Effect of Thickness on Stiffness of Board - A Case Study

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INTRODUCTION

Data is presented here from plant scale routine production run which happened to be unusually at constant conditions. The data would be useful to those who are working in this field. This may be used as supporting data for widening the application field from lab. scale upto actual plant scale. The idea of publishing this report is to give data which are difficult to get unless good efforts are made to collect such data in the mill, in a really comparative state.

The importance of this data is that there was unique opportunity when all the parameters were unusually constant except deliberate changes which were made in substance and thereby corresponding change in the thickness. Therefore, changes in values of various properties were purely because of changes in substance or thickness.

The studies which have been done and the formulae developed are mostly based on such papers and boards which have been made from few plies of uniform furnish having good quality fibres such as solid bleached boards and folding box board. For example, for Solid Bleached Boards and Folding Box Boards, the power (index) to the thickness (T) is, in fact, slightly lower than 3, at about 2.5 to 2.6. If the thickness of a given grade of paper board is doubled the stiffness increases by about 5.5 times. Our sample consisted of several layers, of widely different furnish, hence, this work can serve the purpose of deriving suitable relationship for such materials.

An Attempt has been made here to see different relations and presented in graphical forms.

For ready reference some description and some formulae have been appended at the end.

One day, on the board machine when board was being made in different substances, it so happened, fortunately, that parameters like furnish, processing parameters and machine conditions were surprisingly just same (reasonably constant) for the entire run of more than 24 hrs. The substances were changed after very short runs of few hours for completing small tonnage orders. It was a unique happening. It was assumed that different thicknesses were caused by changes in substance only. The dead weights at some stages eg. calender stack might have effected the bulk to some extent. The changes in substance were done in running machine, hence the operational conditions were unaltered. Thus, any change in properties were due to changes in substance. This encouraged us to take up the stiffness study. With this intention, next day, samples were collected from the out-turn sample-sheets and conditioned for next 36 hours at 25±2^0, 65±3% RH.

The studies on which conventional formulae have been developed are mostly based on such papers and boards which have been made from few plies, and uniform furnish, having good quality fibre, such as pulpboard, duplexboard, solid bleached boards and folding box board. The formation and consolidation of multi layer board, that too with different furnish in the layers made on K-Formers, with or without coating may not follow the following conventional formula.

Stiffness[1], S = Constant, (K) (E) (T^3)

Where K is a constant, E is modulus of elasticity and T is thickness.

