	2.6075	2.4845	4.95
9	2.6164	2.505	4.45
10	2.5929	2.4744	4.79
		Mean	4.72
		Std. Dev.	0.17

Table A-17. Equilibrium Moisture Content of Board 1 at T = 20 °C, RH = 33.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.6274	2.4557	6.99
2	2.6849	2.5114	6.91
3	2.5558	2.3836	7.22
4	2.7079	2.5265	7.18
5	2.7481	2.5667	7.07
6	2.7161	2.5343	7.17
7	2.6321	2.4539	7.26
8	2.6969	2.5155	7.21
9	2.575	2.4024	7.18
10	2.7945	2.6107	7.04
		Mean	7.12
		Std. Dev.	0.12

Table A-18. Equilibrium Moisture Content of Board 1 at T = 20 °C, RH = 54.9%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.9703	2.7513	7.96
2	2.8864	2.6642	8.34
3	2.8661	2.6427	8.45
4	2.7267	2.5071	8.76
5	2.7783	2.5551	8.74
6	2.9028	2.6698	8.73
7	2.9673	2.7275	8.79
8	2.8248	2.5949	8.86
9	2.9562	2.7158	8.85
10	2.7769	2.5479	8.99
		Mean	8.65
		Std. Dev.	0.31

Table A-19. Equilibrium Moisture Content of Board 1 at T = 20 °C, RH = 75.5%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.806	2.5139	11.62
2	2.8576	2.5443	12.31
3	2.9054	2.5933	12.03
4	2.7516	2.4583	11.93
5	2.7856	2.4889	11.92
6	2.755	2.462	11.90
7	2.7692	2.466	12.30
8	2.8484	2.5448	11.93
9	2.7698	2.4744	11.94
10	2.6696	2.3888	11.75
		Mean	11.96
		Std. Dev.	0.21

Table A-20. Equilibrium Moisture Content of Board 1 at T = 20 °C, RH = 93.2%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.9531	2.4732	19.40
2	3.0567	2.5565	19.57
3	3.0433	2.5417	19.73
4	3.0983	2.5947	19.41
5	2.8564	2.3825	19.89
6	2.9601	2.4784	19.44
7	3.0622	2.5559	19.81
8	2.8799	2.4083	19.58
9	3.1355	2.6193	19.71
10	3.1371	2.6181	19.82
		Mean	19.64
		Std. Dev.	0.18

Table A-21. Equilibrium Moisture Content of Board 2 at T = 20 °C, RH = 12.4%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.4784	3.3156	4.91
2	3.4754	3.3121	4.93
3	3.4871	3.3245	4.89
4	3.4647	3.3066	4.78
5	3.4834	3.3167	5.03
6	3.5131	3.3439	5.06
7	3.4731	3.3046	5.10
8	3.4959	3.3256	5.12
9	3.4304	3.2667	5.01
10	3.4763	3.3103	5.01
		Mean	4.98
		Std. Dev.	0.10

Table A-22. Equilibrium Moisture Content of Board 2 at T = 20 °C, RH = 33.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.4945	3.2602	7.19
2	3.5182	3.2805	7.25
3	3.3936	3.161	7.36
4	3.4377	3.2049	7.26
5	3.5046	3.2639	7.37
6	3.4863	3.2508	7.24
7	3.4946	3.2582	7.26
8	3.4131	3.1798	7.34
9	3.4346	3.2011	7.29
10	3.5071	3.2696	7.26
		Mean	7.28
		Std. Dev.	0.06

Table A-23. Equilibrium Moisture Content of Board 2 at T = 20 °C, RH = 54.9%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.6555	3.3554	8.94
2	3.6874	3.3848	8.94
3	3.5515	3.2561	9.07
4	3.5456	3.2522	9.02
5	3.644	3.3484	8.83
6	3.5116	3.2155	9.21
7	3.5137	3.2148	9.30
8	3.6335	3.3224	9.36
9	3.6066	3.2998	9.30
10	3.5903	3.284	9.33
		Mean	9.13
		Std. Dev.	0.19

Table A-24. Equilibrium Moisture Content of Board 2 at T = 20 °C, RH = 75.5%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.7036	3.3255	11.37
2	3.4672	3.1093	11.51
3	3.5865	3.2206	11.36
4	3.5086	3.1531	11.27
5	3.5406	3.1709	11.66
6	3.6366	3.2572	11.65
7	3.5861	3.209	11.75
8	3.5478	3.1754	11.73
9	3.6662	3.2823	11.70
10	3.5614	3.1879	11.72
		Mean	11.57
		Std. Dev.	0.18

Table A-25. Equilibrium Moisture Content of Board 2 at T = 20 °C, RH = 93.2%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.7981	3.1819	19.37
2	4.0878	3.4253	19.34
3	3.8248	3.2049	19.34
4	3.8231	3.2042	19.32
5	3.9297	3.3042	18.93
6	3.9398	3.3114	18.98
7	3.9362	3.3002	19.27
8	3.8622	3.2362	19.34
9	3.9415	3.3027	19.34
10	3.9019	3.2792	18.99
		Mean	19.22
		Std. Dev.	0.18

Table A-26. Equilibrium Moisture Content of Board 3 at T = 20 °C, RH = 12.4%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.4318	4.2394	4.54
2	4.3967	4.1902	4.93
3	4.3978	4.1875	5.02
4	4.2743	4.0732	4.94
5	4.3569	4.1534	4.90
6	4.2829	4.0737	5.14
7	4.2198	4.0204	4.96
8	4.3026	4.1011	4.91
9	4.3202	4.129	4.63
10	4.3456	4.1536	4.62
		Mean	4.86
		Std. Dev.	0.19

Table A-27. Equilibrium Moisture Content of Board 3 at T = 20 °C, RH = 33.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.2129	3.9453	6.78
2	4.4552	4.1721	6.79
3	4.3292	4.0403	7.15
4	4.3557	4.062	7.23
5	4.3231	4.0313	7.24
6	4.4251	4.1272	7.22
7	4.2909	3.9979	7.33
8	4.3431	4.0461	7.34
9	4.2566	3.9664	7.32
10	4.4065	4.1069	7.24
		Mean	7.16
		Std. Dev.	0.21

Table A-28. Equilibrium Moisture Content of Board 3 at T = 20 °C, RH = 54.9%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.5953	4.2089	9.18
2	4.5955	4.2073	9.23
3	4.5249	4.1433	9.21
4	4.4774	4.1009	9.18
5	4.4735	4.0998	9.12
6	4.5061	4.1276	9.17
7	4.6564	4.2657	9.16
8	4.4845	4.1099	9.11
9	4.636	4.2498	9.09
10	4.7821	4.3913	8.90
		Mean	9.13
		Std. Dev.	0.09

Table A-29. Equilibrium Moisture Content of Board 3 at T = 20 °C, RH = 75.5%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.5927	4.1142	11.63
2	4.6795	4.1879	11.74
3	4.5943	4.1112	11.75
4	4.5224	4.0499	11.67
5	4.5185	4.0489	11.60
6	4.6747	4.191	11.54
7	4.5854	4.1079	11.62
8	4.6751	4.1956	11.43
9	4.517	4.0662	11.09
10	4.6675	4.2057	10.98
		Mean	11.50
		Std. Dev.	0.27

Table A-30. Equilibrium Moisture Content of Board 3 at T = 20 °C, RH = 93.2%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	5.0268	4.212	19.34
2	4.9562	4.147	19.51
3	4.9927	4.1818	19.39
4	4.9284	4.135	19.19
5	4.9641	4.1528	19.54
6	4.985	4.1766	19.36
7	4.9342	4.1319	19.42
8	4.9608	4.1515	19.49
9	4.9264	4.1298	19.29
10	5.0189	4.2238	18.82
		Mean	19.34
		Std. Dev.	0.21

