

# Giving deeper insights into the mechanisms of initial wet web strength development by an advanced explanatory model

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## Introduction

The initial wet web strength (IWWS) is one of the most important parameters for effective paper machine performance[1]. As previous research has shown, a huge variety of parameters is already known to have an impact on the IWWS [2]. Despite this fact, there is still an on-going discussion on possible explanations for the mechanisms of initial wet web strength development [3]. One fact is that the mechanisms for strength development at low solid contents are quite different from those of dry paper. However up to today it is not clearly defined which forces are addressed to which fibre characteristics at certain dryness levels, and their effect on the IWWS. The goal of this paper is to discuss existing explanation models for IWWS development and to complement these, generating an advanced model by the inclusion of own trial results.

## Methods

For this study full factorial design of experiments (DOE) [4] was implemented in order to determine the weighting of important factors like dryness level, degree of refining, degree of hornification and conductivity on the IWWS. The goal was to use this DOE-method within the field of paper strength research in order to receive advanced information on the mechanisms of strength development at different dryness levels. The study was carried out with laboratory hand sheets, made of commercial bleached soft wood pulp, which was refined in a laboratory valley beater. The IWWS was measured according to a German standard DIN 54514.

## Results

The data analysis showed that weighing of IWWS-influencing factors is possible. This may lead to a better understanding of paper strength development mechanisms at dryness levels below 50%. The applied method has proven to be reliable for the determination of impact factor weighing. This work carried out to what extent changed parameters changes the IWWS in relation to the baselines of beating and dryness. So it was shown that the effect of dryness level as well as the degree of beating are as expected positive and quite big. In relation to this, the effect of hornification is low and the one of conductivity is highly negative. These results give deeper insights into the mechanism of IWWS development and an advanced explanatory model will be presented. The generated knowledge provides the tool for a better understanding of the phenomena of IWWS development and enables the papermaker to optimize the production processes accordingly.

## Acknowledgements

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4. Eriksson, L., et al., *Design of Experiments: Principles and Applications*. Umetrics Academy. 2008, Umea, Sweden: MKS Umetrics AB. 459.



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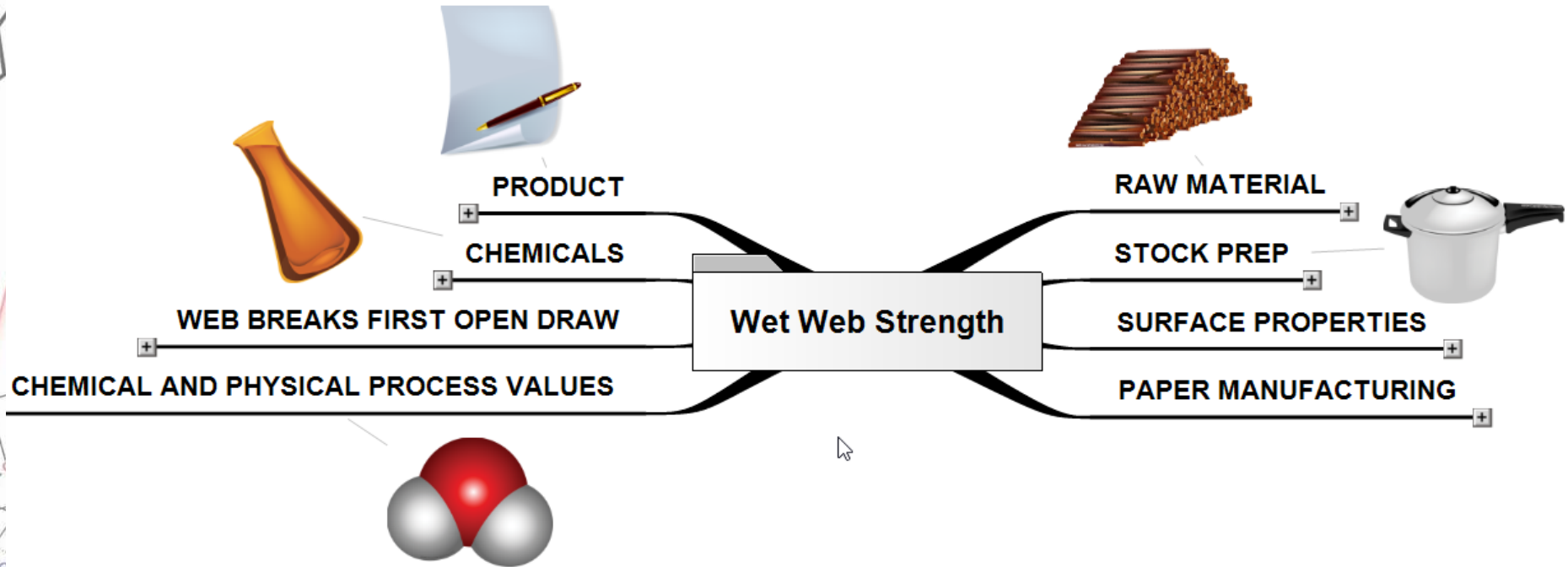
# DEEPER INSIGHTS INTO THE MECHANISM OF WET WEB STRENGTH (WWS) DEVELOPMENT

