

A novel test method for predicting crushing elasticity in medium fluting with higher relevance than for instance currently used methods like CMT

ABSTRACT

During the corrugated board making process the board is passing several rollers and belts, which compress the material more or less. This also happens later in the process when corrugated board sheets are printed, scored and die-cut.

As a damage trouble shooting tool, thickness measurements are not sensitive enough to estimate the amount of crushing in these processes. The loss in thickness will be recovered after the crush and not measurable. The board might lose some of its functionality as packaging protecting its content when it is crushed. Of course a converter doesn't want that.

Adjustment in the converting process might work for minimize permanent damage of the corrugated board. But it is also important to have strong medium with high resistance to crushing.

Testing of crush resistance of medium called CMT is very time consuming. It involves hot corrugating a small test strip of paper in a laboratory fluter, fixing it without delay on a self-adhering pressure sensitive tape and testing it immediately in a laboratory crush tester. Such test yields a final strength of the flute at the moment of total collapse, which is not a relevant value because when the board reaches this point it is already damaged. The more relevant point is when the board starts to lose its elasticity and begins to fail.

Manual testing CMT is a very unpopular test and a difficult one to automate. A new test with the working name S-test can accurately predict the elasticity break point also called CMT plateau.

INTRODUCTION

Product quality is important for all paper producers. Process data from sensors in QCS scanners and other inputs can be used to help run the paper machine in an optimum and stable way but in the end it is the results from standardized tests done in a conditioned laboratory according to ISO, TAPPI and other test methods which decide if the product fulfills the specification or not. Quick feedback of the laboratory tests are decisive then. So can the laboratory tests be done faster?

The project described in this paper concentrates on finding a test method which can be automated and used close to the production. Many paper mills today have automated their laboratory paper testing. That encompasses simply cutting a cross profile strip from the jumbo reel and feeding it into the automated test machine such as L&W Autoline. The testing is fully automated and no manpower is required after the test has started. An important advantage of such tests is a quick feedback which can be used in controlling and/or improving the production.

This project focused also partially on the question of the relevancy of the modern tests – are the results really important to the end user (so to the corrugated board user)? The third challenge is to get the different industry parties agree that the automated test method measured property is relevant? Can it be standardized? Etc.

CORRUGATING MEDIUM TEST (CMT) PREPARATION AND PERFORMING THE TEST

The most important compression strength test for medium fluting producers is Corrugating Medium Test (CMT). The guaranteed levels for this property are listed in the specifications. Other equally important strength measurements are Short Span Compression (SCT) and Fluted Edge crush (CCT) or (CFC).

A CMT is performed in the following way: 10 pieces of paper with the dimensions of 12.7 mm×150 mm ($\frac{1}{2} \times 6$ inches) are cut in the MD direction from a given sample of paper. Those pieces are then fluted in the laboratory fluter set to 177°C ($\pm 8^\circ\text{C}$). The corrugated piece is then placed on the corrugated rack, covered with the comb which ensures the right geometry of the flutes and manually fixated to a piece of self-adhering pressure sensitive tape. After the careful removal to the comb from inside of the flutes the specimen is ready to be either crushed in a crush tester immediately (for the CMT₀ value) or crushed after 30 minutes conditioning in 23°C and 50% RH (for the CMT₃₀ value).

