Building Leadership Excellence

From Theory to Practice: Improving the Foldcrack Resistance of Industrially Produced Triple Coated Paper

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Background

•Foldcrack resistance is a quality aspect with global importance, especially for high coatweight, high grammage paper products.

•Cracking during paper folding operation could lead to (1) “Loss of Mechanical Strength” and/or (2) “Visible Surface Cracks”.

•Foldcrack represents 39% of quality complaints in web offset printing, and even higher for high grammage paper products.

•John Roper, Pekka Salminen etc. proposed solutions to balance fold crack resistance and paper stiffness by optimizing coating layers for double and triple coated products [1-2]. Fold crack was tested by “Residual Strength”.

•Our objective is to further test the proposed solutions on triple coated paper in pilot coater experiments and at mill production level, focusing on the “Visible Surface Cracks” problem.

[1]. Alam, P., Toivakka, M., Carlsson, R., et. al., Balancing between foldcrack resistance and stiffness, Journal of Composite Materials 2009, volume 43, 11, 1265-1283, 2009.
[2]. Salminen, P.J., Carlsson, R., Sandas, S.E., Toivakka, M., Alam, A., Roper, J.A., Combined Modeling and Experimental Studies to Optimize the Balance between Foldcrack Resistance and Stiffness for Multilayered Coatings – Part 1: Introduction and Modeling Studies, 2008 Tappi PaperCon Proceedings.

Hypothesis

Recap from Ref. [1] [2]:

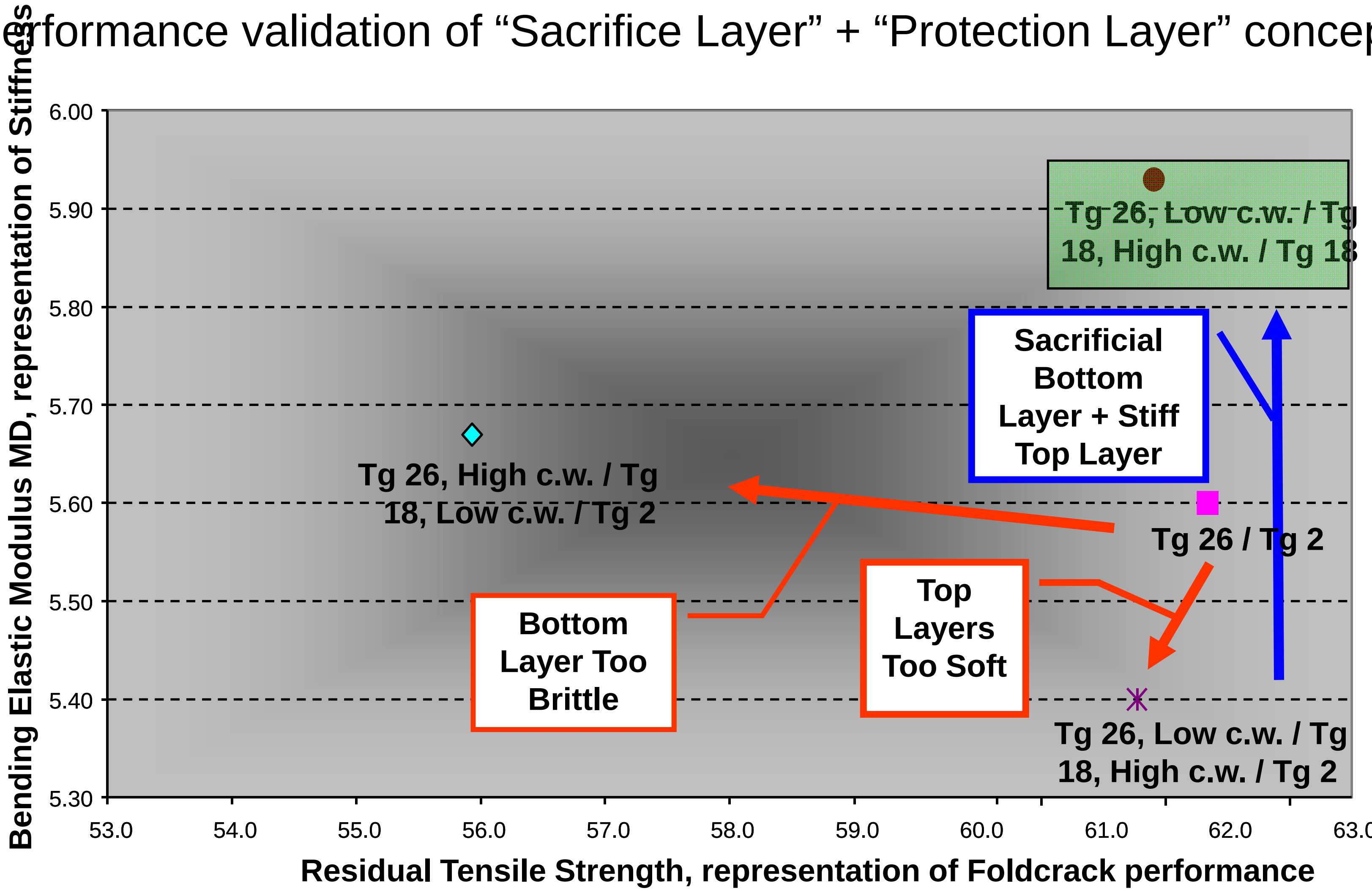
The best balance between foldcrack resistance and paper stiffness could be achieved by control of elastic modulus and thickness of the various layers:

- ✓ **Double coating:** thicker layer dominates.
  - Positive effect of making outer layer stronger, with equal layer thickness or thicker outer layer.
  - If inner layer thicker – improved crack/stiffness balance by making inner layer stronger.
- ✓ **Triple coating:** a layer structure of thin and stiff precoat layer (sacrifice layer) covered by thick and strong middlecoat layer (protection layer).
  - Thin, very stiff inner layer.
  - Thick, medium stiff middle layer.
  - Thin, medium stiff, outer layer.

[1]. Alam, P., Toivakka, M., Carlsson, R., et. al., Balancing between foldcrack resistance and stiffness, Journal of Composite Materials 2009, volume 43, 11, 1265-1283, 2009.
[2]. Salminen, P.J., Carlsson, R., Sandas, S.E., Toivakka, M., Alam, A., Roper, J.A., Combined Modeling and Experimental Studies to Optimize the Balance between Foldcrack Resistance and Stiffness for Multilayered Coatings – Part 1: Introduction and Modeling Studies, 2008 Tappi PaperCon Proceedings.

Hypothesis, Cont.

Performance validation of “Sacrifice Layer” + “Protection Layer” concept:

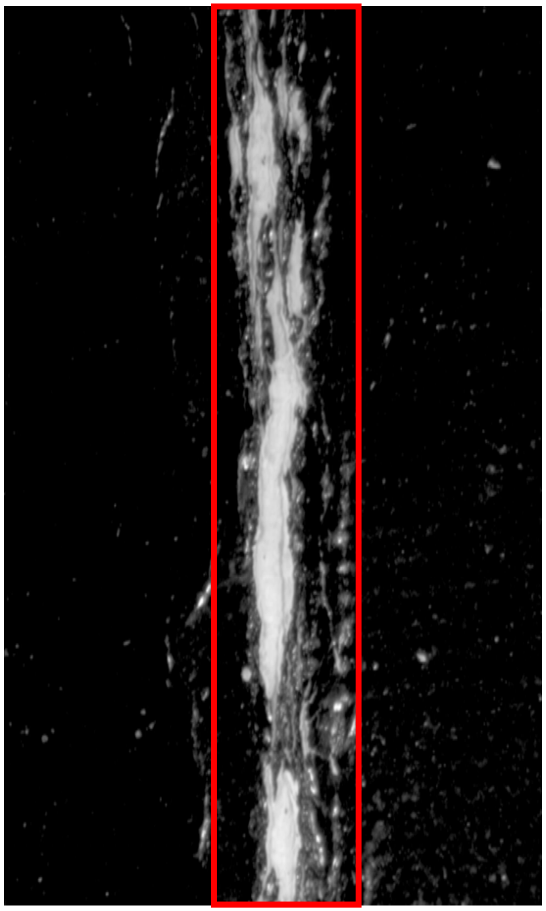


Ref.: Graph reprinted from 2008 TAPPI Presentation; John Roper, Pekka Salminen, et. al.

