Kuratorium für Forschung und Technik
der Zellstoff- und Papierindustrie im VDP e.V.

INFOR-Projekt Nr. 202

Entwicklung eines neuen Prüfverfahrens für Wellpappen-rohpapiere (S-Test)

Schlussbericht

Oktober 2017

Technische Universität Darmstadt
Fachgebiet Papierfabrikation und
Mechanische Verfahrenstechnik

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Final Report of a CEPI-CONTAINERBOARD Project

Observations concerning the S-test used for fluting paper

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Project objectives:	Evaluation of the S-test accuracy and comparison of S-test with CMT und FCT
Funding:	by CEPI-CONTAINERBOARD, VDP (as INFOR 202) and Propapier
Internal Number:	PMV-17-015

October 2017

Content:

1. Summary

The S-test is a new method to characterize flute base papers. Derived from the SCT-test, the procedure is comparable. Therefore, the S-test offers some advantages compared to the common CMT, which is in use to determine the quality of fluting base papers. On the one hand, this new method is less dependent on handling procedure; on the other hand, the test might be enclosed in an automatic paper lab.

The main goal of this study was to evaluate the accuracy of the test method. Obtaining a standard deviation of the repeatability of 8.9 % and a standard deviation of the reproducibility of 9.8 % the accuracy of the test is sufficient. However, the variability of the tested paper grades (88 papers, 20 different grammages and 9 different quality grades) was very high, and during the round robin test, it was observed that some delivered samples didn’t have the status to ensure an accurate test result as requested by standards. In consequence, an even better accuracy can be expected if the round robin is repeated during a standardisation procedure.

Compared with other paper and board parameters, the S-test correlates very well with paper grammage and paper thickness. CMT first peak correlates very well, too. Nevertheless, SCT MD correlates less good, although regression analysis still leads to a coefficient of determination of 0.82. Observing CMT end value, the correlation is far less than with CMT first peak.

Taking the base paper, manufacturing a corrugated board and measuring the FCT offers a good correlation with the S-test, as long as no fine flutes (D, E or even smaller) are used.

2. Introduction

When the Container Corporation of America (CONCORA) introduced testing methods to describe the quality of corrugated board, this was the start-up of a success-story of a new material to protect goods during transportation. The main reason was that the test methods offered the opportunity to evaluate the quality of the base papers and the manufactured corrugated board.

In today’s economy, corrugated board is the most important material to protect goods during storage and shipping. The market share during transportation of goods is in the range of 65 % compared to other packaging materials. The amount of corrugated board exceeded about 51 billion m² in Europe during 2015. However, during the last years, grammage of the board as well as grammage of the base paper decreased. Since 1990, the average grammage of corrugated board dropped by 7.7 % and reached the level of 515 g/m² in 2015. At the same time, the grammage of the base papers shrank from 145 g/m² to 126 g/m². It is common to use 80 g/m² paper or even lower grammage to produce corrugated board today. [1]

These developments led to some inconvenience in the quality management of the supply chain. The common test method CMT (CONCORA Medium Test, see e.g. ISO 7263 [2]) for instance uses the A-flute to give a strength property of the used paper. However, with lightweight papers, CMT-measurement will not end in reasonable results. Therefore, in an ongoing project ISO 7263 shall be divided into two parts that using of B-flute may become possible, too.

On the other hand, it is well known that CMT-measurement includes some shortcomings. The status of the used tape may influence the obtained results in a same important manner as the handling carried out by the laboratorian during proceeding the test. In addition, it may be observed that the failure mechanism during CMT-procedure may vary between buckling and delamination. Considering this, a new test-method is proposed, called “S-test”. [3] This test was derived from the established Shortspan Compression Test (SCT, see e.g. DIN 55518 [4]). The differences are that the gap was extended to 4 mm and the compression force is not applied in one plane, but in parallel planes with a displacement of 1 mm (see **Figure 1**).

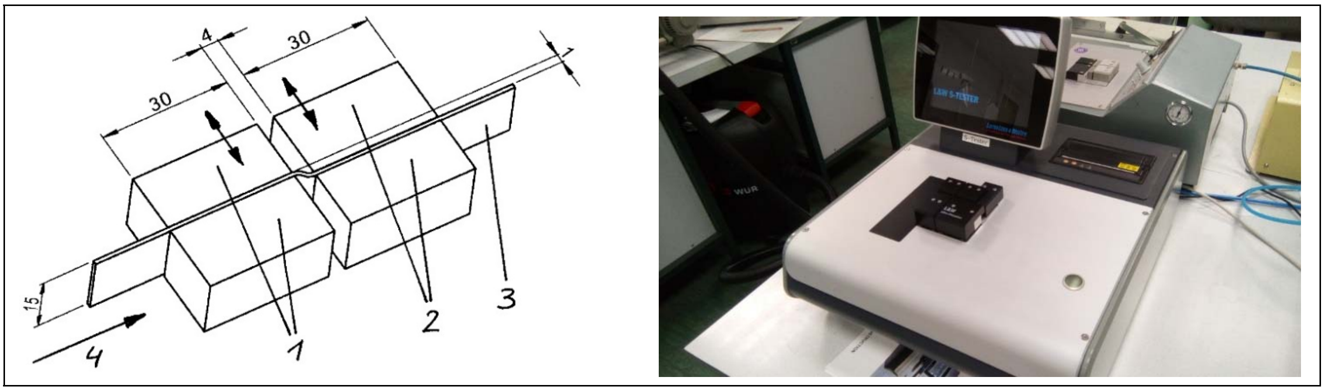

Fig. 1: Dimensions of the S-test and photo of an S-test equipment (design by Martin Stubenberger, photo by Heinz-Joachim Schaffrath)

The influence of varying the dimension of the testing equipment is not examined in this project. However, a 4 mm gap is about half of the A-flute pitch and the 1 mm displacement is about half of a D-flute height. Hence, the chosen dimensions seem to be quite reasonable. It may be expected, that bending stiffness (hence: thickness) and buckling behaviour (represented by SCT MD) are the influencing parameters of the S-value.