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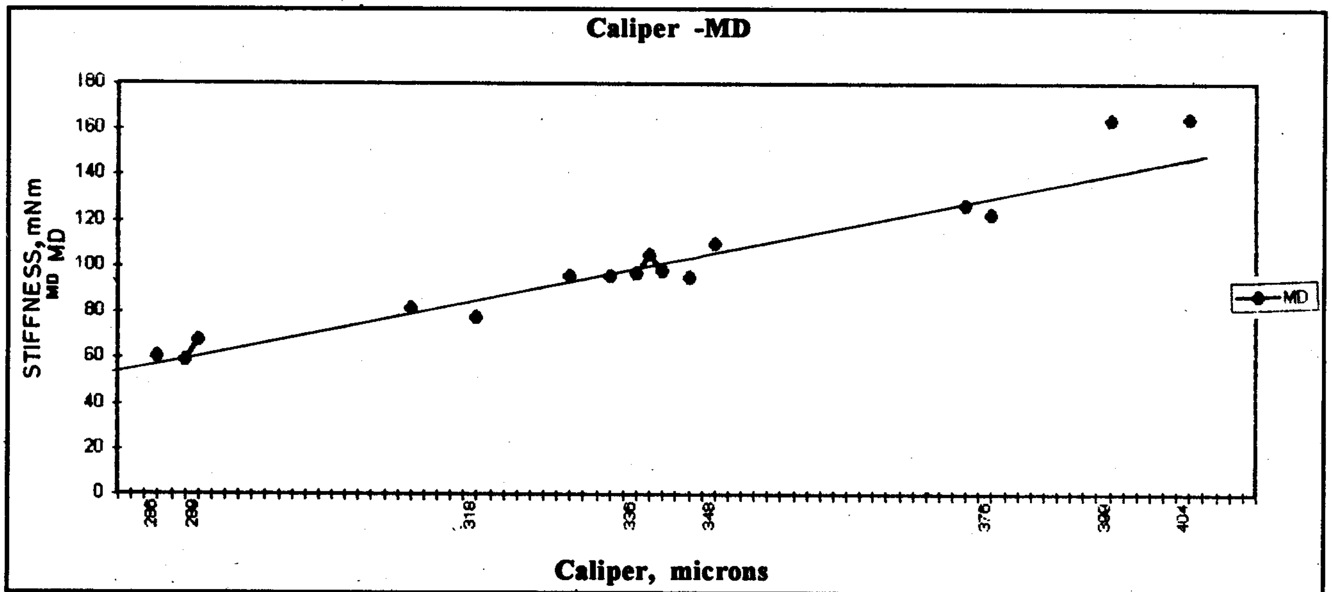
Caliper -MD
STIFFNESS, mNm
MD MD
0
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376
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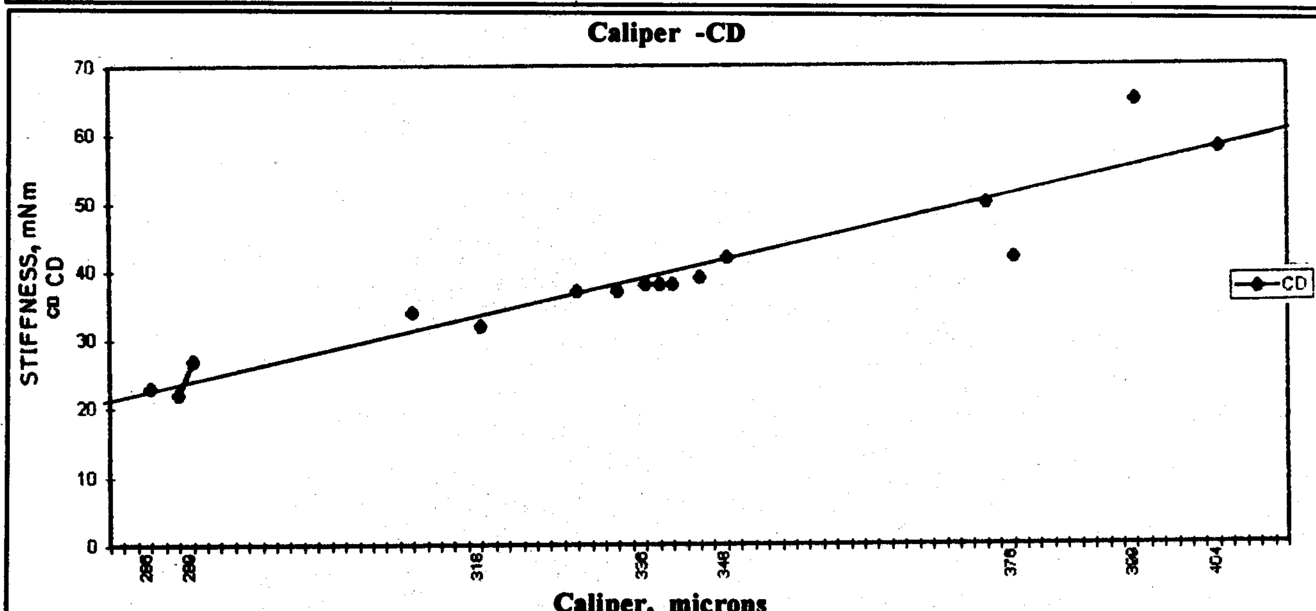
MD
Caliper, microns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STIFFNESS, mNm
CD CD
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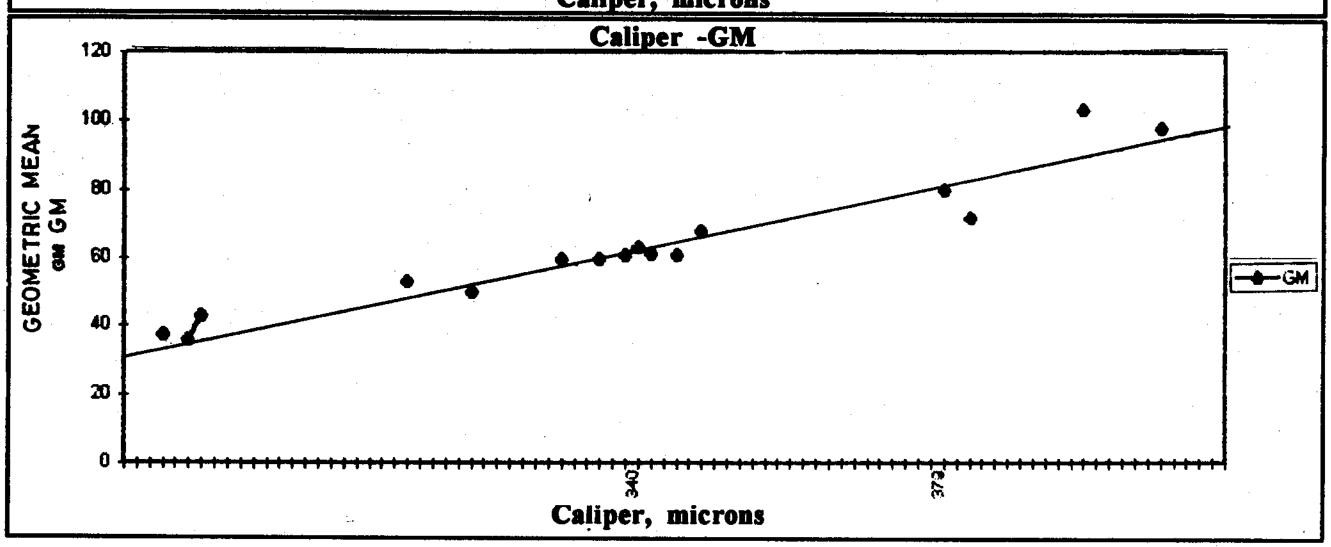
CD
Caliper, microns