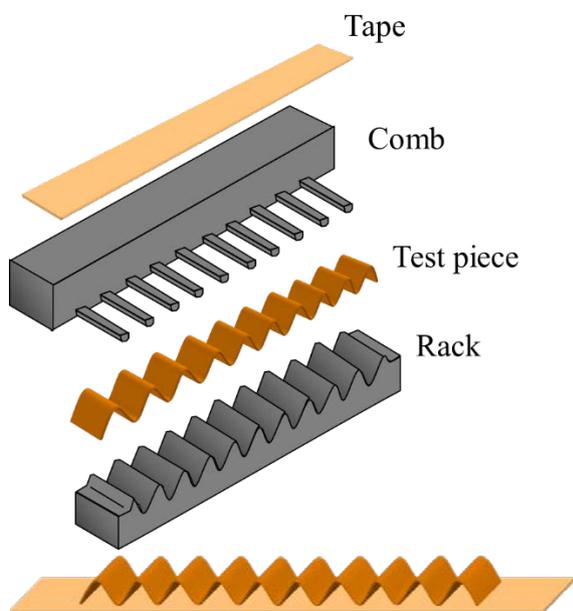


Fig 1. CMT sample preparation

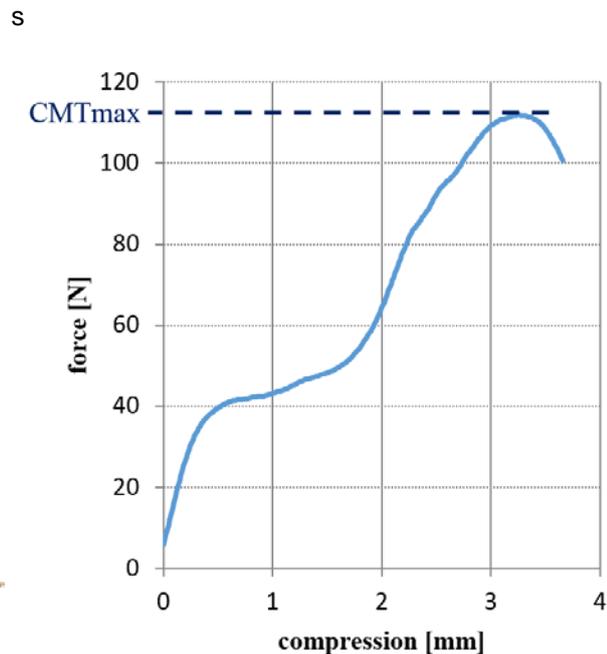


Fig 2. CMT measuring graph

During the compression the test piece will go through different stages of buckling and crushing. The maximum force before total collapse is the CMT value (designed as CMT_{max}).

As mentioned in the method description, the industry uses two versions of CMT test: CMT₀ and CMT₃₀. The choice of the method used depends on the availability of conditioning chamber and time. The main difference between those two versions lies in the moisture content in the samples, for this reason the CMT₀ is higher than the CMT₃₀.

WHAT ARE THE DIFFICULTIES IN PERFORMING CMT MEASUREMENTS?

The main problem with CMT measurements is that it is very time consuming compared to tests like SCT. In case CMT₃₀ is used the time required is even longer. The test is also operator dependent. As well, the type of the tape used has an influence on the end value. Moreover, the condition of the laboratory fluter can affect the test, both when considering the temperature settings and its technical state. A consequence of poor sample preparation could also be "leaning flutes" which will result in under estimation of the paper strength or no reading at all. This is also seen at high basis weights and

high performance papers, due to high (bending) stiffness. The flute are not compressed but “pressed away. Besides technical factors, delamination of paper makes this measurement difficult to interpret.



Fig 3. Leaning flutes

CRUSHED CORRUGATED BOARD DOESN'T MAKE GOOD BOXES

Corrugated board boxes are made to protect its content during storing and transportation. It is then important that it is produced and converted without damaging its structure before it started to fulfill its purpose. A typical damage could be for example introduction of cracks in the structure during slitting, scoring and cutting operation. During the same operation the load could be too high and the flutes would be crushed. Crushing of the flutes can also happen during the printing operation.

The tests used for checking the corrugated board load carrying capacity is its thickness. Another test in the Flat Crush Test, which is not done very often.

In Flat Crush Test a circular test piece is cut out of the corrugated board sheet. The size depends on the crush tester capacity as the force needed to crush the corrugated board could be very high. The test piece is inserted in the gap between the platens in a crush tester. The test is started and the test piece is slowly crushed. During the crushing the force is recorded. The force against compressive strain curve is used to evaluate the result of the test.

The force at stage 6 in the figure 4 is the Flat Crush Test result. In this paper we call this FCT_{peak} or FCT_{max} . This is the highest force just before total collapse. The FCT_{max} value is divided by the surface size of the test piece to make it “independent” of the size of it. The result unit then will be kPa or psi.

The FCT_{max} value is maybe not that relevant as a measurement of the strength of the board because it is recorded when the material has already lost its rigidity and has very little support possibilities.