Table A-31. Equilibrium Moisture Content of Board 1 at T = 5 °C, RH = 14.0%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.6085	2.4379	7.00
2	2.6361	2.4581	7.24
3	2.6387	2.4654	7.03
4	2.559	2.3957	6.82
5	2.7069	2.5433	6.43
6	2.7196	2.5574	6.34
7	2.7131	2.5508	6.36
8	2.7113	2.5492	6.36
9	2.6778	2.5006	7.09
10	2.7382	2.5714	6.49
		Mean	6.72
		Std. Dev.	0.35

Table A-32. Equilibrium Moisture Content of Board 1 at T = 5 °C, RH = 34.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.7679	2.5544	8.36
2	2.7637	2.5432	8.67
3	2.7476	2.5221	8.94
4	2.8333	2.5983	9.04
5	2.7188	2.4909	9.15
6	2.6202	2.3967	9.33
7	2.6602	2.4331	9.33
8	2.8049	2.5665	9.29
9	2.7923	2.5527	9.39
10	2.7426	2.5029	9.58
		Mean	9.11
		Std. Dev.	0.37

Table A-33. Equilibrium Moisture Content of Board 1 at T = 5 °C, RH = 59.2%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.9398	2.6586	10.58
2	2.8488	2.579	10.46
3	2.8358	2.5669	10.48
4	2.8143	2.5463	10.53
5	2.6349	2.3773	10.84
6	2.8199	2.5497	10.60
7	2.5784	2.3343	10.46
8	2.6344	2.3785	10.76
9	2.6301	2.3775	10.62
10	2.8358	2.5503	11.19
		Mean	10.65
		Std. Dev.	0.23

Table A-34. Equilibrium Moisture Content of Board 1 at T = 5 °C, RH = 75.1%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	2.7299	2.3919	14.13
2	2.7759	2.4199	14.71
3	2.7899	2.4425	14.22
4	2.8309	2.4773	14.27
5	2.7503	2.4122	14.02
6	2.7034	2.3698	14.08
7	2.8079	2.4595	14.17
8	2.7789	2.4325	14.24
9	2.8334	2.4813	14.19
10	2.9234	2.5573	14.32
		Mean	14.23
		Std. Dev.	0.19

Table A-35. Equilibrium Moisture Content of Board 1 at T = 5 °C, RH = 96.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.0196	2.4372	23.90
2	3.1361	2.5434	23.30
3	2.9678	2.4094	24.01
4	3.1432	2.543	23.60
5	3.0244	2.4466	23.62
6	2.9776	2.4022	23.95
7	3.0543	2.4718	23.57
8	3.0198	2.4345	24.04
9	3.1001	2.5016	23.92
10	2.9405	2.372	23.97
		Mean	23.79
		Std. Dev.	0.25

Table A-36. Equilibrium Moisture Content of Board 2 at T = 5 °C, RH = 14.0%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.4686	3.2447	6.90
2	3.4744	3.2415	7.18
3	3.4774	3.2321	7.59
4	3.4492	3.208	7.52
5	3.5045	3.2594	7.52
6	3.4977	3.2503	7.61
7	3.4757	3.2271	7.70
8	3.5271	3.275	7.70
9	3.5391	3.2862	7.70
10	3.4335	3.1819	7.91
		Mean	7.53
		Std. Dev.	0.29

Table A-37. Equilibrium Moisture Content of Board 2 at T = 5 °C, RH = 34.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.5509	3.2496	9.27
2	3.5125	3.2158	9.23
3	3.5706	3.2663	9.32
4	3.589	3.2848	9.26
5	3.5822	3.2777	9.29
6	3.5433	3.243	9.26
7	3.6139	3.3101	9.18
8	3.5037	3.2127	9.06
9	3.5571	3.2654	8.93
10	3.539	3.2559	8.69
		Mean	9.15
		Std. Dev.	0.20

Table A-38. Equilibrium Moisture Content of Board 2 at T = 5 °C, RH = 59.2%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.6009	3.2381	11.20
2	3.7802	3.3947	11.36
3	3.7868	3.41	11.05
4	3.7347	3.3567	11.26
5	3.7801	3.396	11.31
6	3.6058	3.2373	11.38
7	3.6021	3.235	11.35
8	3.6002	3.2394	11.14
9	3.4388	3.0933	11.17
10	3.7201	3.3243	11.91
		Mean	11.31
		Std. Dev.	0.23

Table A-39. Equilibrium Moisture Content of Board 2 at T = 5 °C, RH = 75.1%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	3.6798	3.2082	14.70
2	3.7183	3.2573	14.15
3	3.6988	3.2313	14.47
4	3.7632	3.2987	14.08
5	3.6888	3.2332	14.09
6	3.7899	3.3187	14.20
7	3.6894	3.2194	14.60
8	3.7034	3.2464	14.08
9	3.6323	3.1757	14.38
10	3.6821	3.2206	14.33
		Mean	14.31
		Std. Dev.	0.23

Table A-40. Equilibrium Moisture Content of Board 2 at T = 5 °C, RH = 96.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.0419	3.2654	23.78
2	4.1156	3.3258	23.75
3	4.1088	3.3129	24.02
4	3.8932	3.1463	23.74
5	4.0266	3.2486	23.95
6	4.0207	3.2498	23.72
7	4.1137	3.3257	23.69
8	4.0832	3.2929	24.00
9	4.1123	3.3294	23.51
10	3.9604	3.1885	24.21
		Mean	23.84
		Std. Dev.	0.20

Table A-41. Equilibrium Moisture Content of Board 3 at T = 5 °C, RH = 14.0%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.5813	4.2585	7.58
2	4.5925	4.2759	7.40
3	4.5425	4.2277	7.45
4	4.4728	4.1592	7.54
5	4.4741	4.1599	7.55
6	4.5215	4.1972	7.73
7	4.4236	4.0999	7.90
8	4.5768	4.2531	7.61
9	4.5129	4.1961	7.55
10	4.5012	4.1764	7.78
		Mean	7.61
		Std. Dev.	0.15

Table A-42. Equilibrium Moisture Content of Board 3 at T = 5 °C, RH = 34.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.5318	4.1422	9.41
2	4.5733	4.1904	9.14
3	4.5468	4.1469	9.64
4	4.5628	4.1771	9.23
5	4.5011	4.1189	9.28
6	4.501	4.1192	9.27
7	4.5989	4.2124	9.18
8	4.4179	4.046	9.19
9	4.4774	4.1031	9.12
10	4.6616	4.2706	9.16
		Mean	9.26
		Std. Dev.	0.16

Table A-43. Equilibrium Moisture Content of Board 3 at T = 5 °C, RH = 59.2%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.8718	4.3536	11.90
2	4.7778	4.2937	11.27
3	4.7321	4.2233	12.05
4	4.6678	4.1689	11.97
5	4.4123	3.9408	11.96
6	4.4711	3.9923	11.99
7	4.7501	4.2414	11.99
8	4.6988	4.1965	11.97
9	4.5921	4.1311	11.16
10	4.7698	4.2878	11.24
		Mean	11.75
		Std. Dev.	0.37

Table A-44. Equilibrium Moisture Content of Board 3 at T = 5 °C, RH = 75.1%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	4.7906	4.1872	14.41
2	4.7601	4.1409	14.95
3	4.7321	4.1332	14.49
4	4.7569	4.1392	14.92
5	4.6169	4.0159	14.97
6	4.6611	4.0575	14.88
7	4.7501	4.1451	14.60
8	4.8288	4.2261	14.26
9	4.7121	4.1063	14.75
10	4.6812	4.0781	14.79
		Mean	14.70
		Std. Dev.	0.25

Table A-45. Equilibrium Moisture Content of Board 3 at T = 5 °C, RH = 98.6%.
W1 : equilibrium weight before oven dry
W2 : dry weight
EMC : g water/100 g dry weight

Sample	W1 (g)	W2 (g)	EMC (%)
1	5.1401	4.1472	23.94
2	5.1329	4.1597	23.40
3	5.0903	4.1039	24.04
4	5.0712	4.0951	23.84
5	5.0169	4.0549	23.72
6	5.1749	4.1759	23.92
7	5.1201	4.1395	23.69
8	5.1088	4.1238	23.89
9	5.1221	4.1334	23.92
10	5.0858	4.1031	23.95
		Mean	23.83
		Std. Dev.	0.19

Appendix B : Edge Crush Strength

Table B-1. Edge Crush Strength of Board 1 at T = 5 °C, RH = 14.0%.