With these conditions, a round robin test had to be carried out to get an impression how accurate the S-test is. Furthermore, it is of interest how the S-test correlates with common CMT-measurements as well as with FCT-values.

3. Sampling and testing

During a CEPI-ContainerBoard meeting in December 2016, a range of paper and board suppliers were asked to participate in the project. The commitment was to have five laboratories participating at the project in order to be able to give a first estimation on the repeatability and the reproducibility of the new test method.

During the project, some delays come up due to bad sampling procedures. Therefore, some participants were changed, and finally six labs tested the base papers while three labs tested the board properties.

3.1. Round robin S-test

20 different paper grammages (from 60 g/m² up to 220 g/m²) delivered by 10 different suppliers, made from different furnishes (recycled material as well as virgin fibres, so 9 different quality grades were tested) have been used to go in for the round robin test. In sum, 88 different papers were tested. Although the S-test addresses to flute base paper, some liner base papers were tested, too. The reason for that was to have a high variability of paper grades and by this a better estimation of the accuracy.

The results came from 4 to 6 labs, depending on the amount of testing material available and on the fact that some obtained values had to be rejected as outliers. It has to be mentioned that some of the samples have been good enough to carry out the required tests. However, the sampling procedure according to ISO 186 [5] couldn't always be respected.

Tested parameters were, besides the S-value itself, grammage and thickness. Although the main objective of this part of the project was to determine the accuracy, some interesting results came up. It is shown in **Figure 2** that the S-test correlates well with the grammage.

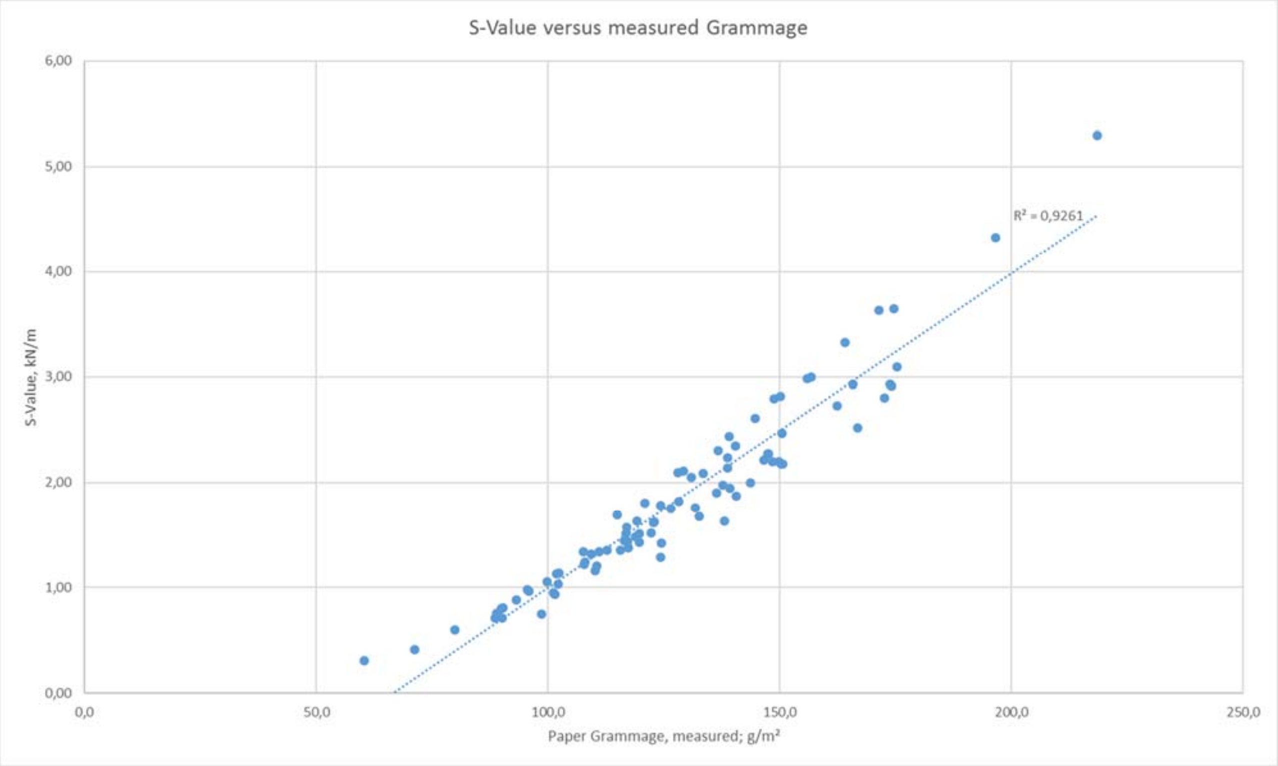

Fig. 2: Correlation between S-test and paper grammage

Taking the thickness, the correlation is in the same order as with grammage, but a little bit less (see **Figure 3**).