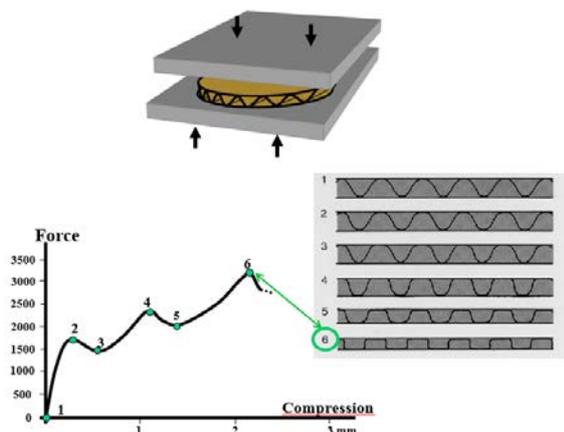
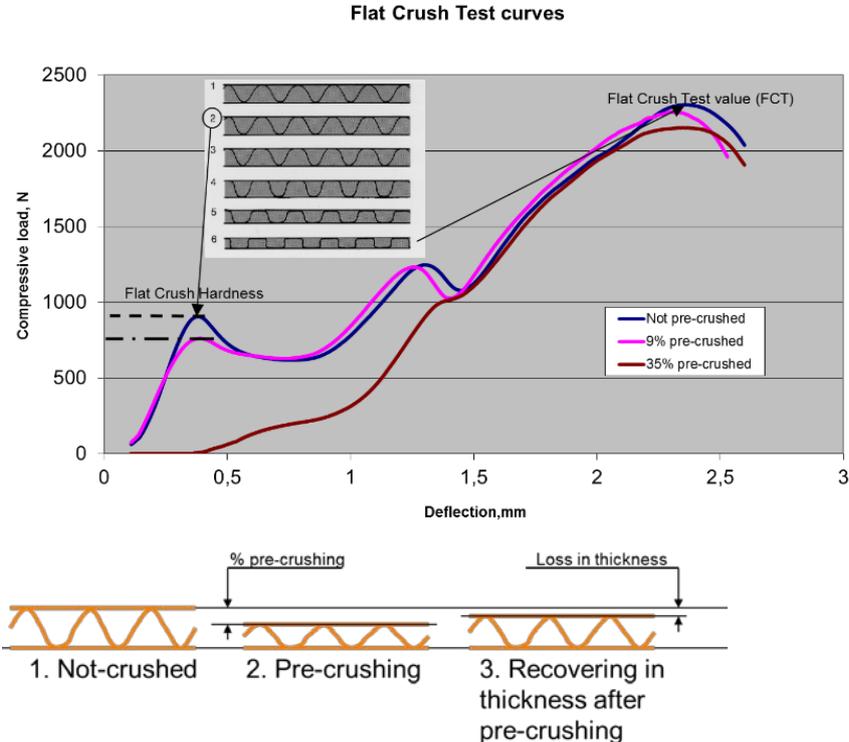


Fig 4. Flat Crush Test (FCT)

In the following example (see fig 5) a series of flat crush tests were performed in a crush tester with various pre-crushed samples.

The shape of the load deflection curve changed a lot for the heavily pre-crushed sample. The board thickness difference measured before and after pre-crushing was insignificant and close to 0 % for the 9 % pre-crushed samples and only 5% for the 35% pre-crushed sample. This shows that thickness measurement is not a sensitive damage evaluation tool.

However, the first peak called the Flat Crush Hardness value is very sensitive to pre-crushing. For a 9% pre-crushed sample the hardness value drops 16% and for a 35% pre-crushed sample the first peak disappears totally!



Pre-crushing	9%	35%
Loss in thickness after recovering	0%	5%
Loss in FCT	2%	7%
Loss in Flat Crush Hardness	16%	100%

Fig 5. Flat Crush Hardness

Considering this. It is clear that the value most relevant for the end user is the first peak, and not the FCT_{max}. Obvious then is that one should start to evaluate this first peak already at the mills producing fluting medium.

MEASUREMENTS ON FLUTING. ALTERNATIVES TO CMT MAX

The different stages of the CMT measurement are shown below (Fig. 6) on the plots and the corresponding photos. First it is a plateau or peak which seems to be connected to a bending failure that happens after the initial elastic compression part is passed. Then there is the traditional CMT value which happens at max force. Clear delamination can be seen in the test piece. Typical delamination can also be seen in fig 9.