Test Method Development

- **1: Residual Strength Test**, adequate for “Loss of Mechanical Strength” as a result of fold crack.
- **2: Visual Rating Test**, qualitative and subjective.
- **3: Fold Crack Area Ratio Test (FCAR)**, quantitative and objective.
  - 1): Paper sample conditioned under constant temperature and moisture;
  - 2): Paper sample surface printed by black ink;
  - 3): Folding line created by IGT / Prufbau printing nips under constant load;
  - 4): Magnified pictures of folding line taken with microscope under constant magnification;
  - 5): Area of white regions caused by foldcrack calculated;
  - 6): FCAR ratio calculated:

$$\text{Fold Crack Area Ratio} = \frac{\text{Total Area of White Regions}}{\text{Total Area of the Picture}}$$



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Test Method Development, Cont.

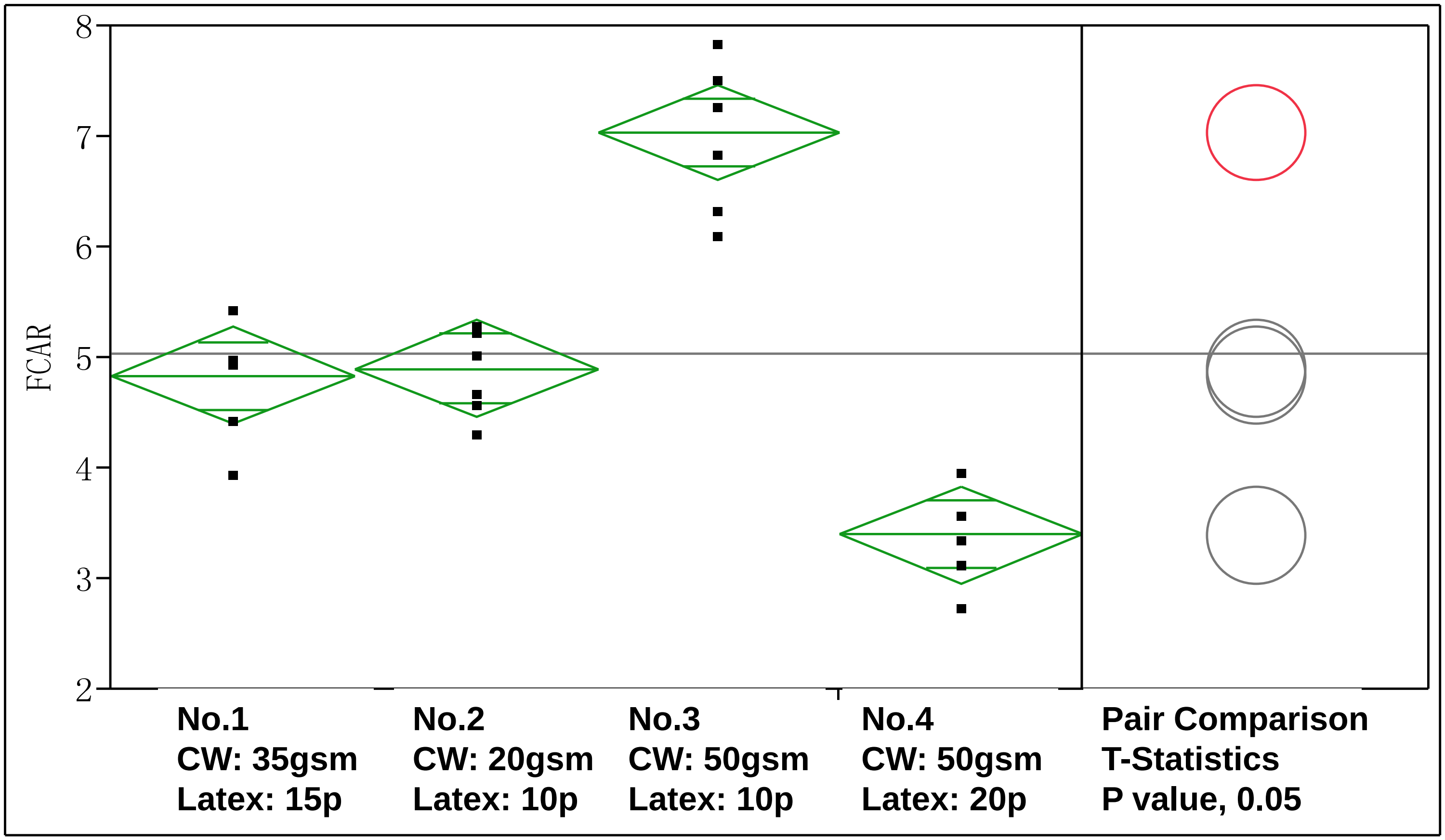
A lab experiment is designed:
To: test the correlation of FCAR test results to fold crack performance.
By: designing model coated paper samples with foldcrack performance being controlled by Latex dosage and coatweight.