Caliper -GM
GEOMETRIC MEAN
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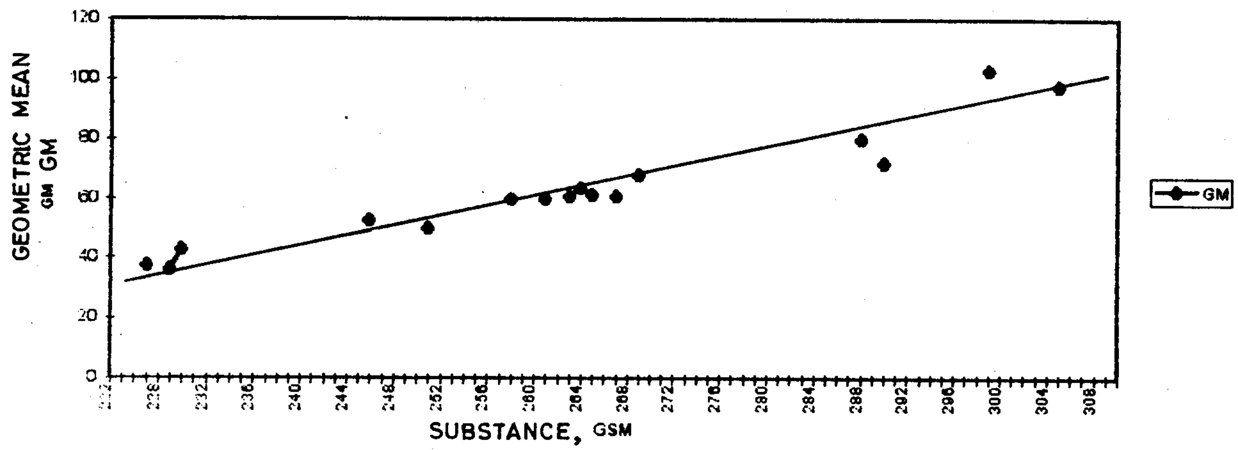
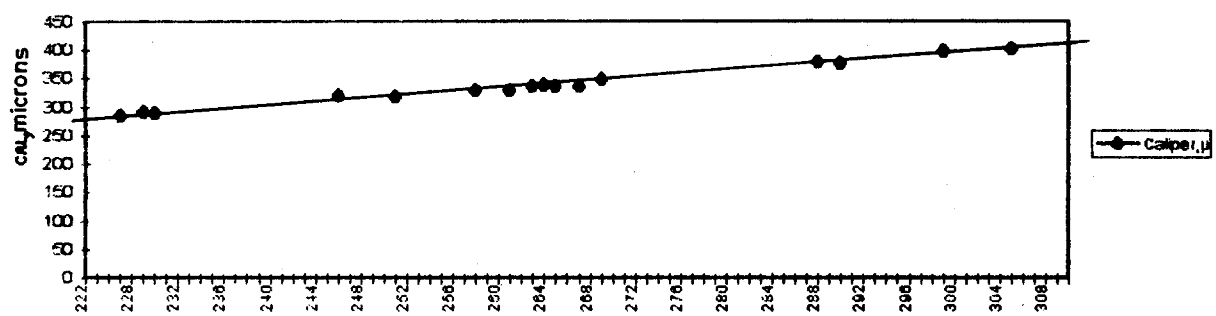
Caliper, microns