Sample	Edge Crush Strength (lbs./in.)
1	23.45
2	30.55
3	24.05
4	25.20
5	26.00
6	23.05
7	27.95
8	30.05
9	22.05
10	24.00
Mean	25.64
Std. Dev.	2.96

Table B-2. Edge Crush Strength of Board 1 at T = 5 °C, RH = 34.6%.

Sample	Edge Crush Strength (lbs./in.)
1	23.95
2	26.95
3	27.35
4	22.95
5	18.50
6	23.55
7	21.05
8	25.05
9	20.05
10	22.95
Mean	23.24
Std. Dev.	2.83

Table B-3. Edge Crush Strength of Board 1 at T = 5 °C, RH = 59.2%.

Sample	Edge Crush Strength (lbs./in.)
1	22.25
2	22.50
3	18.70
4	23.50
5	27.95
6	23.35
7	24.65
8	20.95
9	21.55
10	20.15
Mean	22.56
Std. Dev.	2.57

Table B-4. Edge Crush Strength of Board 1 at T = 5 °C, RH = 75.1%.

Sample	Edge Crush Strength (lbs./in.)
1	19.05
2	18.95
3	21.95
4	18.55
5	20.00
6	17.55
7	18.50
8	21.00
9	18.65
10	19.35
Mean	19.36
Std. Dev.	1.30

Table B-5. Edge Crush Strength of Board 1 at T = 5 °C, RH = 85.0%.

Sample	Edge Crush Strength (lbs./in.)
1	17.20
2	16.05
3	18.75
4	17.85
5	17.05
6	18.00
7	15.75
8	19.05
9	20.95
10	25.65
Mean	18.63
Std. Dev.	2.89

Table B-6. Edge Crush Strength of Board 1 at T = 5 °C, RH = 96.6%.

Sample	Edge Crush Strength (lbs./in.)
1	14.30
2	15.80
3	13.20
4	13.75
5	14.95
6	11.15
7	13.55
8	12.25
9	13.25
10	13.35
Mean	13.56
Std. Dev.	1.31

Table B-7. Edge Crush Strength of Board 2 at T = 5 °C, RH = 14.0%.

Sample	Edge Crush Strength (lbs./in.)
1	30.40
2	26.25
3	33.95
4	25.10
5	31.35
6	32.45
7	30.75
8	34.45
9	29.65
10	31.25
Mean	30.56
Std. Dev.	2.99

Table B-8. Edge Crush Strength of Board 2 at T = 5 °C, RH = 34.6%.

Sample	Edge Crush Strength (lbs./in.)
1	24.20
2	25.95
3	30.35
4	31.55
5	29.00
6	27.75
7	28.90
8	28.85
9	29.65
10	26.35
Mean	28.26
Std. Dev.	2.22

Table B-9. Edge Crush Strength of Board 2 at T = 5 °C, RH = 59.2%.

Sample	Edge Crush Strength (lbs./in.)
1	20.25
2	26.55
3	31.55
4	23.05
5	26.75
6	25.35
7	29.95
8	26.05
9	25.15
10	26.35
Mean	26.10
Std. Dev.	3.17

Table B-10. Edge Crush Strength of Board 2 at T = 5 °C, RH = 75.1%.

Sample	Edge Crush Strength (lbs./in.)
1	22.55
2	27.75
3	20.95
4	21.35
5	23.00
6	22.45
7	23.05
8	22.75
9	23.15
10	23.20
Mean	23.02
Std. Dev.	1.83

Table B-11. Edge Crush Strength of Board 2 at T = 5 °C, RH = 85.0%.

Sample	Edge Crush Strength (lbs./in.)
1	22.35
2	18.35
3	22.30
4	23.55
5	20.05
6	19.95
7	21.75
8	21.55
9	20.05
10	23.30
Mean	21.32
Std. Dev.	1.67

Table B-12. Edge Crush Strength of Board 2 at T = 5 °C, RH = 96.6%.

Sample	Edge Crush Strength (lbs./in.)
1	14.90
2	18.95
3	15.50
4	17.85
5	19.05
6	16.05
7	15.55
8	15.85
9	17.75
10	16.65
Mean	16.81
Std. Dev.	1.49

Table B-13. Edge Crush Strength of Board 3 at T = 5 °C, RH = 14.0%.

Sample	Edge Crush Strength (lbs./in.)
1	32.30
2	30.20
3	31.60
4	33.95
5	30.15
6	32.35
7	34.95
8	31.55
9	30.00
10	31.00
Mean	31.81
Std. Dev.	1.65

Table B-14. Edge Crush Strength of Board 3 at T = 5 °C, RH = 34.6%.

Sample	Edge Crush Strength (lbs./in.)
1	27.45
2	29.50
3	32.05
4	31.50
5	26.75
6	29.95
7	32.05
8	28.15
9	27.00
10	28.50
Mean	29.29
Std. Dev.	2.04

Table B-15. Edge Crush Strength of Board 3 at T = 5 °C, RH = 59.2%.

Sample	Edge Crush Strength (lbs./in.)
1	29.50
2	29.50
3	21.05
4	25.60
5	24.00
6	30.95
7	27.55
8	26.95
9	24.05
10	23.10
Mean	26.23
Std. Dev.	3.21

Table B-16. Edge Crush Strength of Board 3 at T = 5 °C, RH = 75.1%.

Sample	Edge Crush Strength (lbs./in.)
1	31.50
2	28.05
3	22.85
4	19.05
5	21.55
6	20.95
7	21.50
8	21.75
9	20.95
10	23.10
Mean	23.13
Std. Dev.	3.76

Table B-17. Edge Crush Strength of Board 3 at T = 5 °C, RH = 85.0%.

Sample	Edge Crush Strength (lbs./in.)
1	22.50
2	22.85
3	22.55
4	21.95
5	23.05
6	22.95
7	22.00
8	23.15
9	22.05
10	20.00
Mean	22.31
Std. Dev.	0.92

Table B-18. Edge Crush Strength of Board 3 at T = 5 °C, RH = 96.6%.

Sample	Edge Crush Strength (lbs./in.)
1	20.55
2	15.30
3	16.65
4	15.45
5	19.05
6	14.75
7	14.35
8	18.35
9	17.55
10	17.25
Mean	16.93
Std. Dev.	2.01

Table B-19. Edge Crush Strength of Board 1 at T = 20 °C, RH = 12.4%.

Sample	Edge Crush Strength (lbs./in.)
1	29.65
2	32.15
3	35.15
4	29.05
5	27.95
6	30.55
7	29.05
8	30.15
9	33.15
10	30.15
Mean	30.70
Std. Dev.	2.18

Table B-20. Edge Crush Strength of Board 1 at T = 20 °C, RH = 33.6%.

Sample	Edge Crush Strength (lbs./in.)
1	26.70
2	27.25
3	26.10
4	24.80
5	28.15
6	27.45
7	28.10
8	28.00
9	29.60
10	28.00
Mean	27.42
Std. Dev.	1.32

Table B-21. Edge Crush Strength of Board 1 at T = 20 °C, RH = 54.9%.

Sample	Edge Crush Strength (lbs./in.)
1	25.05
2	26.75
3	27.85
4	23.45
5	25.85
6	26.45
7	22.55
8	24.55
9	24.65
10	25.65
Mean	25.28
Std. Dev.	1.58

Table B-22. Edge Crush Strength of Board 1 at T = 20 °C, RH = 75.5%.