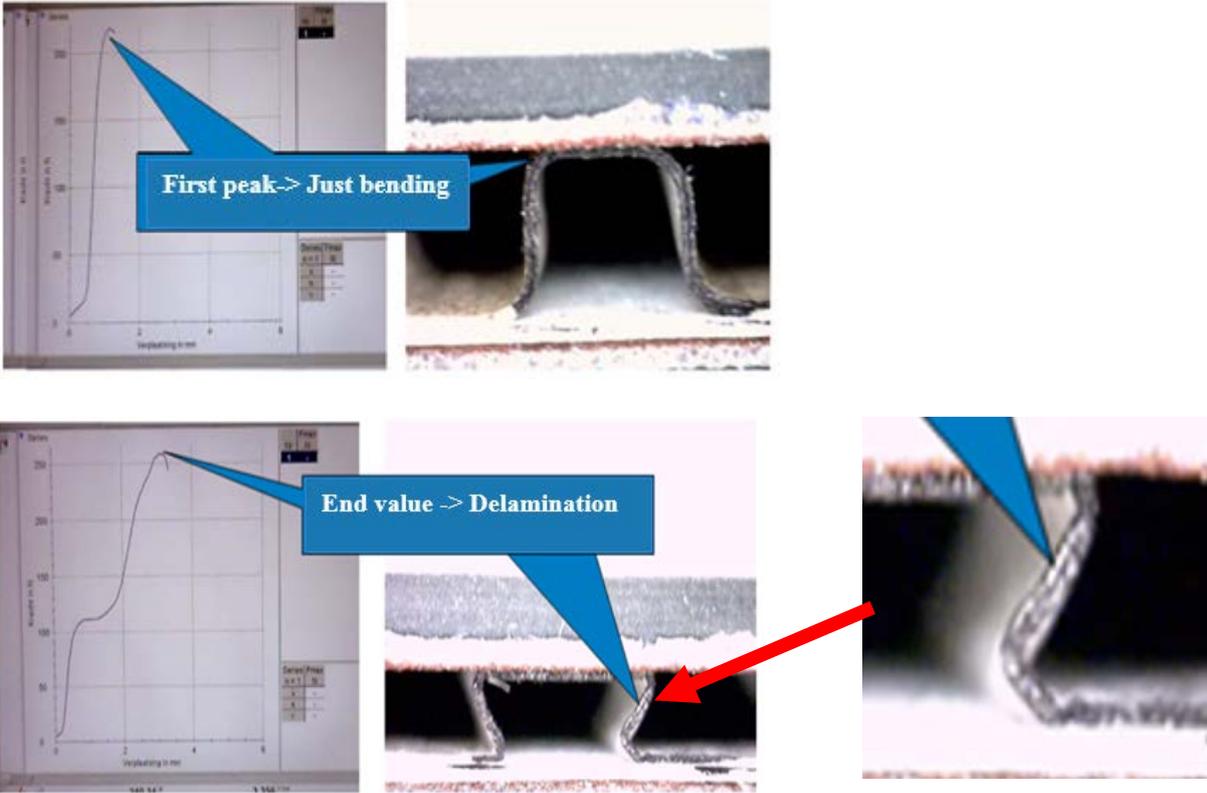


Fig 6. The different stages of the CMT measurement.

WHAT IS CMT PLATEAU AND HOW TO DEFINE IT?

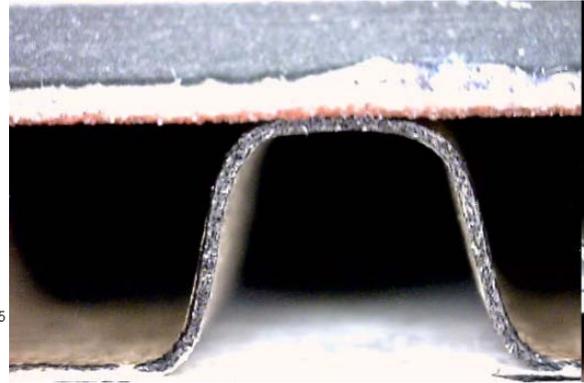
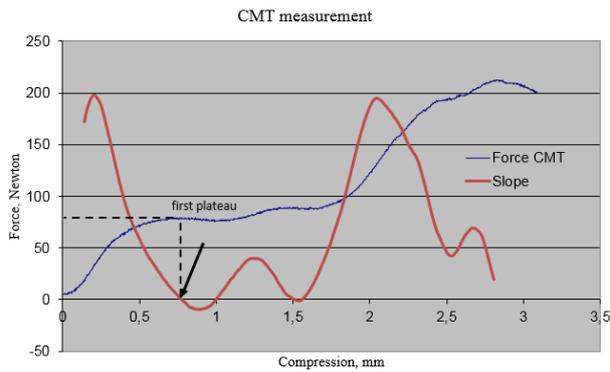