GSM -GMgsm



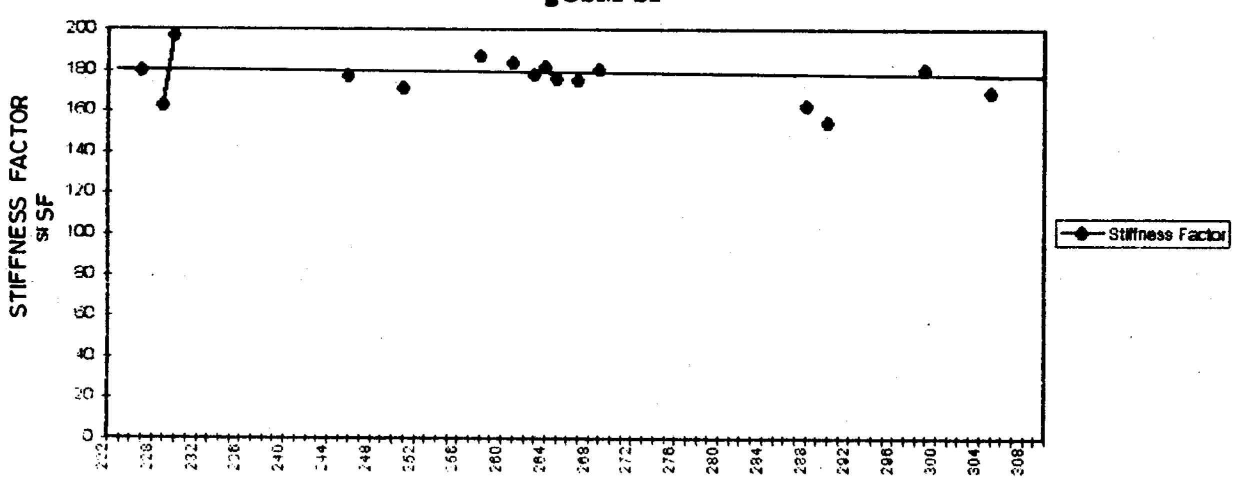
Substance, GSM

GSM-Cal



Substance, GSM

gGSM-SF



Substance, GSM

The above cubic relationship is valid for homogeneous materials provided the elastic limit is not exceeded. For Solid Bleached Boards and Folding Box Boards the power (index) to the thickness (t) is, in fact, slightly lower than 3, at about 2.5 to 2.6. For example, if the thickness of a given grade of paper board is doubled the stiffness increases by about 5.5 times.

Folding Box Board comprises outer layers of good quality pulp where a high modulus of elasticity is particularly important. The inner layer of FBB comprise of mechanical pulp which makes it possible to achieve higher thickness, and hence, higher stiffness at relatively lower grammage compared to other types of board.

The stiffness was determined using Bending Resistance Tester, L & W make, in "mNm" units, at 15^0 angle. The results are presented in different stiffness units in Table No. 1 for arriving at relations between different characteristics. The purpose of calculating stiffness in different forms and units was to see which expression is most informative for describing this property and relationships, especially for comparison purposes.

All the testing was done at one time in a constant temperature and humidity. The thickness and substance were measured first, and then stiffness was determined on the same piece, for better accuracy.

Values have been plotted between different characteristics for relationship between them.

The results confirm the existing views about the dependence of stiffness on the thickness.

1. There is a very good direct relation between different characteristics as may be seen in the figures. The straight line has been drawn passing through most points. This indicates that the relationship is almost directly proportional and is very very close to straight line.

2. It may be seen that there seems to be no correlation between Stiffness ratio, stiffness factor and bending stiffness index with other characters. This may be due to the fact that stiffness ratio, stiffness factor, and stiffness index are the calculated mathematical values which are dependent on basic values eg. gsm, thickness and stiffness (force) have been eliminated.

3. There is a good straight line between gsm and caliper. This shows that the run was very well controlled and external disturbences were almost nil.

4. The exact index to the thickness, T can be found out. This has been left for the dedicated investigators of this field.

APPENDIX

Stiffness enables the paper board to be used for a wide range of packaging and graphical applications. Without stiffness paper board would not be able to perform its prime function of providing the packaged contents with physical protection. Bending Stiffness is often decisive factor when selecting board dimensions for all types of continers especially those for liquid Packaging machines require stiff and dimensionally stable board. News paper is relatively stiffer despite its low substance.

A. Since paper board is anisotropic material, the stiffness ratio, MD/CD, gives an assessment of paper board anisotropy.[1]

Stiffness Ratio : Stiffness in MD / Stiffness in CD

B. An established way of averaging the differences in the various directions is to calculate the Geometric Mean Value (S_{GM}). This facilitates comparison of the levels of different materials regardless of the MD/CD ratio.