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# INTRODUCTION



# CONTENT

- Hypothesis
  - Capillary forces
  - Frictional connection and form fit
  - Fiber swelling and gelation of fiber surfaces
- Trial results
  - hornification
  - salt content / conductivity
- Conclusion

# HYPOTHESIS (Erhard 2010)

## 1. STAGE: Dry content < ~25 %

(Kendall 2001,  
Paavilainen 1993, Weise 1996)

- capillary forces between fibers,
- frictional connection and form fit of fibers,
- fiber collapse is starting and
- initial fiber approach.

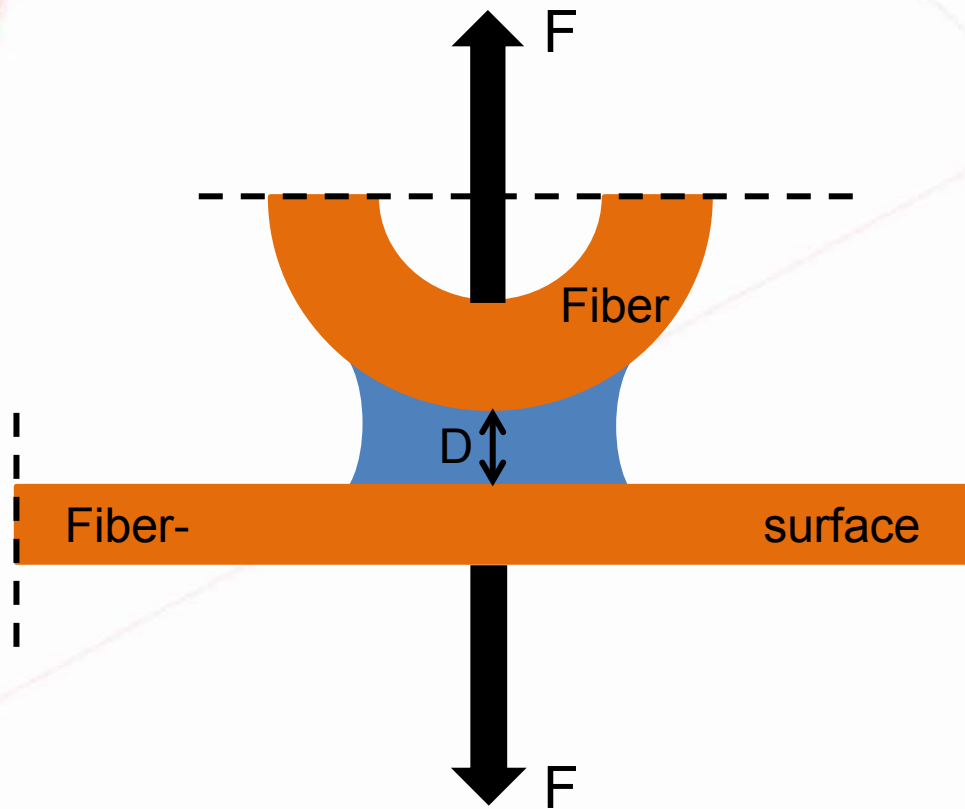
## 2. STAGE: Dry content ~25 - ~50%

(McKenzie 1984, Pelton 1993,  
Wagberg 1997, Nilsson 2000)