Experiment Points	1st Coating Layer	Coating Formulation	2nd Coating Layer	Coating Formulation	3rd Coating Layer	Coating Formulation	Base Paper
No. 1	20gsm	100p C65 15p SPA 001*	15gsm	100p C65 15p SPA 001	N/A	N/A	143gsm Woodfree
No. 2	20gsm	100p C65 10p SPA 001	N/A	N/A	N/A	N/A	143gsm Woodfree
No. 3	20gsm	100p C65 10p SPA 001	15gsm	100p C65 10p SPA 001	15gsm	100p C65 10p SPA 001	143gsm Woodfree
No. 4	20gsm	100p C65 20p SPA 001	15gsm	100p C65 20p SPA 001	15gsm	100p C65 20p SPA 001	143gsm Woodfree

*All formulations were adjusted to: pH =8.5; solid content 70%; Brookfield viscosity under the same level with CMC.

Test Method Development, Cont.

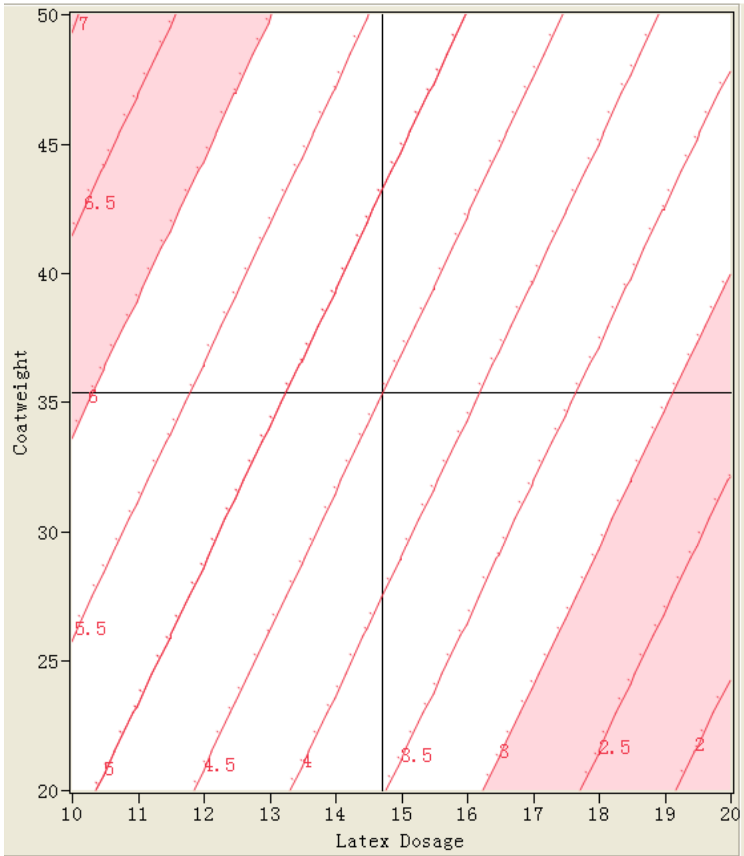
Conclusion: FCAR test is able to provide statistically significantly different results for model coated paper systems which are intentionally designed to have different foldcrack performance.