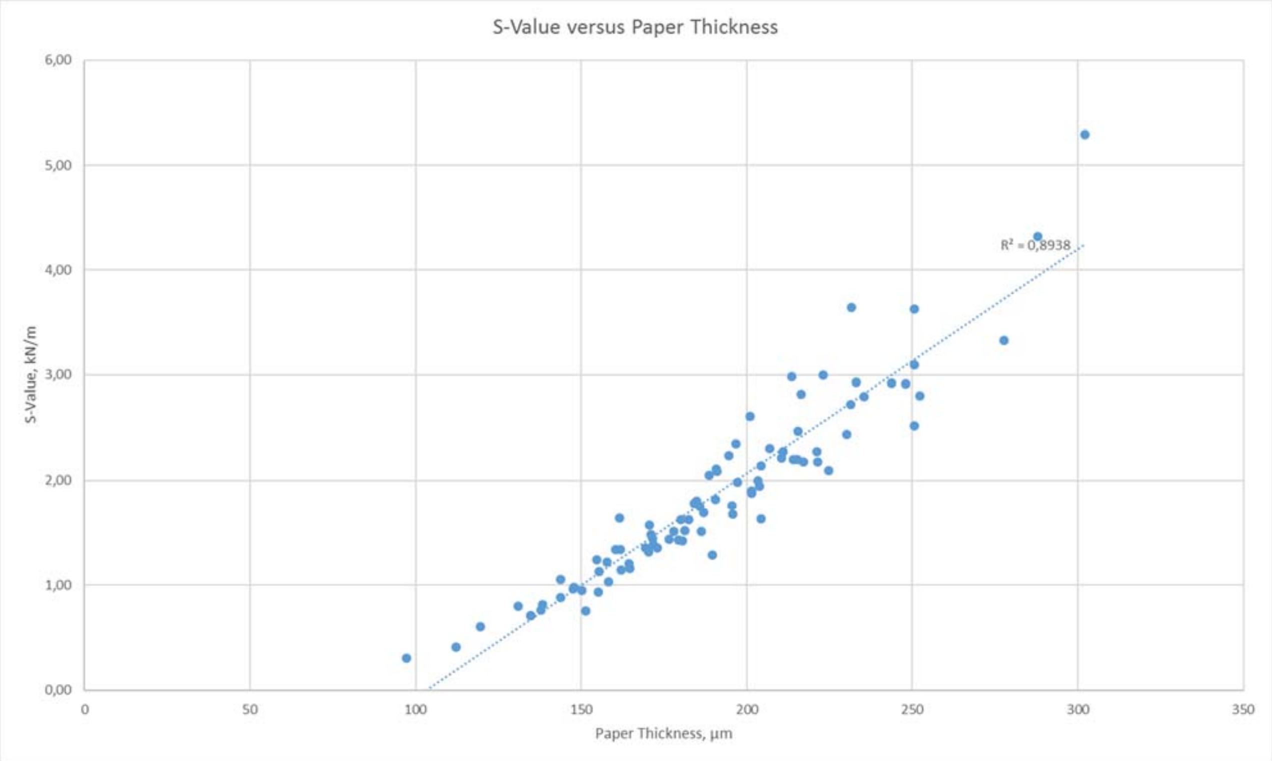

Fig. 3: Correlation between S-test and paper thickness

The test covers low grammages as well as high grammages. No delamination was observed during the tests. From the testing conditions, it seems to be obvious that bending stiffness and buckling strength are important parameters influencing the S-value. As bending stiffness correlates well with grammage and thickness, this hypothesis is supported. Buckling will be observed in comparison with SCT-value. This is done later in chapter 5.

3.2. Corrugated board

For this part of the project, 61 different corrugated boards have been delivered by 8 different suppliers together with the base papers they were manufactured from. The range of qualities went from K-flute down to E-flute (as estimated from the height of the board).

Together with the S-test of the base paper, thickness, grammage, SCT, CMT first peak and CMT have been measured, too. This offered the possibility to correlate the S-value with several paper and board parameters. Taking the boards, height, FCT first peak and FCT have been determinated.

4. Accuracy of the S-test

Quantification of repeatability and reproducibility of the S-test was the main goal of the round robin described in 3.1. In general, the total variance of data may be calculated by the sum of the single variances. As there is a variance in collected data within one single laboratory and another variance of the obtained mean values between different laboratories, the total variance may be calculated as:

$$s_{total}^2 = s_{within\ lab}^2 + s_{between\ labs}^2$$

The square root of the total variance is the standard deviation, that has to be taken into account when comparing single data between different labs. To calculate the accuracy of a test, a 95 % confidence level is common. Therefore, the obtained value of s_{total} has to be multiplied by 2.77 to get the reproducibility. This procedure is described in several standards (see TAPPI T1200 [6] and 1206 [7] or ISO [8]).

To estimate the repeatability on a confidence level of 95 %, the standard deviation within one lab has to be multiplied by 2.77. This leads to **Figure 4** and **Figure 5**.