- A flexible, visco-elastic and soft fiber is needed for inter fiber bonding
  - diffusion of microfibrils, polymer chains and polyelectrolytes from wood polysaccharides, especially from xylan
- H-bridge-bonds
- Van der Waals bonds

# 1. STAGE: CAPILLARY FORCES

Dryness  
< 25%



$$F \sim \frac{1}{D^2}$$

**D:** water film thickness

With increased dewatering **D** is getting smaller and the capillary force increases.

# 1. STAGE: CAPILLARY FORCE

Dryness  
< 25%

Research Question:

- This model acts on the assumption of rigid bodies.
- Surfaces have to be smooth to develop proper adhesion.

**BUT**

- Cellulose fibers are flexible and elastic!
- The fiber surface is rough!

# 1.STAGE: RESEARCH QUESTION

## CAPILLARY FORCE

Dryness  
< 25%

- In-elastic, hornificated fibers should increase the capillary forces
  - High lignin content
  - Dried fibers
  - Low fiber swelling
- Smooth fiber surface
  - Virgin fibers,
  - Unbleached hardwood pulp



# 1. STAGE: FRICTIONAL CONNECTION AND FORM FIT ARE DEPENDING ON ..

Dryness  
< 25%

- initial approach of fibers
- entanglement of fibers
- roughness of fibers
- rigidity of fibers

# 1. STAGE: UN-SWOLLEN FIBER

Dryness  
< 25%



For example due to:

- hornification of fibers
  - Dried pulp
  - Recycled pulp/paper
- high pulp suspension conductivity

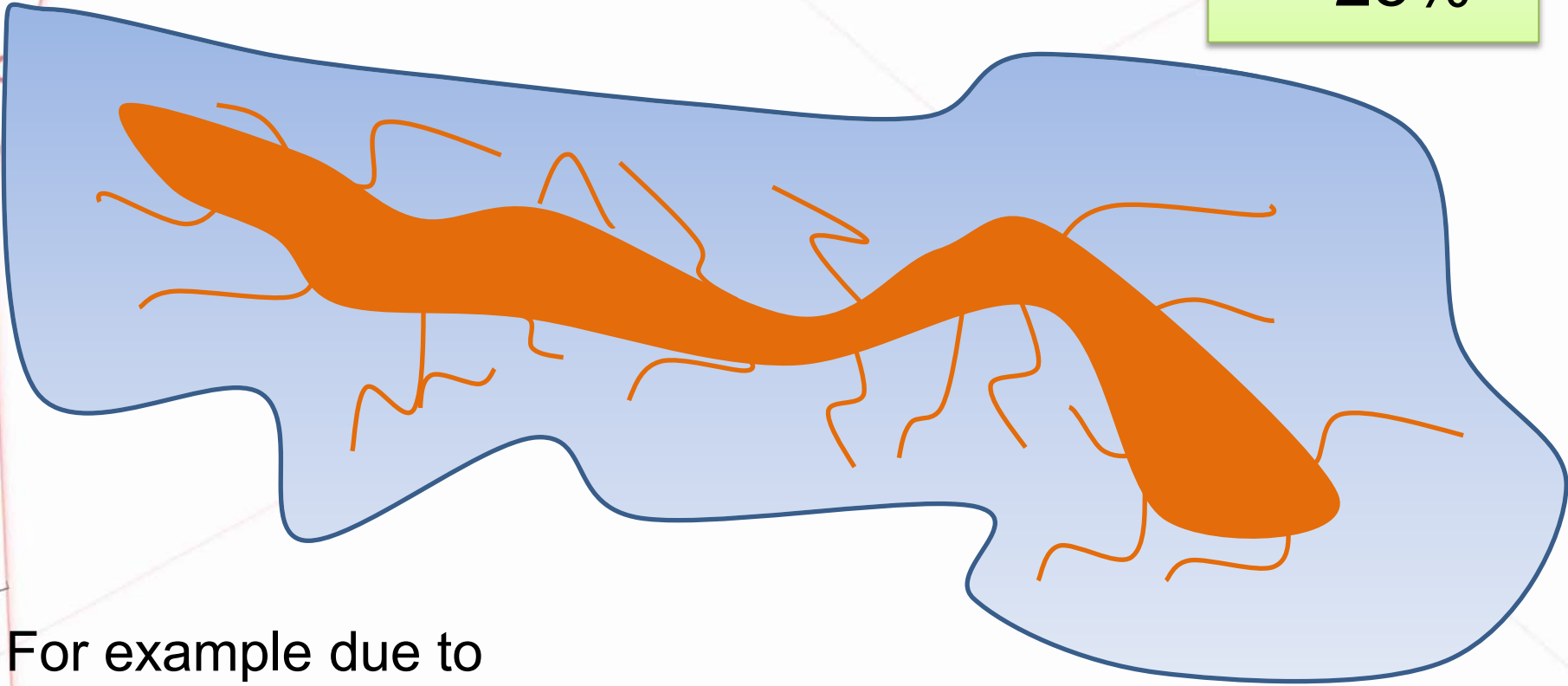
## 2. STAGE: FLEXIBLE, VISCOELASTIC, SMOOTH FIBER SURFACE...