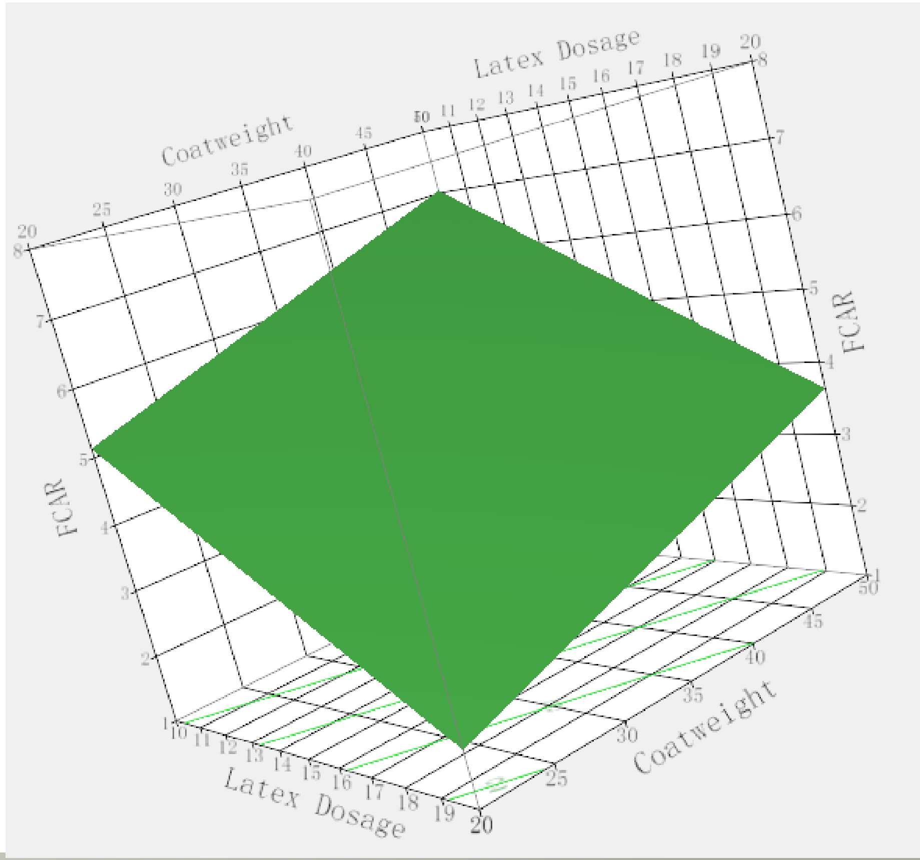
Test Method Development, Cont.

Fit Model Analysis: fitting FCAR test result vs. Latex dosage and coatweight, could provide a significant prediction model (p value < 0.001), as plotted in the following pictures.

Contour Plot



3-D Plot



Experimental Details, Materials

Raw Materials	Name	Supplier	Key Properties	Note
Calcium Carbonate	C60, C95	OMYA	C60: 60% of particles< 2um; C95: 95% < 2um	
Latex	SPA 001	Styron LLC	Tg* = -6.5 ºC Particle Size = 150nm	Carboxylated Styrene-Butadiene Latex, for pre coating layer, with tailor-made optimization on elasticity
Latex	SPA 002	Styron LLC	Tg = +5ºC Particle Size = 150nm	Carboxylated Styrene-Butadiene Latex, for pre coating layer without direct interaction with ink during printing process
Latex	SPA 003	Styron LLC	Tg = +16 ºC Particle Size = 140nm	Carboxylated Styrene-Butadiene Latex, for top coating layer with direct interaction with ink during printing process
Latex	SPA 004	Styron LLC	Tg = +16 ºC Particle Size = 90nm	High strength Carboxylated Styrene-Butadiene Latex offering 20% strength improvement vs. SPA 003, for top coating layer, with tailor-made optimization on elasticity
Starch				Hydroxyethylated corn starch

* Tg represents glass transition temperature.