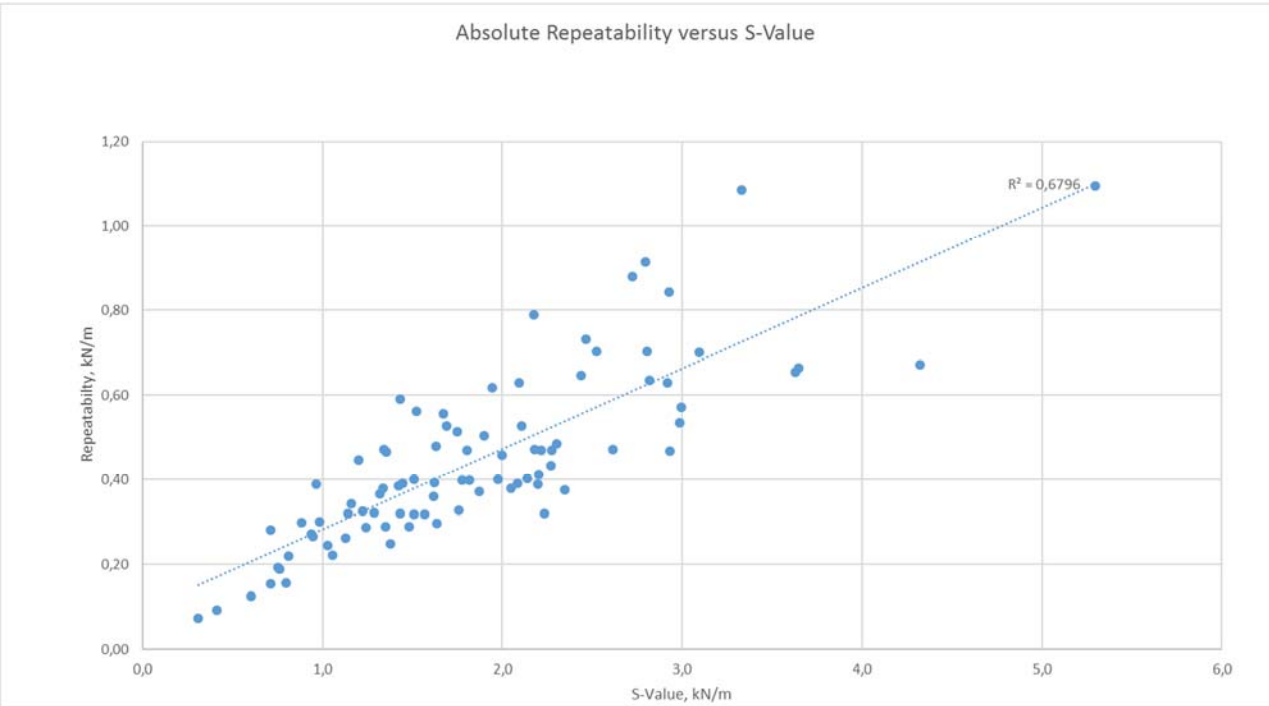

Fig. 4: Absolute repeatability in kN/m

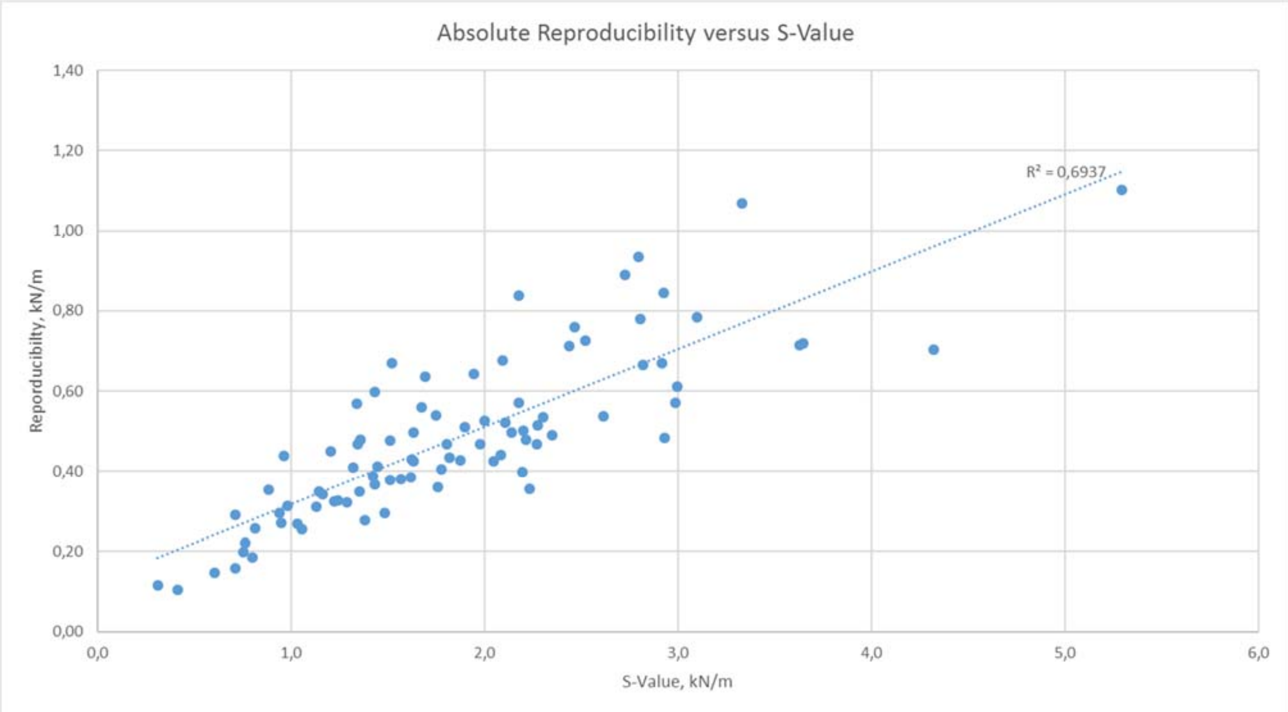

Fig. 5: Absolute reproducibility in kN/m

As to see from the trends, the absolute deviation increases with increasing mean value. In a second step, the coefficient of variation is taken to evaluate the accuracy level (see **Figure 6** and **Figure 7**).