Dryness  
> 25%

- Plastic flow of the fiber surface (Persson 2013)
- Needed conditions:
  - High degree of swelling
  - Low Young's modulus of single fiber
  - Low amount of lignin
  - High degree of refining
  - Many fibrils
  - High water retention value

## 2. STAGE: SWOLLEN FIBER

Dryness  
> 25%

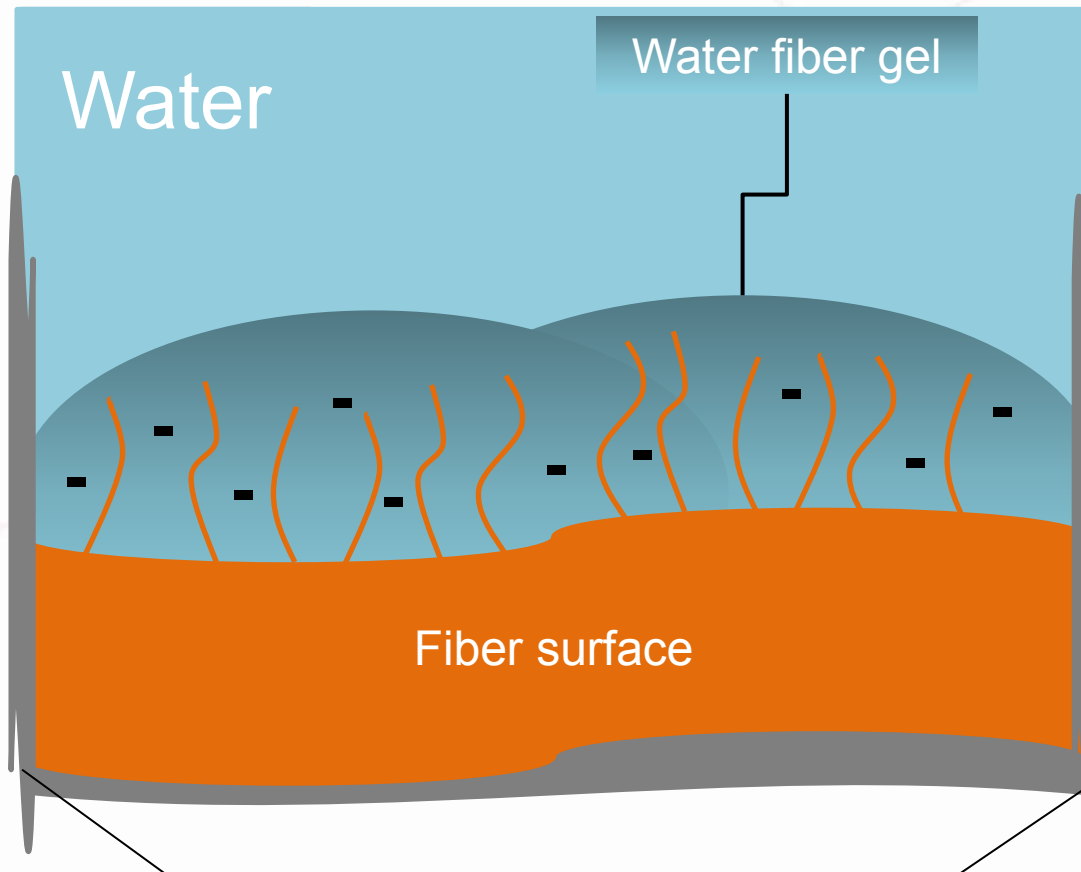


For example due to

- Low pulp suspension conductivity
- Never dried pulp

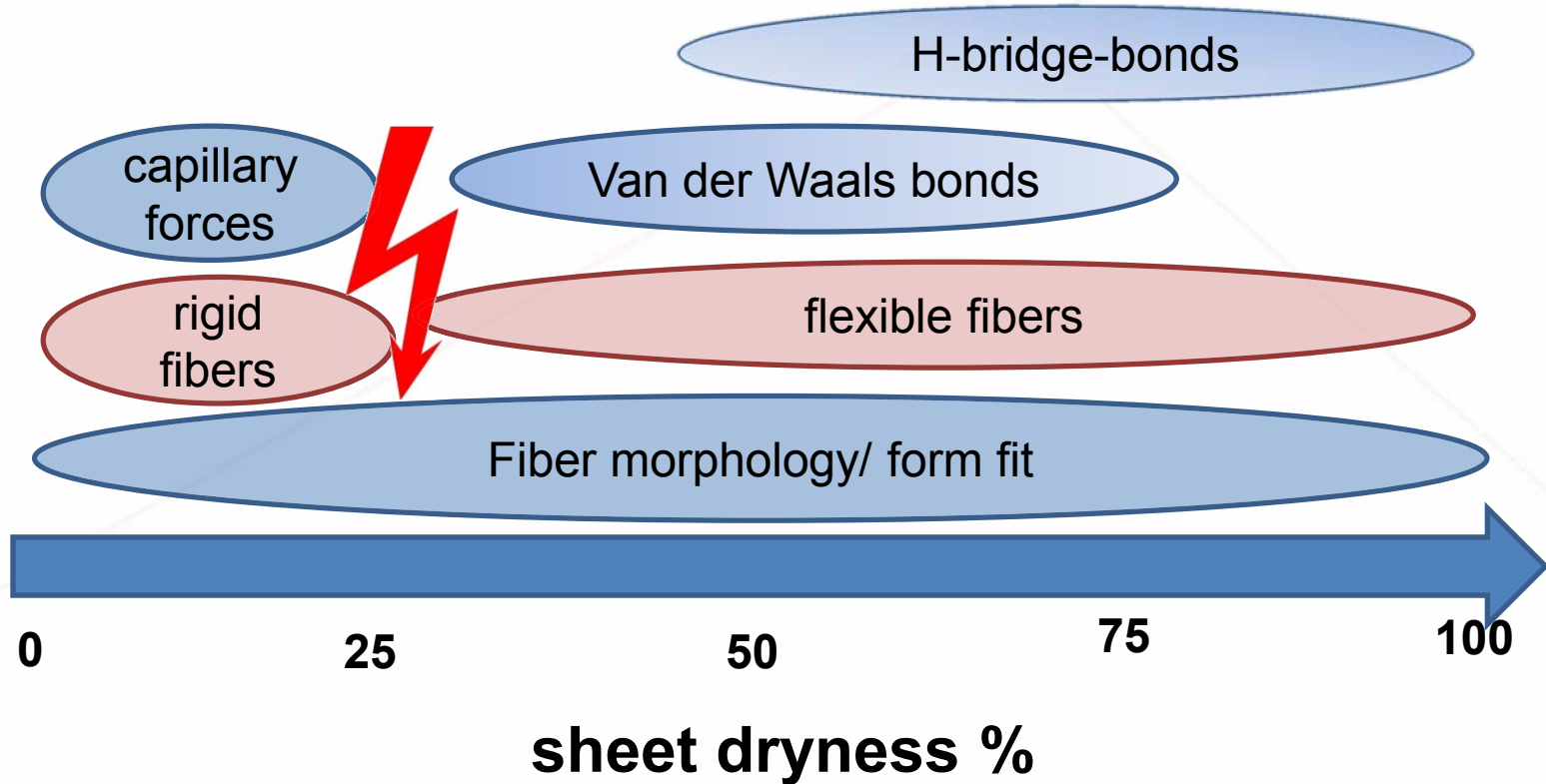
# GEL STRUCTURE: surface interaction: fiber-water