Geometric Mean Value(1) of stiffness (S_{GM}) :

$= \sqrt{S_{MD} X S_{CD}}$, (in mN)

C. Stiffness Factor = $\frac{(MD + CD) / 2}{(10)\ (T^3)}$ Where : T is thickness in mm.

D. A number of methods of measuring stiffness are as below : [1]

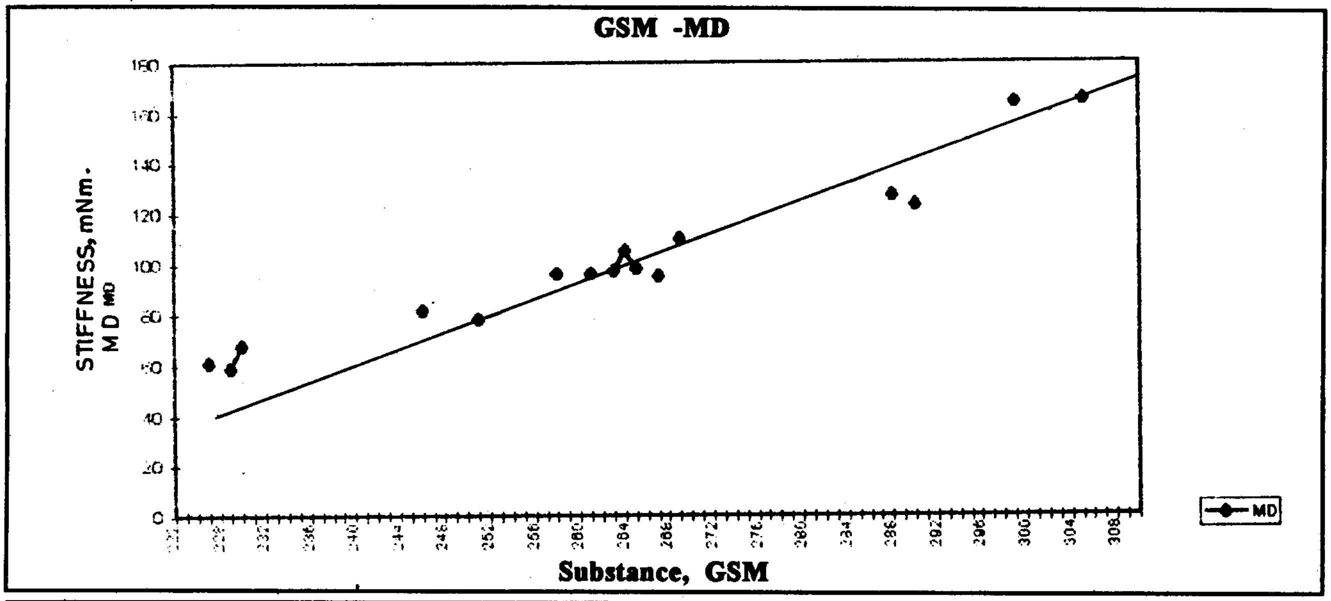
a. Bending Stiffness (L & W, 5^0), mNm, ISO 5628, DIN 53121

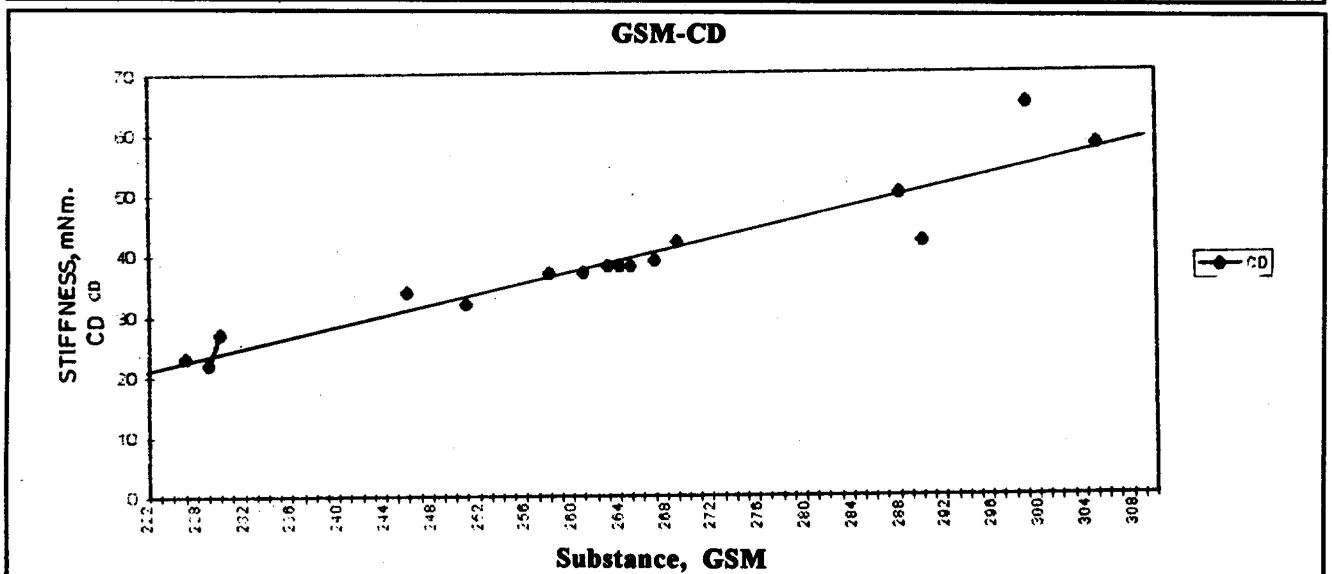
b. Bending Resistance (L & W, 15^0), mN ISO 2493