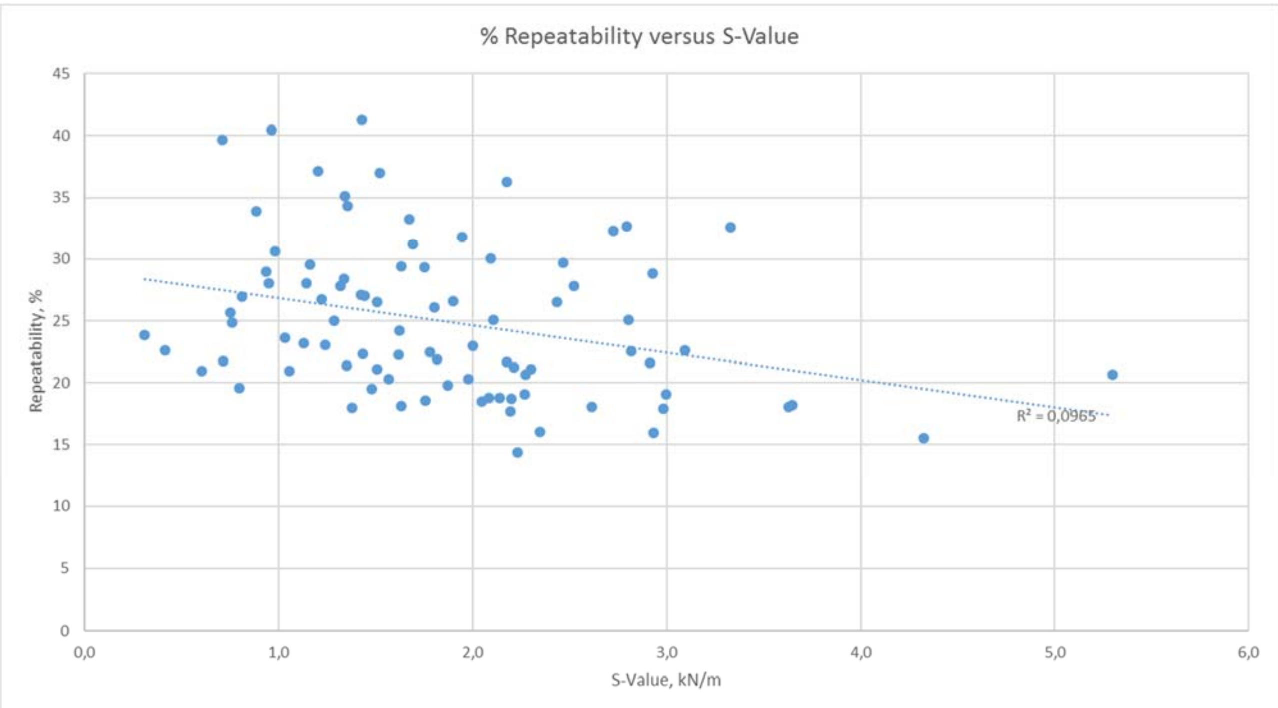

Fig. 6: Relative repeatability in %

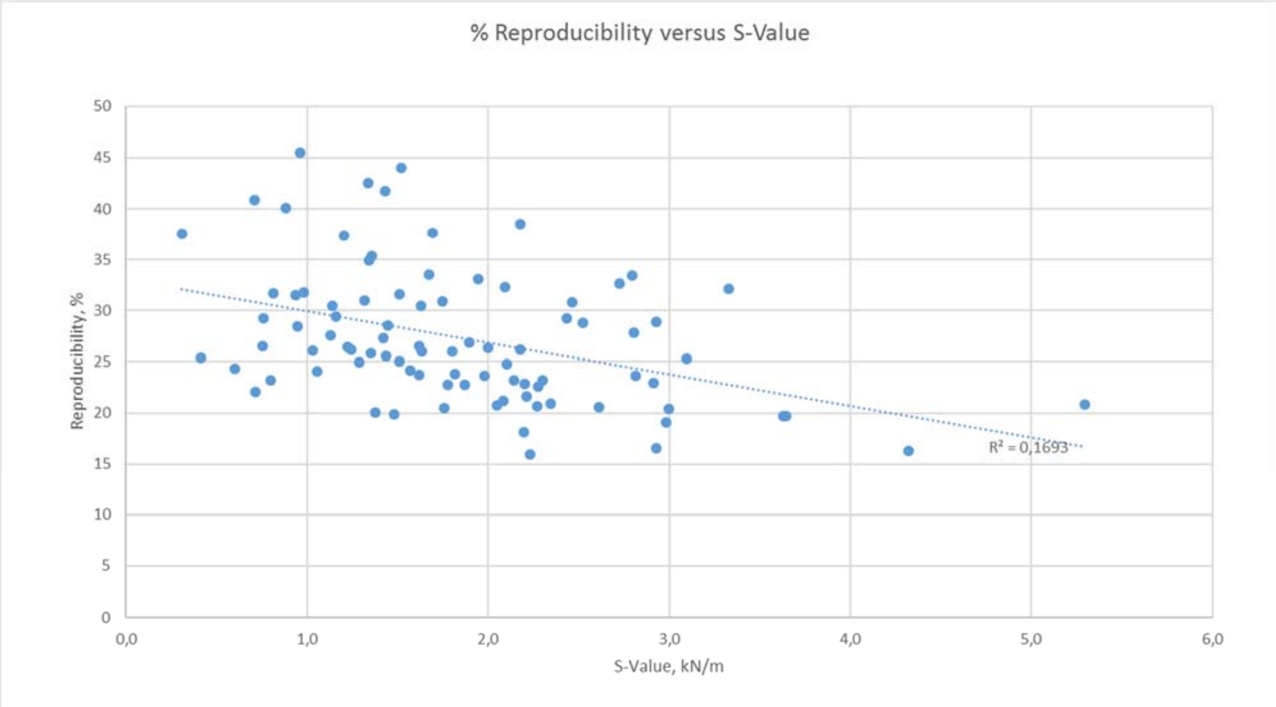

Fig. 7: Relative reproducibility in %

The observed lines are close to a parallel to the x-axis. This means, that the percentage of the deviation of obtained data is independent of the paper grade. Therefore, in an ongoing project at the German standard organisation DIN to establish the S-test as a standard, the author of this report will propose to take the percentage values as a general estimation of the repeatability and the reproducibility.

If the committee for standardisation proceeds like this, the standard deviation of the repeatability of the S-test will be estimated to 8.9 %, the repeatability limit to 24.9 %. The standard deviation of the reproducibility will be estimated to 9.8 % and the reproducibility limit to 27.3 %.

However, the high variability of papers may lead to separated accuracy values in different quality grades. Probably, the round robin will be repeated by the standard organisations. As the experience of this project will enrich a new round robin test, closer values can be expected.

5. Comparison of S-test with CMT, FCT and other parameters

As the idea was to replace the CMT method by the S-test, the correlation of CMT and S-test is of course of interest (see **Figure 8**). There is a correlation; however, the coefficient of determination exceeds 0.76 only.

Far better, looking at CMT first peak (see **Figure 9**), the coefficient of determination results to 0.95. As mentioned in the introduction, CMT shows some shortcomings. Especially delamination takes place at higher paper grammages. In case the first peak is taken, this problem doesn't exist. Comparing the graphs of CMT and CMT first peak, it is well to see that the distribution in high paper grammages mostly influences the correlation.