Dryness  
> 25%

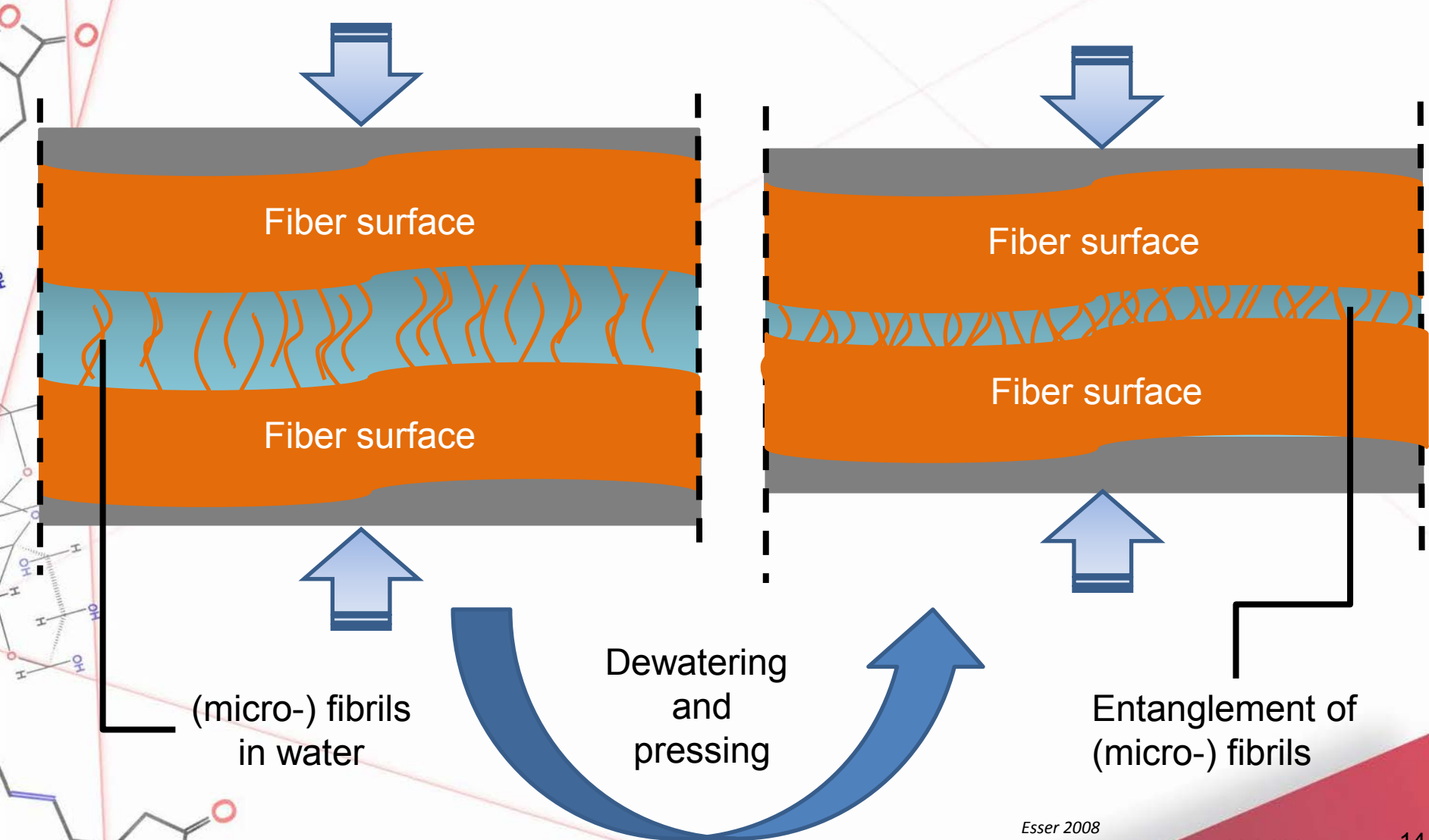


Cutting edge

# STRENGTH DEVELOPEMENT MODEL



# STRENGTH DEVELOPMENT: dewatering and pressing