Fig 7.

The force –compression curve of CMT measurements doesn't always have a distinct first peak but more like a plateau. A way to define this plateau is to look at the first derivative (red curve). The derivative is description of the slope of the curve. The plateau is visible then as the derivative curve intersects the x axis, which means the change in force without the change of displacement (or with minimal change). If the derivative doesn't cross the zero level the displacement at the first minimum is used instead.

If there is a peak or plateau visible in the test seems also to be dependent of how the flutes are fixed in their position. A laser cut single faced corrugated strip in the shape of CMT test piece is tested in a Crush tester. Both samples show then the same plateau and Fmax levels, but for the board sample. The graph looks more like the FCT profile, with a distinct first peak. Could it be because of the more stability in the sample introduced by the glue itself?

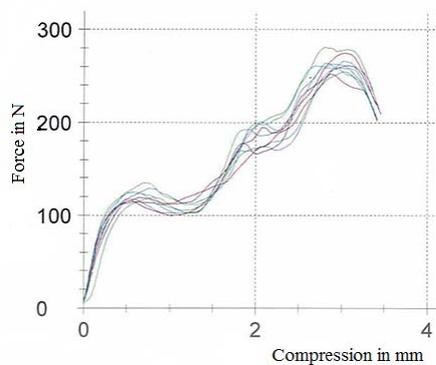


Fig 8. Glued test piece

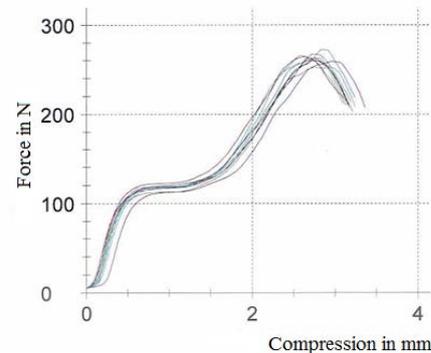


Fig 9. Taped test piece

CMT MAX DISQUALIFY HIGH BASIS WEIGHTS FLUTING

CMT plateau is more stable and doesn't have the delamination problem that CMT_{max} has. F_{max} (CMT_{max}) in this example, is at the same level for 175 g/m² as for 130 g/m² fluting which leads to the question of whether using the more expensive 175 g/m² fluting is justified, if the same strength can be delivered using thinner and cheaper 130 g/m² fluting. The same problem is not influencing the CMT plateau which easily distinguishes between various levels of fluting grades. So CMT first plateau could be the judge for a good performing fluting which give 175 g/m² higher rank than 130 g/m².