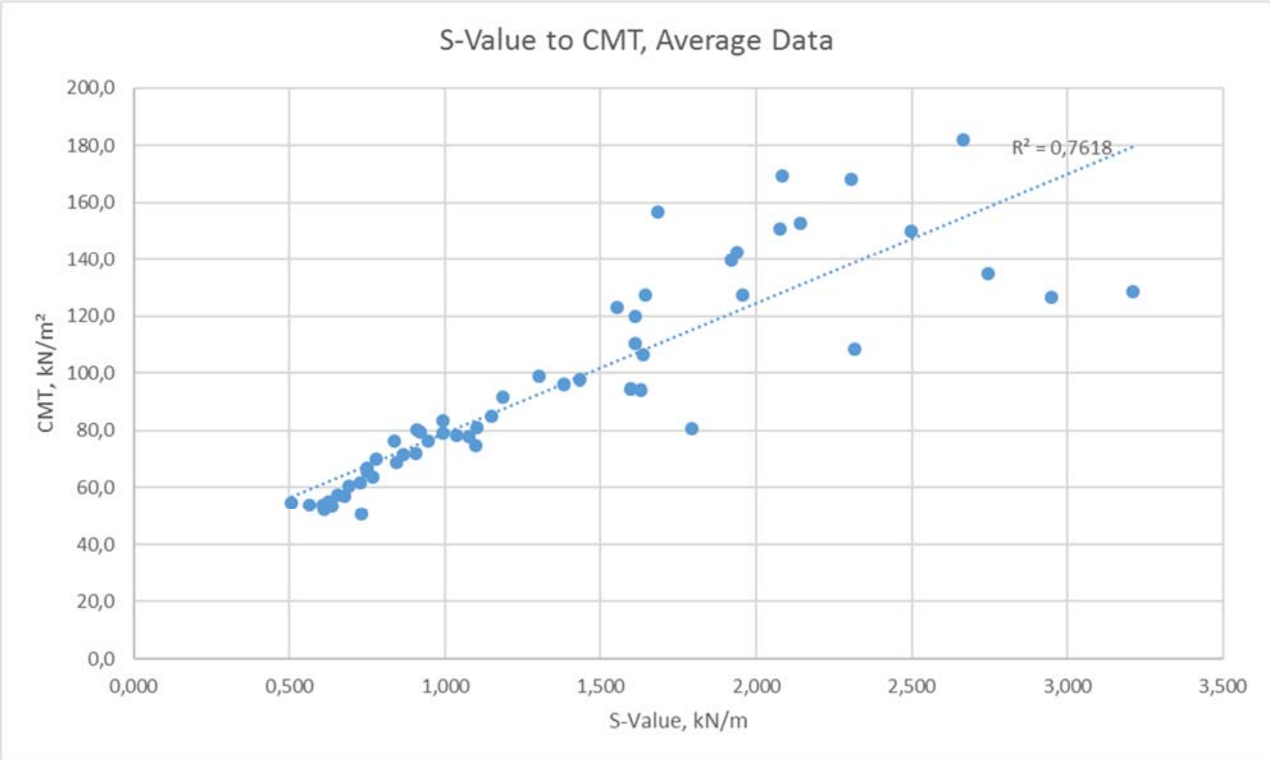

Fig. 8: CMT end value compared to S-value

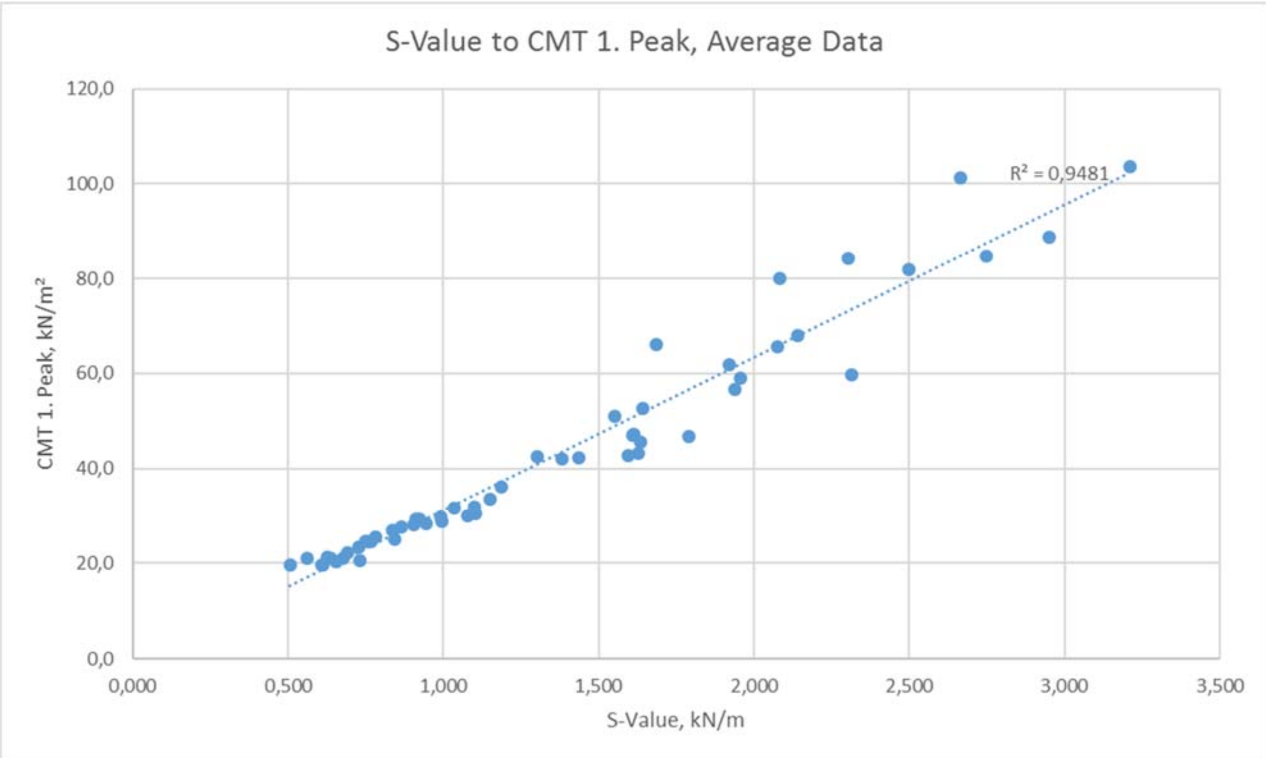

Fig. 9: CMT first peak compared to S-value

Doing the same with FCT and FCT first peak, no correlation may be observed between the S-value of the flute base paper and the obtained values at the corrugated boards. The coefficient of determination is 0.35 in case of FCT first peak to S-value and 0.41 for FCT end value to S-value.

But taking the CMT instead, the correlation is bad, too. Correlating CMT end value to FCT end value gives 0.52, first peak to first peak 0.35. That means, regarding the whole range of boards, neither the CMT nor the S-value can predict FCT or FCT first peak of the corrugated board.

Regarding these results it seems to be reasonable to have a separate look at different flute types.

Table 1 shows the coefficients of determination for different flutes. The number in brackets indicates the amount of corrugated boards of this flute type that have been tested. The yellow emphasized numbers indicate an inverse correlation.