Sample	Edge Crush Strength (lbs./in.)
1	24.25
2	23.65
3	20.85
4	24.35
5	23.45
6	21.95
7	21.75
8	20.65
9	22.85
10	23.05
Mean	22.68
Std. Dev.	1.33

Table B-23. Edge Crush Strength of Board 1 at T = 20 °C, RH = 85.0%.

Sample	Edge Crush Strength (lbs./in.)
1	19.95
2	18.85
3	21.15
4	22.55
5	19.95
6	21.30
7	20.05
8	21.00
9	22.00
10	20.55
Mean	20.74
Std. Dev.	1.09

Table B-24. Edge Crush Strength of Board 1 at T = 20 °C, RH = 93.2%.

Sample	Edge Crush Strength (lbs./in.)
1	17.95
2	18.90
3	19.30
4	17.65
5	17.00
6	17.05
7	16.75
8	17.75
9	18.00
10	17.85
Mean	17.82
Std. Dev.	0.81

Table B-25. Edge Crush Strength of Board 2 at T = 20 °C, RH = 12.4%.

Sample	Edge Crush Strength (lbs./in.)
1	39.50
2	36.55
3	34.00
4	35.05
5	38.95
6	35.65
7	34.55
8	40.85
9	33.55
10	38.00
Mean	36.67
Std. Dev.	2.53

Table B-26. Edge Crush Strength of Board 2 at T = 20 °C, RH = 33.6%.

Sample	Edge Crush Strength (lbs./in.)
1	30.95
2	33.55
3	34.00
4	32.05
5	36.95
6	31.85
7	32.25
8	33.45
9	36.50
10	36.00
Mean	33.76
Std. Dev.	2.10

Table B-27. Edge Crush Strength of Board 2 at T = 20 °C, RH = 54.9%.

Sample	Edge Crush Strength (lbs./in.)
1	30.45
2	31.00
3	30.00
4	29.90
5	31.95
6	33.00
7	29.50
8	30.85
9	28.75
10	30.95
Mean	30.64
Std. Dev.	1.22

Table B-28. Edge Crush Strength of Board 2 at T = 20 °C, RH = 75.5%.

Sample	Edge Crush Strength (lbs./in.)
1	29.00
2	26.00
3	27.65
4	27.00
5	28.95
6	27.95
7	26.00
8	29.95
9	28.00
10	28.95
Mean	27.95
Std. Dev.	1.32

Table B-29. Edge Crush Strength of Board 2 at T = 20 °C, RH = 85.0%.

Sample	Edge Crush Strength (lbs./in.)
1	21.35
2	24.55
3	26.95
4	22.05
5	23.45
6	24.65
7	26.95
8	28.00
9	23.00
10	21.95
Mean	24.29
Std. Dev.	2.35

Table B-30. Edge Crush Strength of Board 2 at T = 20 °C, RH = 93.2%.

Sample	Edge Crush Strength (lbs./in.)
1	21.95
2	19.55
3	20.00
4	21.05
5	20.95
6	20.95
7	22.55
8	21.00
9	19.00
10	18.95
Mean	20.60
Std. Dev.	1.20

Table B-31. Edge Crush Strength of Board 3 at T = 20 °C, RH = 12.4%.

Sample	Edge Crush Strength (lbs./in.)
1	43.95
2	40.55
3	39.85
4	35.00
5	34.55
6	36.65
7	34.85
8	36.00
9	39.15
10	39.00
Mean	37.96
Std. Dev.	3.06

Table B-32. Edge Crush Strength of Board 3 at T = 20 °C, RH = 33.6%.

Sample	Edge Crush Strength (lbs./in.)
1	39.00
2	34.65
3	31.00
4	32.00
5	36.75
6	35.05
7	33.00
8	35.05
9	36.95
10	36.00
Mean	34.95
Std. Dev.	2.43

Table B-33. Edge Crush Strength of Board 3 at T = 20 °C, RH = 54.9%.

Sample	Edge Crush Strength (lbs./in.)
1	31.25
2	33.00
3	31.05
4	29.85
5	31.00
6	29.45
7	30.00
8	32.05
9	33.00
10	32.00
Mean	31.27
Std. Dev.	1.26

Table B-34. Edge Crush Strength of Board 3 at T = 20 °C, RH = 75.5%.

Sample	Edge Crush Strength (lbs./in.)
1	29.65
2	28.45
3	24.95
4	25.00
5	26.75
6	25.55
7	25.00
8	26.75
9	26.00
10	30.95
Mean	26.91
Std. Dev.	2.11

Table B-35. Edge Crush Strength of Board 3 at T = 20 °C, RH = 85.0%.

Sample	Edge Crush Strength (lbs./in.)
1	25.15
2	24.65
3	25.95
4	26.00
5	25.00
6	26.10
7	25.95
8	25.45
9	25.15
10	25.00
Mean	25.44
Std. Dev.	0.52

Table B-36. Edge Crush Strength of Board 3 at T = 20 °C, RH = 93.2%.

Sample	Edge Crush Strength (lbs./in.)
1	19.95
2	19.00
3	21.95
4	23.00
5	18.05
6	19.95
7	19.00
8	21.00
9	19.05
10	20.85
Mean	20.18
Std. Dev.	1.52

Table B-37. Edge Crush Strength of Board 1 at T = 40 °C, RH = 11.6%.

Sample	Edge Crush Strength (lbs./in.)
1	33.95
2	34.95
3	35.00
4	35.00
5	34.00
6	33.50
7	33.55
8	32.00
9	33.75
10	33.50
Mean	33.92
Std. Dev.	0.92

Table B-38. Edge Crush Strength of Board 1 at T = 40 °C, RH = 32.1%.

Sample	Edge Crush Strength (lbs./in.)
1	30.95
2	28.55
3	29.45
4	30.75
5	31.00
6	29.05
7	31.00
8	32.00
9	29.85
10	30.95
Mean	30.36
Std. Dev.	1.08

Table B-39. Edge Crush Strength of Board 1 at T = 40 °C, RH = 49.2%.

Sample	Edge Crush Strength (lbs./in.)
1	31.00
2	30.00
3	29.00
4	28.95
5	26.75
6	27.55
7	28.05
8	26.75
9	28.00
10	27.95
Mean	28.40
Std. Dev.	1.36

Table B-40. Edge Crush Strength of Board 1 at T = 40 °C, RH = 75.4%.

Sample	Edge Crush Strength (lbs./in.)
1	25.05
2	24.45
3	26.00
4	26.15
5	24.75
6	25.05
7	26.45
8	24.95
9	25.00
10	23.00
Mean	25.09
Std. Dev.	0.98

Table B-41. Edge Crush Strength of Board 1 at T = 40 °C, RH = 85.0%.

Sample	Edge Crush Strength (lbs./in.)
1	22.25
2	21.10
3	22.30
4	23.30
5	21.30
6	24.60
7	22.60
8	21.35
9	20.30
10	22.35
Mean	22.15
Std. Dev.	1.22

Table B-42. Edge Crush Strength of Board 1 at T = 40 °C, RH = 87.9%.

Sample	Edge Crush Strength (lbs./in.)
1	21.95
2	23.45
3	22.95
4	21.60
5	20.75
6	23.85
7	19.00
8	24.00
9	21.95
10	23.00
Mean	22.25
Std. Dev.	1.55

Table B-43. Edge Crush Strength of Board 2 at T = 40 °C, RH = 11.6%.

Sample	Edge Crush Strength (lbs./in.)
1	39.95
2	38.75
3	38.00
4	38.95
5	40.00
6	39.05
7	40.45
8	39.05
9	38.75
10	39.00
Mean	39.20
Std. Dev.	0.73

Table B-44. Edge Crush Strength of Board 2 at T = 40 °C, RH = 32.1%.