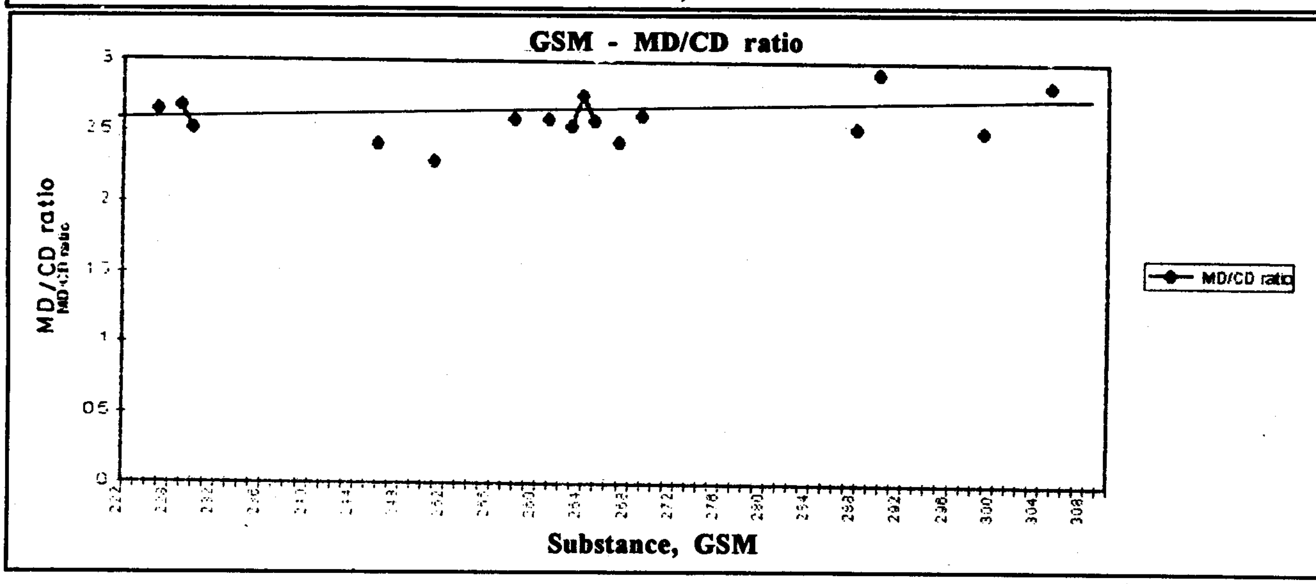
c. Bending Moment (Taber, 15^0), mNm ISO 2493.

Bending Resistance [1] is the force required to bend a rectangular paper board sample through an angle of 15^0. Bending Stiffness is calculated from the force registered at an angular deflection of 5^0. For the majority of boards a bending angle of 15^0 greatly exceeds the elastic limit, an angle of 5^0, however usually remains within the elastic.

Limit, and is accepted as a standard value.


GSM -MD
STIFFNESS, mNm. MD
Substance, GSM
MD


GSM-CD
STIFFNESS, mNm. CD
Substance, GSM
CD


GSM - MD/CD ratio
MD/CD ratio
Substance, GSM
MD/CD ratio

Bending Resistance is closely related to bending stiffness.

Bending resistance = (Bending moment) (20.70).

(L & W, 15° mN) (Taber 15°), mNm

Bending Moment = (Bending Resistance) (0.0483).