Experimental Details, Pilot Coater

Variables:

•Latex technologies (with different elastic modulus);
•Latex/Starch ratio in middle coating layer;
•Total coatweight, and coatweight distribution.

Experiment Points	1st Coating Layer	Coating Formulation	2nd Coating Layer	Coating Formulation	3rd Coating Layer	Coating Formulation	Base Paper
Point I	16gsm	100p C65 10.5p SPA 002 8.0p Starch*	22gsm	100p C65 7.5p SPA 002 6.0p Starch	22gsm	100p C95 11p Latex SPA 003	105gsm Woodfree
Point II	16gsm	100p C65 10.5p SPA 001 8.0p Starch	22gsm	100p C65 7.5p SPA 001 6p Starch	22gsm	100p C95 11p Latex SPA 004	105gsm Woodfree
Point III	14gsm	100p C65 10.5p SPA 001 8.0p Starch	34gsm	100p C65 9p SPA 001 3.0p Starch	22gsm	100p C95 11p SPA 004	105gsm Woodfree

* All formulations contain same amount of lubricant, cross-linker; Brookfield viscosity was adjusted to similar level with CMC.

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Experimental Details, Pilot Coater, Cont.

Pilot coater operation parameters:

•Woodfree base paper, 105gsm;

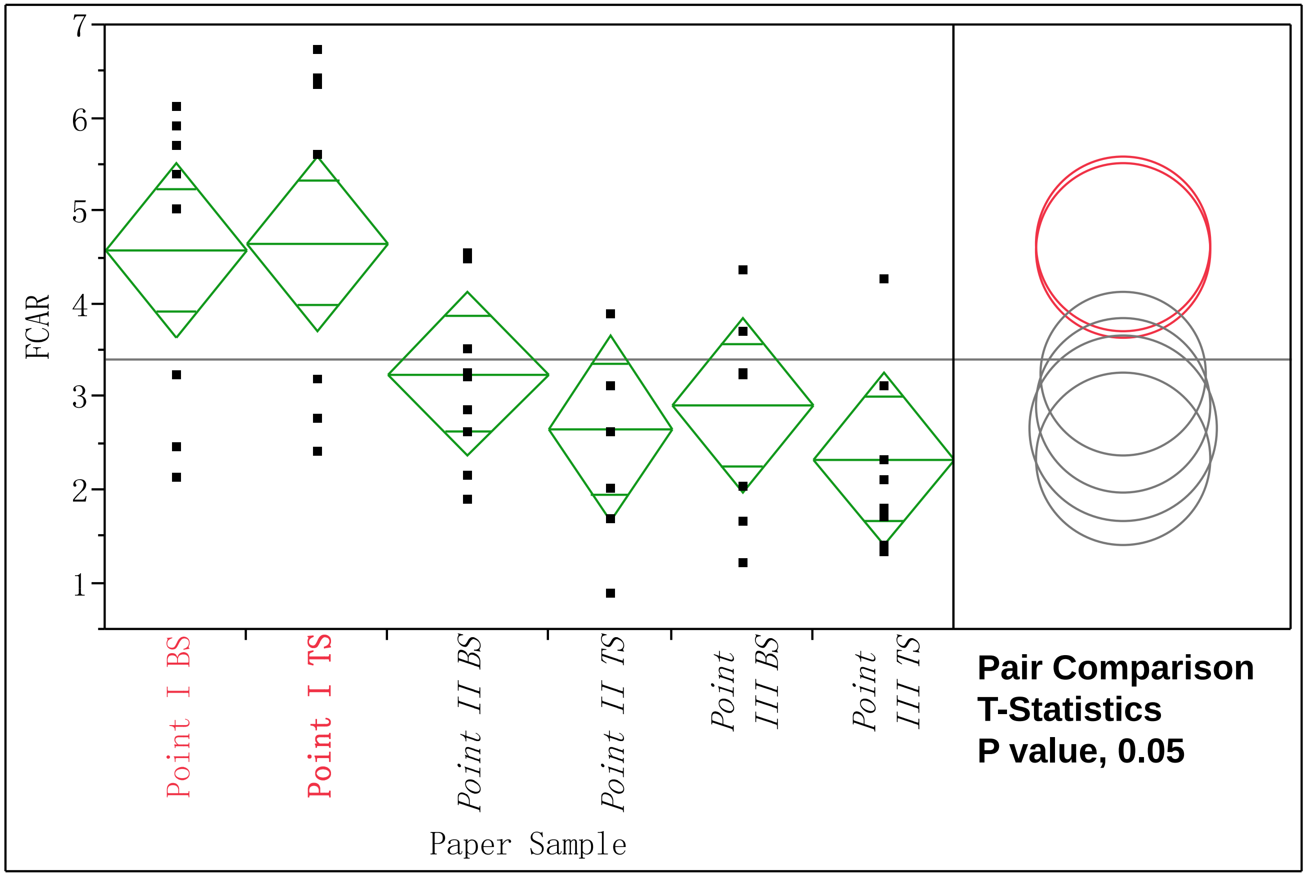
•1st coating layer, pre-metered size press, machine speed 1500m/min; coating solid 62.0%;
•2nd coating layer, bent blade, machine speed 1600m/min; coating solid 68.0%;
•3rd coating layer, stiff blade, machine speed 1600m/min; coating solid 69.0%.