Sample	Edge Crush Strength (lbs./in.)
1	36.55
2	37.65
3	35.75
4	37.00
5	38.00
6	35.65
7	36.00
8	36.05
9	36.75
10	35.05
Mean	36.45
Std. Dev.	0.92

Table B-45. Edge Crush Strength of Board 2 at T = 40 °C, RH = 49.2%.

Sample	Edge Crush Strength (lbs./in.)
1	34.50
2	36.75
3	38.00
4	37.80
5	34.00
6	33.05
7	32.05
8	33.00
9	31.55
10	33.00
Mean	34.37
Std. Dev.	2.35

Table B-46. Edge Crush Strength of Board 2 at T = 40 °C, RH = 75.4%.

Sample	Edge Crush Strength (lbs./in.)
1	29.15
2	33.05
3	30.95
4	31.00
5	29.95
6	28.00
7	29.05
8	30.00
9	31.25
10	30.25
Mean	30.27
Std. Dev.	1.40

Table B-47. Edge Crush Strength of Board 2 at T = 40 °C, RH = 85.0%.

Sample	Edge Crush Strength (lbs./in.)
1	25.15
2	24.50
3	23.00
4	22.00
5	28.00
6	26.75
7	27.95
8	25.55
9	24.85
10	27.15
Mean	25.49
Std. Dev.	2.02

Table B-48. Edge Crush Strength of Board 2 at T = 40 °C, RH = 87.9%.

Sample	Edge Crush Strength (lbs./in.)
1	23.15
2	26.75
3	24.95
4	27.05
5	23.55
6	27.85
7	26.00
8	24.00
9	25.50
10	24.55
Mean	25.34
Std. Dev.	1.57

Table B-49. Edge Crush Strength of Board 3 at T = 40 °C, RH = 11.6%.

Sample	Edge Crush Strength (lbs./in.)
1	40.00
2	40.15
3	38.95
4	39.15
5	41.00
6	39.00
7	41.05
8	40.95
9	41.00
10	40.95
Mean	40.22
Std. Dev.	0.90

Table B-50. Edge Crush Strength of Board 3 at T = 40 °C, RH = 32.1%.

Sample	Edge Crush Strength (lbs./in.)
1	38.55
2	39.00
3	38.00
4	39.95
5	37.95
6	38.15
7	38.95
8	39,05
9	38.00
10	39.00
Mean	38.62
Std. Dev.	0.67

Table B-51. Edge Crush Strength of Board 3 at T = 40 °C, RH = 49.2%.

Sample	Edge Crush Strength (lbs./in.)
1	35.95
2	36.50
3	35.00
4	36.00
5	36.50
6	37.05
7	36.55
8	38.05
9	35.45
10	34.95
Mean	36.20
Std. Dev.	0.95

Table B-52. Edge Crush Strength of Board 3 at T = 40 °C, RH = 75.4%.

Sample	Edge Crush Strength (lbs./in.)
1	29.95
2	34.05
3	31.00
4	32.15
5	33.00
6	30.45
7	35.00
8	31.75
9	29.00
10	28.00
Mean	31.44
Std. Dev.	2.20

Table B-53. Edge Crush Strength of Board 3 at T = 40 °C, RH = 85.0%.

Sample	Edge Crush Strength (lbs./in.)
1	30.20
2	23.00
3	22.45
4	31.70
5	24.60
6	26.30
7	20.35
8	31.25
9	32.60
10	20.10
Mean	26.26
Std. Dev.	4.84

Table B-54. Edge Crush Strength of Board 3 at T = 40 °C, RH = 87.9%.

Sample	Edge Crush Strength (lbs./in.)
1	31.15
2	21.45
3	24.45
4	29.15
5	23.95
6	26.05
7	21.00
8	28.00
9	23.00
10	27.00
Mean	25.52
Std. Dev.	3.34

Appendix C : Flat Crush Resistance

Table C-1. Flat Crush Resistance of Board 1 at T = 5 °C, RH = 14.0%.

Sample	Flat Crush Resistance (lbs./square in.)
1	28.40
2	29.00
3	27.50
4	26.00
5	27.10
6	28.00
7	27.10
8	27.50
9	27.10
10	26.00
Mean	27.37
Std. Dev.	0.95

Table C-2. Flat Crush Resistance of Board 1 at T = 5 °C, RH = 34.6%.

Sample	Flat Crush Resistance (lbs./square in.)
1	20.00
2	18.15
3	21.10
4	19.20
5	22.30
6	17.40
7	19.50
8	22.00
9	23.10
10	21.00
Mean	20.38
Std. Dev.	1.85

Table C-3. Flat Crush Resistance of Board 1 at T = 5 °C, RH = 59.2%.

Sample	Flat Crush Resistance (lbs./square in.)
1	16.70
2	18.60
3	17.90
4	15.60
5	19.00
6	18.50
7	17.70
8	20.00
9	16.90
10	17.20
Mean	17.81
Std. Dev.	1.28

Table C-4. Flat Crush Resistance of Board 1 at T = 5 °C, RH = 75.1%.

Sample	Flat Crush Resistance (lbs./square in.)
1	14.80
2	15.10
3	17.90
4	15.00
5	20.10
6	16.70
7	15.90
8	16.00
9	15.40
10	16.80
Mean	16.37
Std. Dev.	1.63

Table C-5. Flat Crush Resistance of Board 1 at T = 5 °C, RH = 85.0%.

Sample	Flat Crush Resistance (lbs./square in.)
1	13.40
2	10.00
3	12.60
4	14.00
5	13.50
6	13.70
7	14.80
8	11.90
9	10.50
10	12.00
Mean	12.64
Std. Dev.	1.54

Table C-6. Flat Crush Resistance of Board 1 at T = 5 °C, RH = 96.6%.

Sample	Flat Crush Resistance (lbs./square in.)
1	8.40
2	8.60
3	8.70
4	8.70
5	8.60
6	8.50
7	8.80
8	8.70
9	8.90
10	9.00
Mean	8.69
Std. Dev.	0.18

Table C-7. Flat Crush Resistance of Board 2 at T = 5 °C, RH = 14.0%.

Sample	Flat Crush Resistance (lbs./square in.)
1	26.30
2	27.60
3	25.90
4	26.10
5	24.55
6	26.00
7	27.90
8	27.40
9	27.90
10	29.05
Mean	26.87
Std. Dev.	1.32

Table C-8. Flat Crush Resistance of Board 2 at T = 5 °C, RH = 34.6%.

Sample	Flat Crush Resistance (lbs./square in.)
1	23.10
2	22.50
3	26.90
4	21.70
5	23.80
6	21.20
7	20.30
8	22.60
9	21.00
10	22.00
Mean	22.51
Std. Dev.	1.86

Table C-9. Flat Crush Resistance of Board 2 at T = 5 °C, RH = 59.2%.