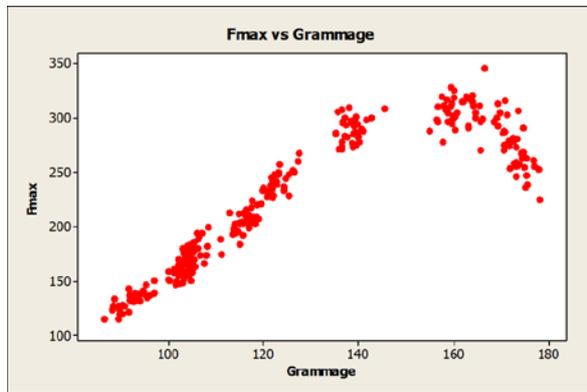


Fig 10. CMT max

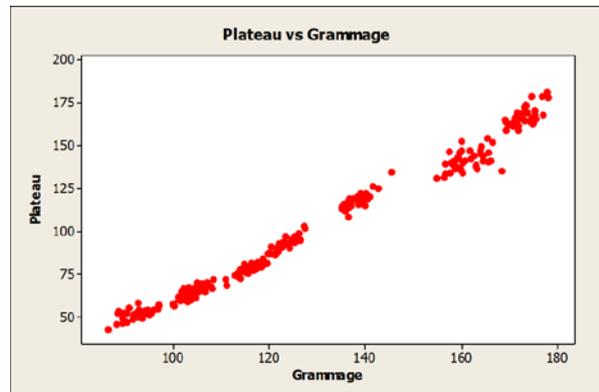


Fig 11. CMT plateau

B-PROFILE FLUTE INSTEAD OF A-PROFILE IN CMT TESTS

There is an ongoing discussion whether to introduce another profile type in standardized CMT measurement. The currently used flute is an A flute, with flute height around 4.5 mm (0.18 in). The suggestion is to introduce B-flute instead in the CMT measurements for lower basis weights such as 90 g/m² (18#) and below. B-flute has a height of around 2.5 mm (0.1 in). But using two different flute types only complicates the measurements and makes it impossible to compare flutings throughout the whole basis weight range.

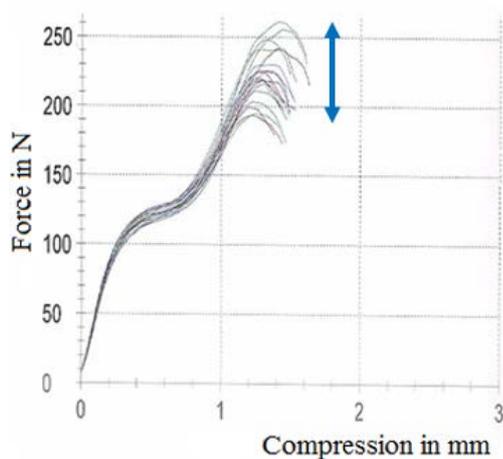


Fig 12. Recycled Fluting 100 g/m² B-flute

Using B-flute in a CMT test still has a lot of spread in the CMT max value. It suffers also from delamination, because even though the basis weight of the used fluting is lower so are also the dimension of the flute itself. It might be possible to use the CMT first plateau for the B flute as well; this needs further investigation.

FIRST PAPER MILL PRODUCTION TRAILS

The tests were done in a SmurfitKappa mill in EU. The mill were producing recycled medium. The question was. Is CMTplateau sensitive to the added starch amount?

By adding starch at the size press (fig 13) , CMT_{max} increased as expected but also the CMT plateau increased. For recycled 90 g/m² 6–7 N per % starch. Although the effect of 1 % starch on the CMT_{max} is higher (15 N per %). The effect on CMT fp is high enough to control a paper machine on strength. However more studies with the effect on the S test needs to be done here.