•Rod load and blade load was carefully controlled to minimize coatweight variation in both MD and CD directions.

•Coated paper was calendered to achieve target paper gloss of 70 degrees.

Results and Discussions, Pilot Coater

•Latex with lower elastic modulus improves fold crack performance under same coatweight, and coatweight distribution (Point I and Point II);
•Fold crack could be further improved by the concept of “sacrifice layer” + “protection layer” (Point II and Point III).



Experimental Details, Mill Production

Variables:

•Latex technologies (with different elastic modulus);

•Coatweight distribution.

Experiment Points	1st Coating Layer	Coating Formulation	2nd Coating Layer	Coating Formulation	3rd Coating Layer	Coating Formulation	Base Paper
Trial I	16gsm	100p C65 10.5p SPA 001 8.0p Starch *	22gsm	100p C65 7.5p SPA 001 5p Starch	22gsm	100p C95 11p SPA 003	90gsm Woodfree
Trial II	13gsm	100p C65 10.5p SPA 002 8.0p Starch	30gsm	100p C65 7.5p SPA 002 5.0p Starch	17gsm	100p C95 11p SPA 004	90gsm Woodfree
Trial III	16gsm	100p C65 10.5p SPA 002 8.0p Starch	22gsm	100p C65 7.5p SPA 002 5.0p Starch	22gsm	100p C95 11p SPA 004	90gsm Woodfree

* All formulations contain same amount of lubricant, cross-linker; Brookfield viscosity was adjusted to similar level with CMC.

Experimental Details, Mill Production, Cont.

Mill production operation parameters:

•Woodfree base paper, 90gsm;

•1st coating layer, pre-metered size press, machine speed 1350m/min; coating solid 62.0%;
•2nd coating layer, bent blade, machine speed 1650m/min; coating solid 68.0%;
•3rd coating layer, stiff blade, machine speed 1650m/min; coating solid 69.0%.