Tab. 1: Coefficient of determination correlating S-value, CMT end value and CMT first peak (1.P) with FCT end value and FCT first peak (1.P)

Flute	A (5)		B (28)		C (14)		D+E (7)	
	FCT 1.P	FCT end	FCT 1.P	FCT end	FCT 1.P	FCT end	FCT 1.P	FCT end
S-value	0.99	0.95	0.82	0.63	0.92	0.89	0.34	0.61
CMT 1.P	0.99	./.	0.93	./.	0.84	./.	0.34	./.
CMT end	./.	0.97	./.	0.91	./.	0.89	./.	0.53

It doesn’t surprise that FCT values measured at small flutes do not lead to reasonable numbers. Hence, bad correlation and even inverse correlation (which doesn’t make sense at all) can be seen for D and E flute.

The high values determined with the A flute are due to the low number of corrugated boards that have been measured as well as to the fact that FCT testing procedure leads to more reliable results if the dimensions are high.

In conclusion it can be stated, that the S-test correlates well with FCT first peak if the dimensions of the flutes are not too small. Nevertheless, the same may be stated concerning CMT or CMT first peak. Therefore, S-test and CMT lead to comparable results.

Finally, during the testing of paper and board by three labs in this working package, the SCT MD of the flute base paper has been determined, too. The results are shown in **Figure 10**.

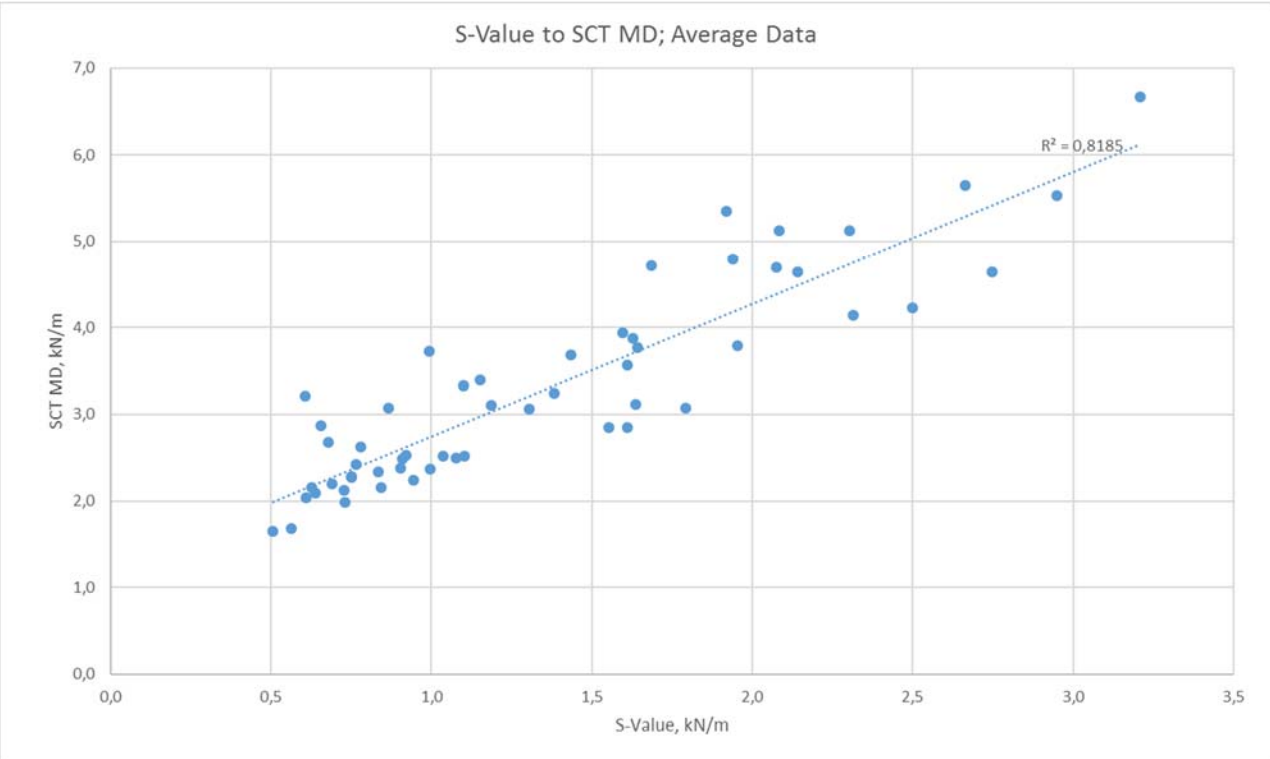

Fig. 10: SCT value in MD compared to S-value

The coefficient of correlation is quite high, although it doesn't exceed the value obtained with paper thickness. Nevertheless, the dependence of the S-value on buckling stiffness is obvious. Therefore, the second part of the hypothesis – S-value is influenced by stiffness and buckling – ist supported by these results, too.

6. List of figures

7. List of tables

8. Bibliography

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Appendix:

Together with this report, two excel files are available. One contains the data collected during the round robin test, the other one the data obtained from board testing.

To do your own analysis, just chose the data you want to select by using the drop-down buttons in the sheet “Overview”. The connected diagrams will adapt to the chosen data.

File names:

1. PMV-17-015 Round Robin S-Test - Estimation of accuracy
2. PMV-17-015 Comparison S-Test with other parameters