(Taber 15°, mNm) (L & W, 15° mN)

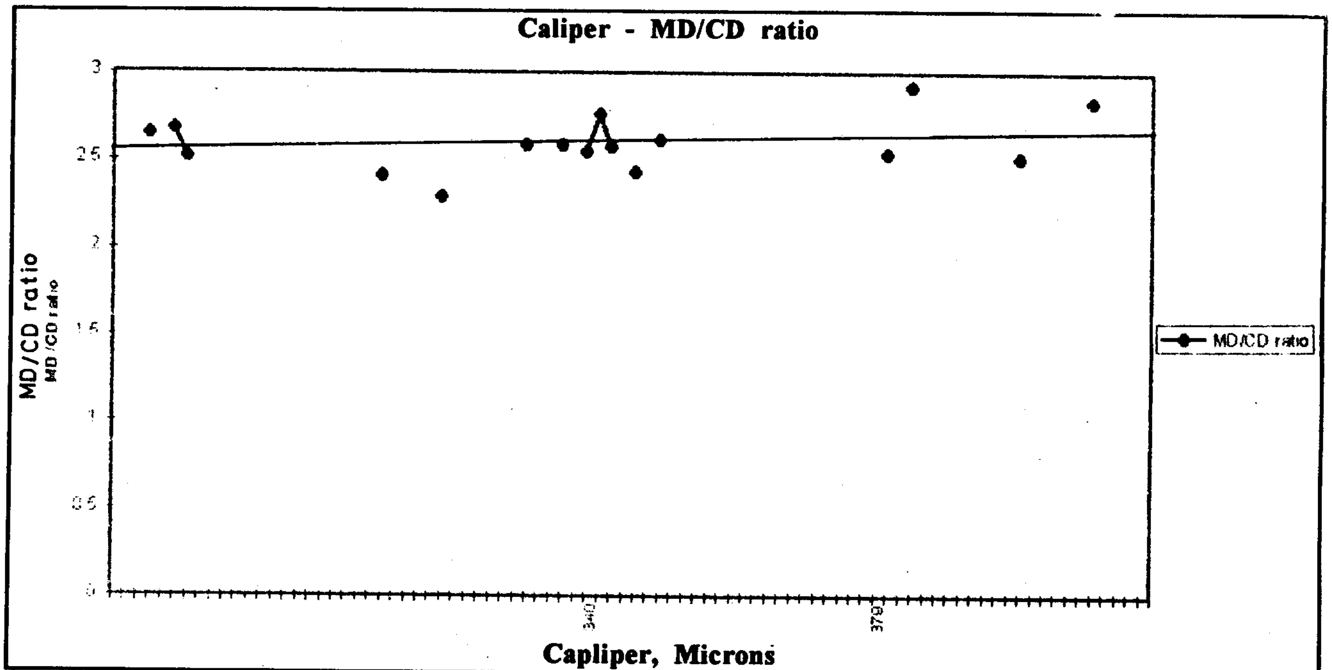
Bending moment is the product of bending resistance and the sample length to which a force has been applied to bend the sample through an angle of 15°.

Measurement of bonding moment may be made using a Teledyne Taber Stiffness Tester. In this test A 38 mm wide strip is clamped at one end and a force applied to the other to induce a 15° bend. The bending moment is read directly from the scale and corrected for the range weight used. The mean value of readings taken in opposing direction is recorded and expressed in mNm.

If Taber is expressed in gram. cm, then:

Taber in mNm = Taber in g.cm X 0.0981

Bending Stiffness is defined [4] as the relationship between the applied bending moment and the deflection within the plastic region.