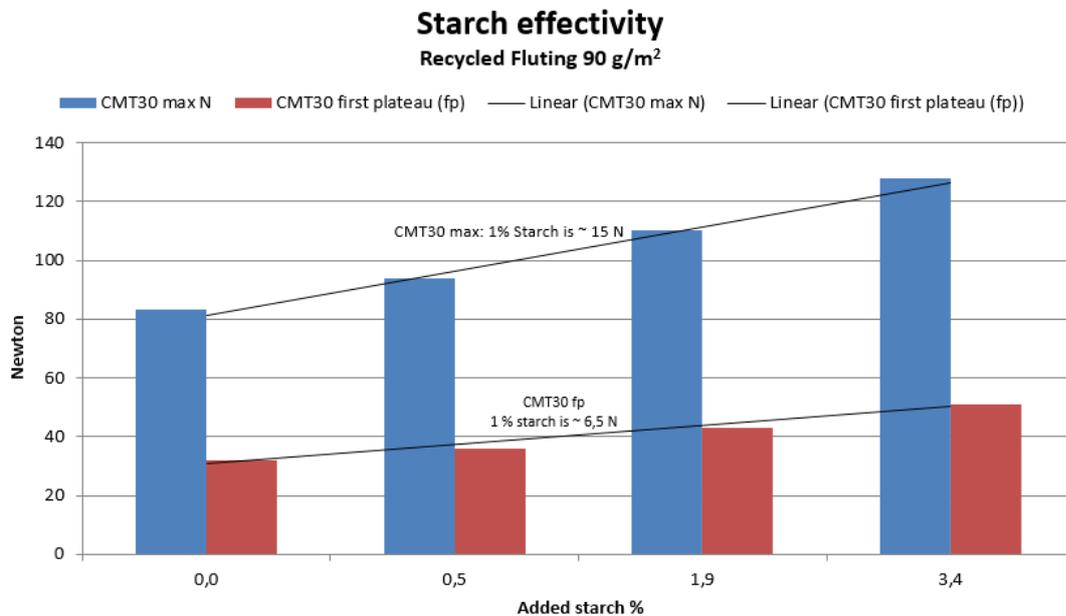


Fig 13. Starch effectivity in mill production trails

S-TEST AS A WAY TO SIMULATE CMT PLATEAU MEASUREMENT

In this project there was a lot of work done concentrated on correlating CMT_{max} and CMT_{plateau} with other paper properties measured in the laboratory today. The goal has been to find a method that is quick, doesn't need a laboratory corrugating process and is sensitive to changes in the manufacturing process and above all easily automated and possible to use in L&W Autoline.

If one studies the CMT process visually it become obvious that the flutes are formed as a sine wave with a height of around 4 mm (A flute). When compressed from top and bottom the wave will be loaded in a matter bringing to mind compression test with a long span. After the initial elastic compression part the bending of the wave will fail which will lead to the first permanent damage.

To simulate those forces the standard SCT instrument was modified – the span was changed from 0.7 mm to 4 mm (about the same as the height of A-flute). The initial tests did not show any significant correlation between the CMT results and the modified SCT (so called SCT long) due to a non-reproducible buckling of the samples.

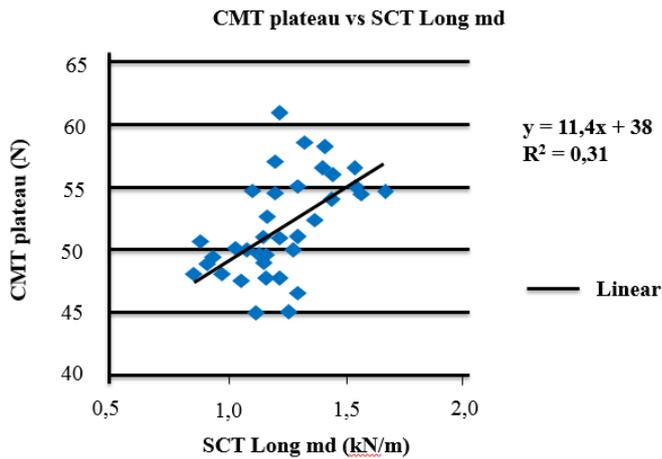


Fig 14. CMT plateau and SCT long

S-TEST – CMT PLATEAU CORRELATION

To overcome the uncontrolled buckling an offset of 1 mm in the 4 mm span was introduced. The shape of the test piece then resembled the letter “S”, thus leading to the name of the test. The working name became S-test.

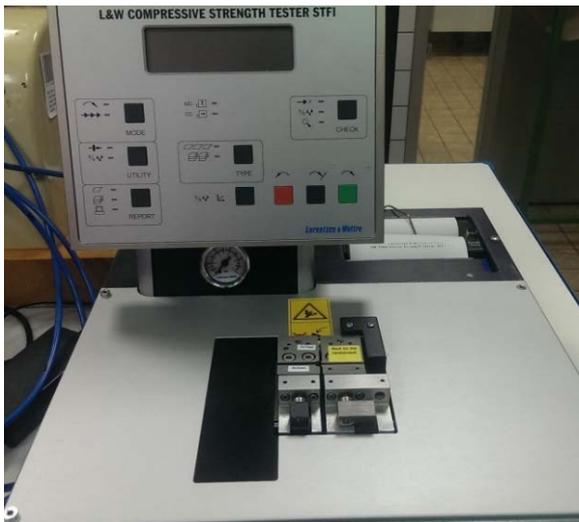


Fig 15. Modified L&W Compressive strength Tester -STFI

In the correlation attempt in April 2015 samples of 10 different grades from 17 European mills were collected which makes a total of 170 samples. The major part of the samples was 100% recycled fluting medium. The result of one Semi Chemical fluting were deviating from the main bulk of measurements.