Sample	Flat Crush Resistance (lbs./square in.)
1	19.90
2	17.40
3	19.90
4	18.70
5	21.20
6	19.90
7	18.00
8	17.00
9	17.50
10	18.00
Mean	18.75
Std. Dev.	1.40

Table C-10. Flat Crush Resistance of Board 2 at T = 5 °C, RH = 75.1%

Sample	Flat Crush Resistance (lbs./square in.)
1	15.60
2	15.90
3	14.70
4	15.90
5	16.50
6	15.00
7	15.90
8	15.00
9	16.75
10	17.80
Mean	15.91
Std. Dev.	0.93

Table C-11. Flat Crush Resistance of Board 2 at T = 5 °C, RH = 85.0%

Sample	Flat Crush Resistance (lbs./square in.)
1	11.50
2	12.00
3	11.80
4	10.60
5	12.00
6	11.40
7	10.80
8	11.00
9	10.35
10	12.70
Mean	11.42
Std. Dev.	0.73

Table C-12. Flat Crush Resistance of Board 2 at T = 5 °C, RH = 96.6%

Sample	Flat Crush Resistance (lbs./square in.)
1	7.70
2	8.00
3	7.60
4	7.40
5	7.30
6	7.70
7	7.40
8	6.50
9	7.80
10	8.50
Mean	7.59
Std. Dev.	0.52

Table C-13. Flat Crush Resistance of Board 3 at T = 5 °C, RH = 14.0%

Sample	Flat Crush Resistance (lbs./square in.)
1	25.90
2	26.90
3	24.50
4	24.70
5	25.70
6	24.00
7	25.60
8	26.30
9	25.00
10	24.90
Mean	25.35
Std. Dev.	0.89

Table C-14. Flat Crush Resistance of Board 3 at T = 5 °C, RH = 34.6%

Sample	Flat Crush Resistance (lbs./square in.)
1	20.80
2	20.80
3	19.90
4	19.40
5	21.90
6	21.40
7	20.80
8	21.80
9	18.85
10	19.95
Mean	20.56
Std. Dev.	1.02

Table C-15. Flat Crush Resistance of Board 3 at T = 5 °C, RH = 59.2%

Sample	Flat Crush Resistance (lbs./square in.)
1	16.80
2	17.00
3	15.90
4	17.00
5	16.30
6	16.70
7	15.90
8	15.40
9	16.40
10	16.50
Mean	16.39
Std. Dev.	0.53

Table C-16. Flat Crush Resistance of Board 3 at T = 5 °C, RH = 75.1%

Sample	Flat Crush Resistance (lbs./square in.)
1	15.80
2	16.90
3	14.00
4	16.20
5	15.90
6	15.10
7	15.80
8	14.90
9	15.80
10	15.00
Mean	15.54
Std. Dev.	0.81

Table C-17. Flat Crush Resistance of Board 3 at T = 5 °C, RH = 85.0%

Sample	Flat Crush Resistance (lbs./square in.)
1	10.10
2	10.70
3	10.90
4	11.90
5	12.00
6	11.50
7	10.90
8	10.20
9	11.00
10	10.50
Mean	10.97
Std. Dev.	0.65

Table C-18. Flat Crush Resistance of Board 3 at T = 5 °C, RH = 96.6%

Sample	Flat Crush Resistance (lbs./square in.)
1	6.80
2	7.40
3	7.30
4	7.80
5	7.10
6	7.00
7	6.90
8	7.20
9	7.10
10	7.10
Mean	7.17
Std. Dev.	0.28

Table C-19. Flat Crush Resistance of Board 1 at T = 20 °C, RH = 12.4%.

Sample	Flat Crush Resistance (lbs./square in.)
1	34.60
2	33.70
3	35.90
4	36.70
5	35.10
6	36.70
7	33.50
8	34.00
9	36.00
10	35.90
Mean	35.21
Std. Dev.	1.21

Table C-20. Flat Crush Resistance of Board 1 at T = 20 °C, RH = 33.6%.

Sample	Flat Crush Resistance (lbs./square in.)
1	28.90
2	27.80
3	29.05
4	28.20
5	28.30
6	27.00
7	26.90
8	28.00
9	29.10
10	30.00
Mean	28.33
Std. Dev.	0.97

Table C-21. Flat Crush Resistance of Board 1 at T = 20 °C, RH = 54.9%.

Sample	Flat Crush Resistance (lbs./square in.)
1	23.80
2	24.50
3	22.10
4	23.20
5	24.10
6	22.45
7	23.50
8	23.35
9	23.10
10	23.00
Mean	23.31
Std. Dev.	0.72

Table C-22. Flat Crush Resistance of Board 1 at T = 20 °C, RH = 75.5%.

Sample	Flat Crush Resistance (lbs./square in.)
1	19.60
2	20.10
3	21.50
4	23.10
5	22.50
6	20.40
7	21.00
8	19.60
9	20.40
10	19.50
Mean	20.77
Std. Dev.	1.25

Table C-23. Flat Crush Resistance of Board 1 at T = 20 °C, RH = 85.0%.

Sample	Flat Crush Resistance (lbs./square in.)
1	17.50
2	17.40
3	16.30
4	15.30
5	17.00
6	18.05
7	17.50
8	18.00
9	17.40
10	17.70
Mean	17.22
Std. Dev.	0.84

Table C-24. Flat Crush Resistance of Board 1 at T = 20 °C, RH = 93.2%.

Sample	Flat Crush Resistance (lbs./square in.)
1	13.90
2	13.30
3	12.00
4	14.05
5	13.50
6	14.00
7	13.30
8	13.05
9	13.45
10	12.95
Mean	13.35
Std. Dev.	0.61

Table C-25. Flat Crush Resistance of Board 2 at T = 20 °C, RH = 12.4%.

Sample	Flat Crush Resistance (lbs./square in.)
1	33.40
2	33.90
3	34.10
4	32.50
5	33.10
6	34.60
7	31.80
8	35.40
9	33.10
10	35.00
Mean	33.69
Std. Dev.	1.13

Table C-26. Flat Crush Resistance of Board 2 at T = 20 °C, RH = 33.6%.

Sample	Flat Crush Resistance (lbs./square in.)
1	28.70
2	27.90
3	26.80
4	29.50
5	25.90
6	28.90
7	27.90
8	29.05
9	27.10
10	26.90
Mean	27.87
Std. Dev.	1.17

Table C-27. Flat Crush Resistance of Board 2 at T = 20 °C, RH = 54.9%.

Sample	Flat Crush Resistance (lbs./square in.)
1	23.50
2	34.90
3	26.10
4	23.60
5	22.00
6	25.00
7	24.90
8	23.10
9	23.70
10	23.00
Mean	24.98
Std. Dev.	3.68

Table C-28. Flat Crush Resistance of Board 2 at T = 20 °C, RH = 75.5%.

Sample	Flat Crush Resistance (lbs./square in.)
1	19.85
2	18.60
3	23.20
4	18.10
5	21.30
6	22.30
7	21.00
8	22.50
9	18.80
10	22.15
Mean	20.78
Std. Dev.	1.83

Table C-29. Flat Crush Resistance of Board 2 at T = 20 °C, RH = 85.0%.

Sample	Flat Crush Resistance (lbs./square in.)
1	16.60
2	16.20
3	16.00
4	16.90
5	16.40
6	15.90
7	15.50
8	16.80
9	17.50
10	16.90
Mean	16.47
Std. Dev.	0.59

Table C-30. Flat Crush Resistance of Board 2 at T = 20 °C, RH = 93.2%.

Sample	Flat Crush Resistance (lbs./square in.)
1	10.90
2	11.90
3	11.50
4	11.00
5	10.30
6	10.20
7	11.80
8	12.00
9	10.30
10	11.10
Mean	11.10
Std. Dev.	0.69

Table C-31. Flat Crush Resistance of Board 3 at T = 20 °C, RH = 12.4%.

Sample	Flat Crush Resistance (lbs./square in.)
1	32.60
2	33.40
3	34.90
4	31.60
5	34.20
6	33.90
7	34.10
8	32.90
9	33.00
10	32.60
Mean	33.32
Std. Dev.	0.97

Table C-32. Flat Crush Resistance of Board 3 at T = 20 °C, RH = 33.6%.

Sample	Flat Crush Resistance (lbs./square in.)
1	28.90
2	27.10
3	26.90
4	27.60
5	29.00
6	29.10
7	26.30
8	25.10
9	27.20
10	27.10
Mean	27.43
Std. Dev.	1.28

Table C-33. Flat Crush Resistance of Board 3 at T = 20 °C, RH = 54.9%.

Sample	Flat Crush Resistance (lbs./square in.)
1	22.30
2	23.10
3	22.80
4	21.05
5	23.00
6	25.00
7	21.05
8	20.00
9	23.00
10	22.00
Mean	22.33
Std. Dev.	1.40

Table C-34. Flat Crush Resistance of Board 3 at T = 20 °C, RH = 75.5%.