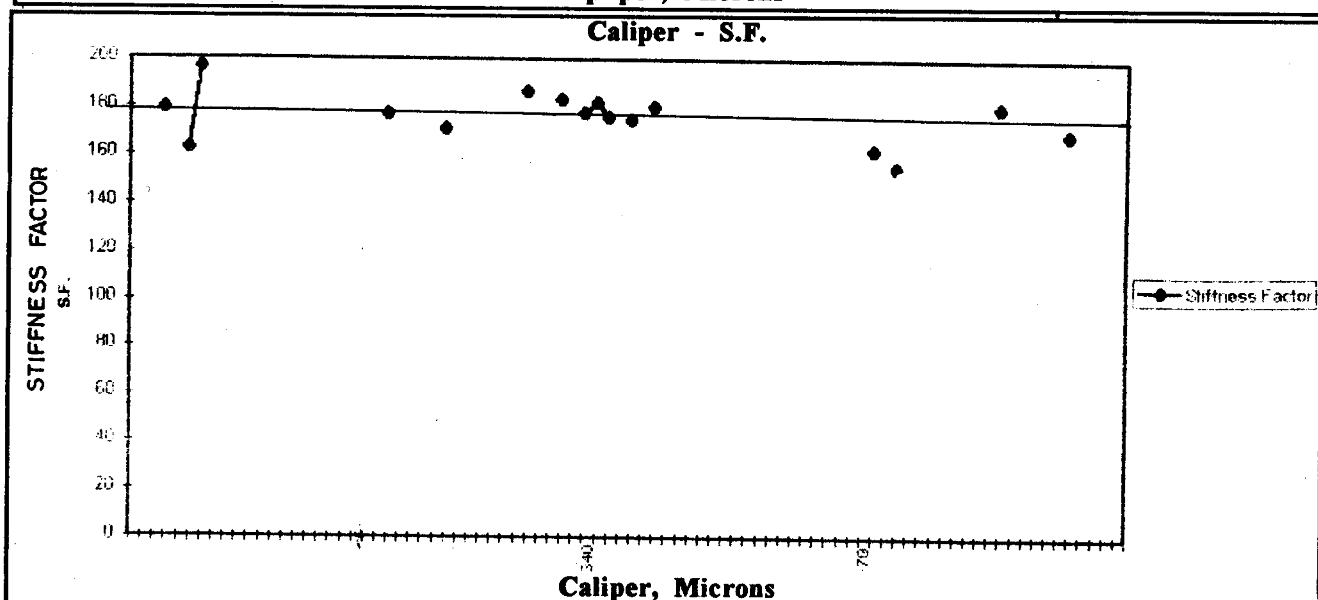


TABLE -B

Substance	Stiffness mNm		Geometric MEAN mNm			
GSM	MD	CD	GM	MD/CD ratio	Caliper, µ Micron	Stiffness factor
227	61	23	37.46	2.65	286	180
229	59	22	36.03	2.68	292	163
230	68	27	42.85	2.52	289	197
246	82	34	52.8	2.41	320	177
251	78	32	49.96	2.29	318	171
258	96	37	59.6	2.59	329	187
261	96	37	59.6	2.59	331	183
263	97	38	60.71	2.55	336	178
264	105	38	63.17	2.76	340	182
265	98	38	61.02	2.58	338	176
267	95	39	60.87	2.43	337	175
269	110	42	67.97	2.62	348	30
288	127	50	79.69	2.54	379	163
290	123	42	71.87	2.92	376	155
299	164	65	103.25	2.52	399	180
305	165	58	97.83	2.84	404	169

E. Bending stiffness is commonly measured using a L & W Stiffness tester. A 38 mm wide strip is clamped in the instrument and bend through an angle of 5°. The free end of the paper board makes contact with the load cell and the force registered is proportional to the paper board - stiffness. The clamp is then turned through a further 10° and then, force at 15° is registered as the bending resistance 15°, in mN.

$$\text{Bending Stiffness (L \& W } 5^0\text{) in mNm} = \frac{(60)\,(l^2)\,(\text{Bending force, } 5^0)}{(\pi)\,(\text{deg})\,(b)}$$

Where: l = sample length, m, = 0.050 π = 3.14 deg =bending angle (^{0}) = 5 b = sample width, (m), = 0.038

There are, Bending Stiffness = (0.2514) (Bending force, 5°) (L & W, 5°).

Note that is not possible to convert from bending stiffness to bending moment or bending resistance with any degree of accuracy.

Bending Stiffness is often decisive factor when selecting board dimensions for all types of continers especially those for liquid. Packaging machines require stiff and dimensionally stable board. News paper is relatively stiffer despite its low substance.

Not all boards of the same grammage or thickness have the same stiffness.[1] Solid Bleached Board (SBB) offer excellent stiffness and strength characteristics per unit grammage of material. Folding Box Board (FBB) products on the other hand, because of their high bulk characteristics offer high level of stiffness in relation to grammage. Because board is porous and compressible, it is preferable to express the stiffness in terms of different material properties like bulk and substance.

The following equation[2] describes the bending stiffness in terms of mass (W) and bulk (1/p). The bending stiffness depends on the grammage to the third power. The concept of Bending Stiffness Index S^*_b is therefore:

$$S^*_b = S_b / W^3$$

Where : S^*_b = Bending Stiffness Index (Nm^7/Kg^3)

Sb = Bending Stiffness (Nm)

W = Grammage (Kg/m^2)

The Bending Stiffness Index for paper is of the order of 0.5 to 2 Nm^7/Kg^3

REFERENCES:

1. "Paper Boards Reference Manual", Iggesund Paperboard AB, 1993. Printed at Halls Office AB. Vaxjo. Pages 102 to 115.

2. "The Elastic Properties of paper", by Hakan Markstrom, published by L & W, Stockholm, 1991.

3. Hand Book of Paper Testing & Process Optimisation Catalog of L & W 1995.

4. "Testing Methods & Instruments for Corrugated Boards" By Hakan Markstrom, Published by L & W, Stockholm, 1988, Page 26.