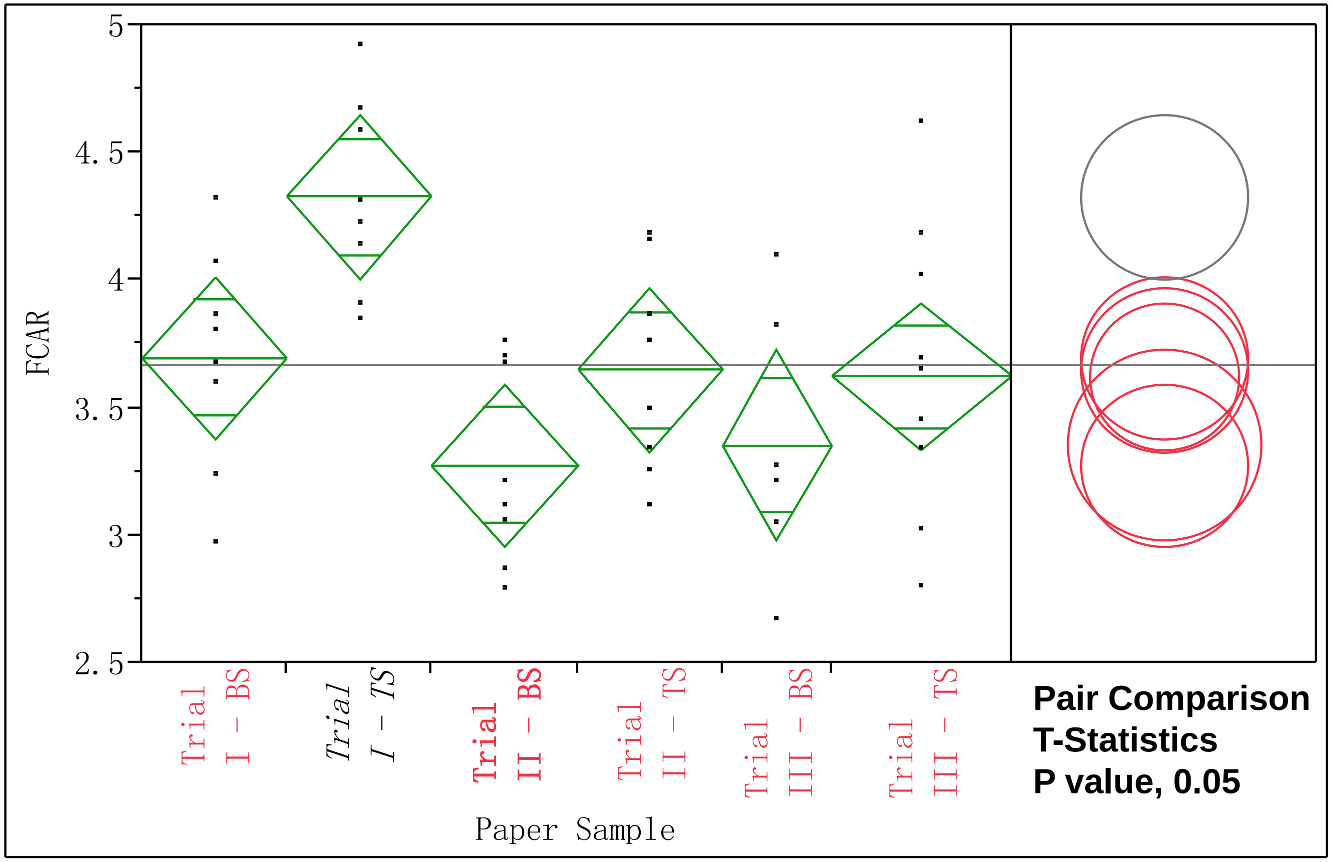
•Rod load and blade load was carefully controlled to minimize coatweight variation in both MD and CD directions.

•Coated paper was calendered to achieve target paper gloss of 70 degrees.

Results and Discussions, Mill Production

•Latex with lower elastic modulus helps improve fold crack performance under same coatweight, and coatweight distribution (Trial I and Trial III);

•The creation of a thin bottom layer and a thick middle layer was not satisfying, as Latex and starch dosage remained the same for middle layer (Trial II and Trial III).



Conclusions

- Latex with lower elastic modulus could help improve fold crack resistance in terms of “Visual Surface Defects”. This is validated in pilot coater experiments and at mill production level.

- There are opportunities to further improve fold crack in terms of “Visual Surface Defects”, by implementing the concept of “Sacrifice Layer” + “Protection Layer” in triple coated paper products. This is validated in pilot coater experiments, and partially tested at mill production level.

- The possibility of combing high strength Latex technologies, tailor-optimization on elasticity, concept of “sacrifice layer” + “protection layer”, to further improve fold crack in terms of “Visual Surface Defects”, needs further exploration.

Questions?