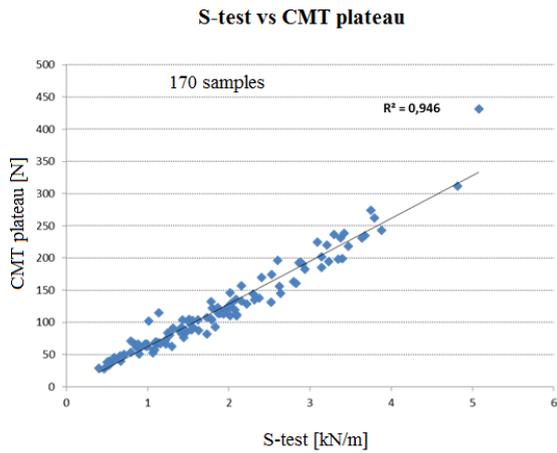


Fig 16. S-test – CMT plateau correlation 170 samples

Additional 120 samples were measured 6 month later which confirmed the high correlation.

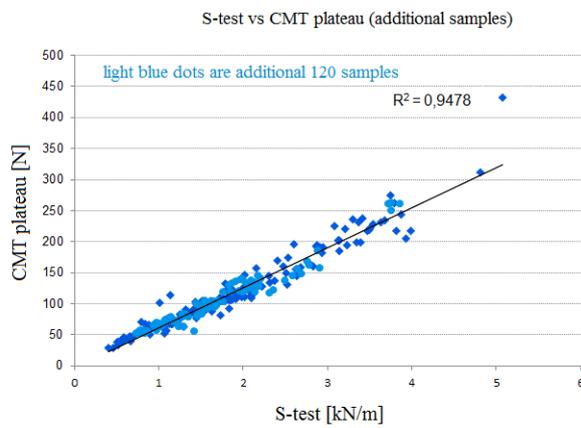


Fig 17. S-test – CMT plateau correlation 170 + 120 samples

At the same time traditional CMT_{max} was measured. Correlation was clearly lower. Probably due to failure issues in the CMT test like delamination or leaning flutes.

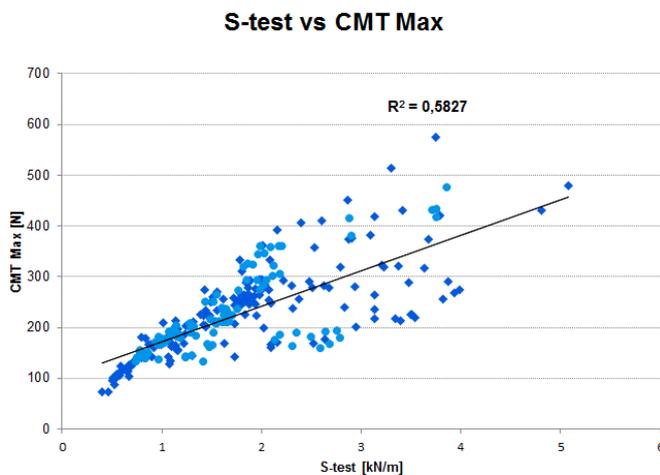


Fig 18. S-test – CMT Max correlation 170 + 120 samples

MILL TRAILS

After confirming the validity of the S-test on the laboratory scale the production test was established at Smurfit Kappa Mill Hoya in Germany. Since May 2015 an S-test measuring unit is mounted in L&W Autoline and is running daily measurements.



Fig 19. S-Test module in L&W Autoline

Up to now this test has shown a correlation coefficient of 97.6% between the measured S-test and the real CMTplateau value. An ongoing investigation is to find out the S-test sensitivity to machine tuning, refining, starch levels, jet/ wire ratios and other variables.

FUTURE WORK

Verification of the correlation S-Test result to CMT plateau and FCT first peak is needed on actual paper. Executing corrugator trials, producing board with known paper and measure all influencing parameters on crushing.

Influence of hot treatment on S-test have been executed but need deeper investigation.

SUMMARY

This paper tries to point that the converters who die-cut and print corrugated sheet should be more interested in the crush elasticity of corrugated board. Fluting medium mills will find a more attractive test method in S-test. Which is faster and more automated for optimizing the crush elasticity potential of their medium fluting product.

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