Sample	Flat Crush Resistance (lbs./square in.)
1	22.25
2	19.70
3	21.60
4	20.80
5	20.85
6	19.55
7	22.65
8	21.60
9	20.20
10	19.00
Mean	20.82
Std. Dev.	1.21

Table C-35. Flat Crush Resistance of Board 3 at T = 20 °C, RH = 85.0%.

Sample	Flat Crush Resistance (lbs./square in.)
1	15.30
2	15.90
3	16.00
4	16.30
5	15.20
6	14.90
7	15.00
8	14.00
9	15.30
10	15.40
Mean	15.33
Std. Dev.	0.65

Table C-36. Flat Crush Resistance of Board 3 at T = 20 °C, RH = 93.2%.

Sample	Flat Crush Resistance (lbs./square in.)
1	10.80
2	10.60
3	10.10
4	9.90
5	11.30
6	11.00
7	9.95
8	9.00
9	10.90
10	9.90
Mean	10.35
Std. Dev.	0.69

Table C-37. Flat Crush Resistance of Board 1 at T = 40 °C, RH = 11.6%.

Sample	Flat Crush Resistance (lbs./square in.)
1	37.90
2	38.20
3	39.20
4	36.10
5	38.05
6	36.40
7	37.50
8	37.50
9	36.20
10	36.10
Mean	37.32
Std. Dev.	1.07

Table C-38. Flat Crush Resistance of Board 1 at T = 40 °C, RH = 32.1%.

Sample	Flat Crush Resistance (lbs./square in.)
1	33.90
2	34.80
3	33.60
4	34.95
5	32.50
6	34.00
7	35.00
8	32.90
9	34.95
10	34.65
Mean	34.13
Std. Dev.	0.90

Table C-39. Flat Crush Resistance of Board 1 at T = 40 °C, RH = 49.2%.

Sample	Flat Crush Resistance (lbs./square in.)
1	30.60
2	32.80
3	33.70
4	31.00
5	33.90
6	34.20
7	27.90
8	28.00
9	29.20
10	28.40
Mean	30.97
Std. Dev.	2.54

Table C-40. Flat Crush Resistance of Board 1 at T = 40 °C, RH = 75.4%.

Sample	Flat Crush Resistance (lbs./square in.)
1	25.60
2	23.10
3	22.90
4	26.70
5	21.90
6	23.00
7	21.00
8	23.10
9	22.90
10	24.30
Mean	23.45
Std. Dev.	1.68

Table C-41. Flat Crush Resistance of Board 1 at T = 40 °C, RH = 85.0%.

Sample	Flat Crush Resistance (lbs./square in.)
1	19.90
2	18.80
3	17.90
4	18.10
5	19.90
6	17.90
7	20.00
8	17.50
9	18.50
10	18.00
Mean	18.65
Std. Dev.	0.95

Table C-42. Flat Crush Resistance of Board 1 at T = 40 °C, RH = 87.9%.

Sample	Flat Crush Resistance (lbs./square in.)
1	18.05
2	18.60
3	20.00
4	19.95
5	18.10
6	18.30
7	18.30
8	17.90
9	19.00
10	19.85
Mean	18.81
Std. Dev.	0.84

Table C-43. Flat Crush Resistance of Board 2 at T = 40 °C, RH = 11.6%.

Sample	Flat Crush Resistance (lbs./square in.)
1	38.90
2	38.20
3	37.10
4	38.80
5	37.40
6	37.40
7	38.10
8	37.20
9	38.30
10	37.00
Mean	37.84
Std. Dev.	0.71

Table C-44. Flat Crush Resistance of Board 2 at T = 40 °C, RH = 32.1%.

Sample	Flat Crush Resistance (lbs./square in.)
1	32.40
2	33.90
3	34.70
4	32.50
5	33.10
6	32.90
7	33.00
8	32.70
9	33.60
10	34.00
Mean	33.28
Std. Dev.	0.75

Table C-45. Flat Crush Resistance of Board 2 at T = 40 °C, RH = 49.2%.

Sample	Flat Crush Resistance (lbs./square in.)
1	29.50
2	28.90
3	27.70
4	28.80
5	30.80
6	29.40
7	28.90
8	29.10
9	28.60
10	29.00
Mean	29.07
Std. Dev.	0.78

Table C-46. Flat Crush Resistance of Board 2 at T = 40 °C, RH = 75.4%.

Sample	Flat Crush Resistance (lbs./square in.)
1	25.90
2	26.00
3	25.00
4	24.60
5	25.00
6	26.50
7	24.95
8	25.00
9	24.80
10	25.20
Mean	25.30
Std. Dev.	0.62

Table C-47. Flat Crush Resistance of Board 2 at T = 40 °C, RH = 85.0%.

Sample	Flat Crush Resistance (lbs./square in.)
1	17.50
2	16.90
3	17.80
4	16.40
5	17.90
6	17.00
7	16.70
8	17.80
9	17.00
10	16.50
Mean	17.15
Std. Dev.	0.56

Table C-48. Flat Crush Resistance of Board 2 at T = 40 °C, RH = 87.9%.

Sample	Flat Crush Resistance (lbs./square in.)
1	18.00
2	17.10
3	18.20
4	17.90
5	16.50
6	18.75
7	17.00
8	16.95
9	17.20
10	17.30
Mean	17.49
Std. Dev.	0.69

Table C-49. Flat Crush Resistance of Board 3 at T = 40 °C, RH = 11.6%.

Sample	Flat Crush Resistance (lbs./square in.)
1	36.80
2	36.00
3	34.50
4	36.90
5	37.70
6	35.95
7	37.50
8	36.50
9	36.80
10	36.90
Mean	36.56
Std. Dev.	0.91

Table C-50. Flat Crush Resistance of Board 3 at T = 40 °C, RH = 32.1%.

Sample	Flat Crush Resistance (lbs./square in.)
1	31.80
2	31.10
3	30.90
4	32.60
5	30.50
6	32.00
7	30.45
8	30.80
9	30.60
10	32.15
Mean	31.29
Std. Dev.	0.78

Table C-51. Flat Crush Resistance of Board 3 at T = 40 °C, RH = 49.2%.

Sample	Flat Crush Resistance (lbs./square in.)
1	27.90
2	27.80
3	29.00
4	26.90
5	27.20
6	27.80
7	27.60
8	27.90
9	27.70
10	27.60
Mean	27.74
Std. Dev.	0.55

Table C-52. Flat Crush Resistance of Board 3 at T = 40 °C, RH = 75.4%.

Sample	Flat Crush Resistance (lbs./square in.)
1	23.90
2	22.10
3	23.90
4	23.80
5	23.90
6	22.90
7	23.00
8	22.70
9	23.80
10	22.50
Mean	23.25
Std. Dev.	0.69

Table C-53. Flat Crush Resistance of Board 3 at T = 40 °C, RH = 85.0%.

Sample	Flat Crush Resistance (lbs./square in.)
1	15.90
2	16.90
3	15.00
4	16.70
5	15.95
6	16.10
7	16.00
8	16.90
9	17.00
10	16.50
Mean	16.30
Std. Dev.	0.62

Table C-54. Flat Crush Resistance of Board 3 at T = 40 °C, RH = 87.9%.

Sample	Flat Crush Resistance (lbs./square in.)
1	17.30
2	16.70
3	16.40
4	17.40
5	16.50
6	17.00
7	16.80
8	16.50
9	17.00
10	18.00
Mean	16.96
Std. Dev.	0.50

Appendix D : Bursting Strength

Table D-1. Bursting Strength of Board 1 at T = 5 °C, RH = 85%.

Sample	Bursting Strength (lbs./square in.) 1	2	3	4	Average
1	91	100	100	91	96
2	87	80	125	105	99
3	75	90	115	115	99
4	85	102	86	100	93
5	90	96	82	70	85
				Mean	94
				Std. Dev.	6

Table D-2. Bursting Strength of Board 1 at T = 20 °C, RH = 85%.

Sample	Bursting Strength (lbs./square in.) 1	2	3	4	Average
1	165	125	115	180	146
2	85	115	100	110	103
3	105	110	125	90	108
4	130	133	96	125	121
5	96	85	101	124	102
				Mean	116
				Std. Dev.	19

Table D-3. Bursting Strength of Board 1 at T = 40 °C, RH = 85%.

Sample	Bursting Strength (lbs./square in.) 1	2	3	4	Average
1	121	120	100	120	115
2	102	146	115	90	113
3	95	150	112	98	114
4	145	114	100	141	125
5	120	122	112	156	128
				Mean	119
				Std. Dev.	7

Table D-4. Bursting Strength of Board 2 at T = 5 °C, RH = 85%.

Sample	Bursting Strength (lbs./square in.) 1	2	3	4	Average
1	157	185	155	150	162
2	200	175	165	160	175
3	195	160	175	225	189
4	225	187	170	180	191
5	167	180	180	165	173
				Mean	178
				Std. Dev.	12

Table D-5. Bursting Strength of Board 2 at T = 20 °C, RH = 85%.

Sample	Bursting Strength (lbs./square in.) 1	2	3	4	Average
1	185	211	210	206	203
2	267	211	260	245	246
3	220	250	255	314	260
4	285	285	315	245	283
5	186	215	229	223	213
				Mean	241
				Std. Dev.	33

Table D-6. Bursting Strength of Board 2 at T = 40 °C, RH = 85%.

Sample	Bursting Strength (lbs./square in.) 1	2	3	4	Average
1	254	230	265	286	259
2	264	243	236	206	237
3	242	290	260	235	257
4	222	240	298	224	246
5	266	236	240	261	251
				Mean	250
				Std. Dev.	9

Table D-7. Bursting Strength of Board 3 at T = 5 °C, RH = 85%.

	Bursting Strength (lbs./square in.)				
Sample	1	2	3	4	Average
1	165	195	212	205	194
2	215	200	213	196	206
3	207	215	214	224	215
4	220	222	243	240	231
5	260	226	230	220	234
				Mean	216
				Std. Dev.	17

Table D-8. Bursting Strength of Board 3 at T = 20 °C, RH = 85%.

	Bursting Strength (lbs./square in.)				
Sample	1	2	3	4	Average
1	269	270	265	250	264
2	243	255	226	230	239
3	264	258	244	285	263
4	265	258	260	255	260
5	276	253	260	241	258
				Mean	256
				Std. Dev.	10

Table D-9. Bursting Strength of Board 3 at T = 40 °C, RH = 85%.

	Bursting Strength (lbs./square in.)				
Sample	1	2	3	4	Average
1	250	240	254	266	253
2	231	256	272	280	260
3	245	232	235	236	237
4	255	245	260	246	252
5	280	305	305	282	293
				Mean	259
				Std. Dev.	21

Appendix E: Linear Regression Model for Re-building Data

Table E-1. Linear Regression Model for Claculating the ECT and FCR of Board 1 at 40 °C.

RH	Aw	EMC	ECT	FCR
10	0.1	3.23	32.94	37.33
20	0.2	4.27	31.84	35.45
30	0.3	5.15	30.91	33.88
40	0.4	5.99	30.01	32.35
50	0.5	6.90	29.06	30.73
60	0.6	7.93	27.96	28.86
70	0.7	9.24	26.58	26.50
80	0.8	11.14	24.58	23.10
90	0.9	14.74	20.77	16.61

Table E-2. Linear Regression Model for Claculating the ECT and FCR of Board 1 at 20 °C.

RH	Aw	EMC	ECT	FCR
10	0.1	4.34	29.81	32.38
20	0.2	5.57	28.79	30.72
30	0.3	6.58	27.96	29.36
40	0.4	7.54	27.16	28.06
50	0.5	8.55	26.33	26.71
60	0.6	9.69	25.38	25.17
70	0.7	11.11	24.21	23.27
80	0.8	13.12	22.55	20.56
90	0.9	16.86	19.46	15.54

Table E-3. Linear Regression Model for Claculating the ECT and FCR of Board 1 at 5 °C.

RH	Aw	EMC	ECT	FCR
10	0.1	6.07	25.62	24.65
20	0.2	7.41	24.69	23.37
30	0.3	8.46	23.96	22.36
40	0.4	9.43	23.28	21.44
50	0.5	10.42	22.60	20.49
60	0.6	11.51	21.84	19.45
70	0.7	12.84	20.92	18.19
80	0.8	14.65	19.65	16.45
90	0.9	17.88	17.40	13.36

Table E-4. Linear Regression Model for Claculating the ECT and FCR of Board 2 at 40 °C.

RH	Aw	EMC	ECT	FCR
10	0.1	3.42	39.37	37.48
20	0.2	4.46	37.93	35.43
30	0.3	5.32	36.74	33.73
40	0.4	6.14	35.59	32.10
50	0.5	7.01	34.39	30.38
60	0.6	8.01	33.01	28.42
70	0.7	9.25	31.29	25.97
80	0.8	11.03	28.82	22.45
90	0.9	14.38	24.18	15.84

Table E-5. Linear Regression Model for Claculating the ECT and FCR of Board 2 at 20 °C.

RH	Aw	EMC	ECT	FCR
10	0.1	4.46	36.60	32.82
20	0.2	5.76	35.15	30.84
30	0.3	6.82	33.96	29.21
40	0.4	7.84	32.82	27.65
50	0.5	8.91	31.63	26.02
60	0.6	10.12	30.27	24.16
70	0.7	11.63	28.58	21.85
80	0.8	13.78	26.18	18.56
90	0.9	17.79	21.70	12.43

Table E-6. Linear Regression Model for Claculating the ECT and FCR of Board 2 at 5 °C.

RH	Aw	EMC	ECT	FCR
10	0.1	6.61	30.36	25.61
20	0.2	7.95	29.26	24.13
30	0.3	8.99	28.41	22.99
40	0.4	9.95	27.63	21.94
50	0.5	10.91	26.84	20.88
60	0.6	11.97	25.97	19.71
70	0.7	13.24	24.94	18.32
80	0.8	14.98	23.52	16.41
90	0.9	18.02	21.03	13.06

Table E-7. Linear Regression Model for Claculating the ECT and FCR of Board 3 at 40 °C.

RH	Aw	EMC	ECT	FCR
10	0.1	3.04	41.19	35.68
20	0.2	4.08	39.70	33.81
30	0.3	4.96	38.44	32.23
40	0.4	5.81	37.21	30.68
50	0.5	6.73	35.89	29.03
60	0.6	7.80	34.36	27.12
70	0.7	9.15	32.42	24.68
80	0.8	11.12	29.60	21.14
90	0.9	14.91	24.16	14.32

Table E-8. Linear Regression Model for Claculating the ECT and FCR of Board 3 at 20 °C.

RH	Aw	EMC	ECT	FCR
10	0.1	4.50	37.54	31.71
20	0.2	5.72	36.03	29.87
30	0.3	6.72	34.80	28.38
40	0.4	7.66	33.64	26.97
50	0.5	8.64	32.43	25.50
60	0.6	9.74	31.07	23.84
70	0.7	11.11	29.38	21.79
80	0.8	13.03	27.01	18.89
90	0.9	16.58	22.63	13.56

Table E-9. Linear Regression Model for Claculating the ECT and FCR of Board 3 at 5 °C.

RH	Aw	EMC	ECT	FCR
10	0.1	6.75	31.43	23.79
20	0.2	8.11	30.22	22.41
30	0.3	9.17	29.28	21.33
40	0.4	10.14	28.42	20.35
50	0.5	11.11	27.55	19.36
60	0.6	12.18	26.59	18.27
70	0.7	13.47	25.45	16.97
80	0.8	15.22	23.89	15.19
90	0.9	18.29	21.15	12.07

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