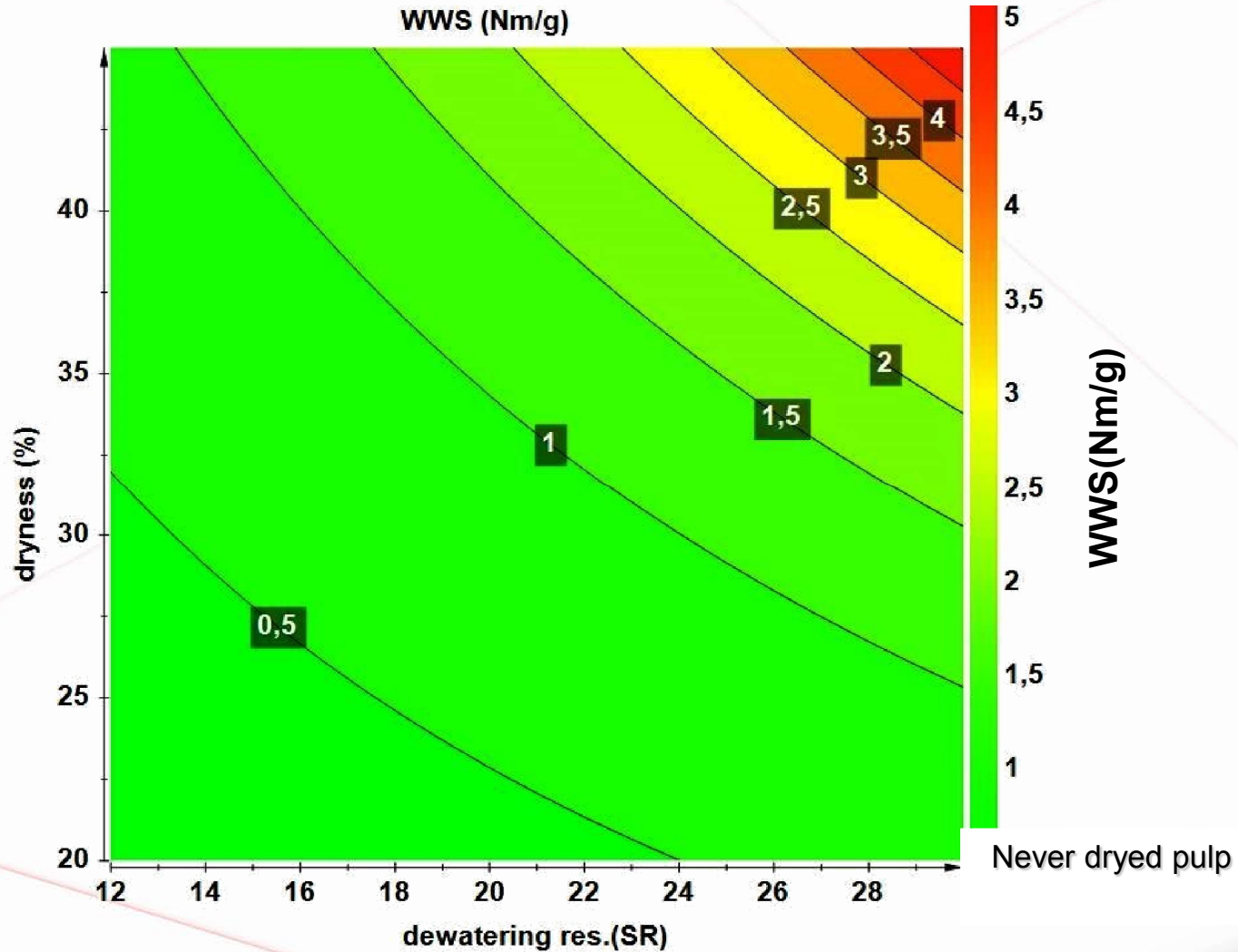


# APPROACH

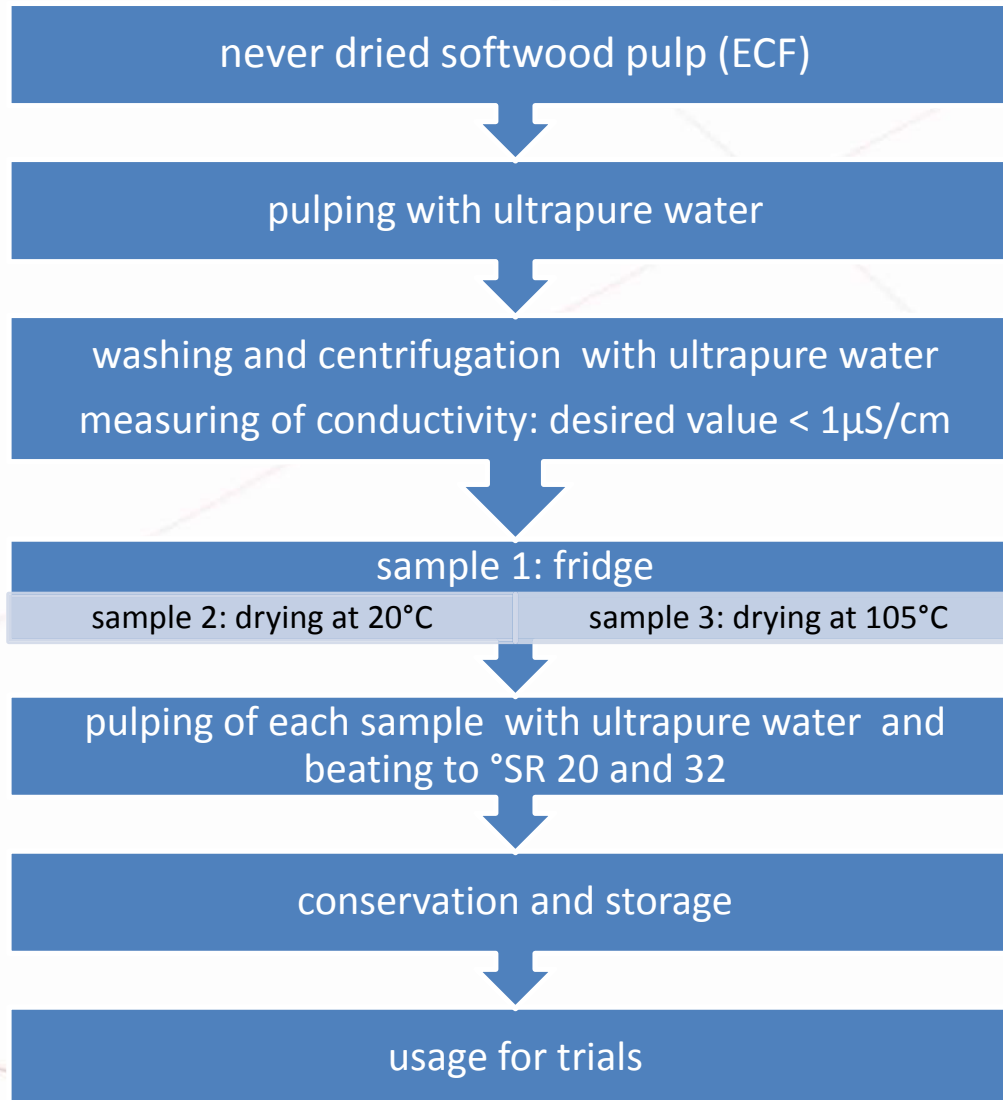
- Show the difference between the mechanisms at dryness levels  $< 25\%$  and  $> 25\%$ 
  - capillary forces via hornification and
  - response on salt content / conductivity.
- ▶ Show a possible weighing of the impact factors.



# SR vs. DRYNESS

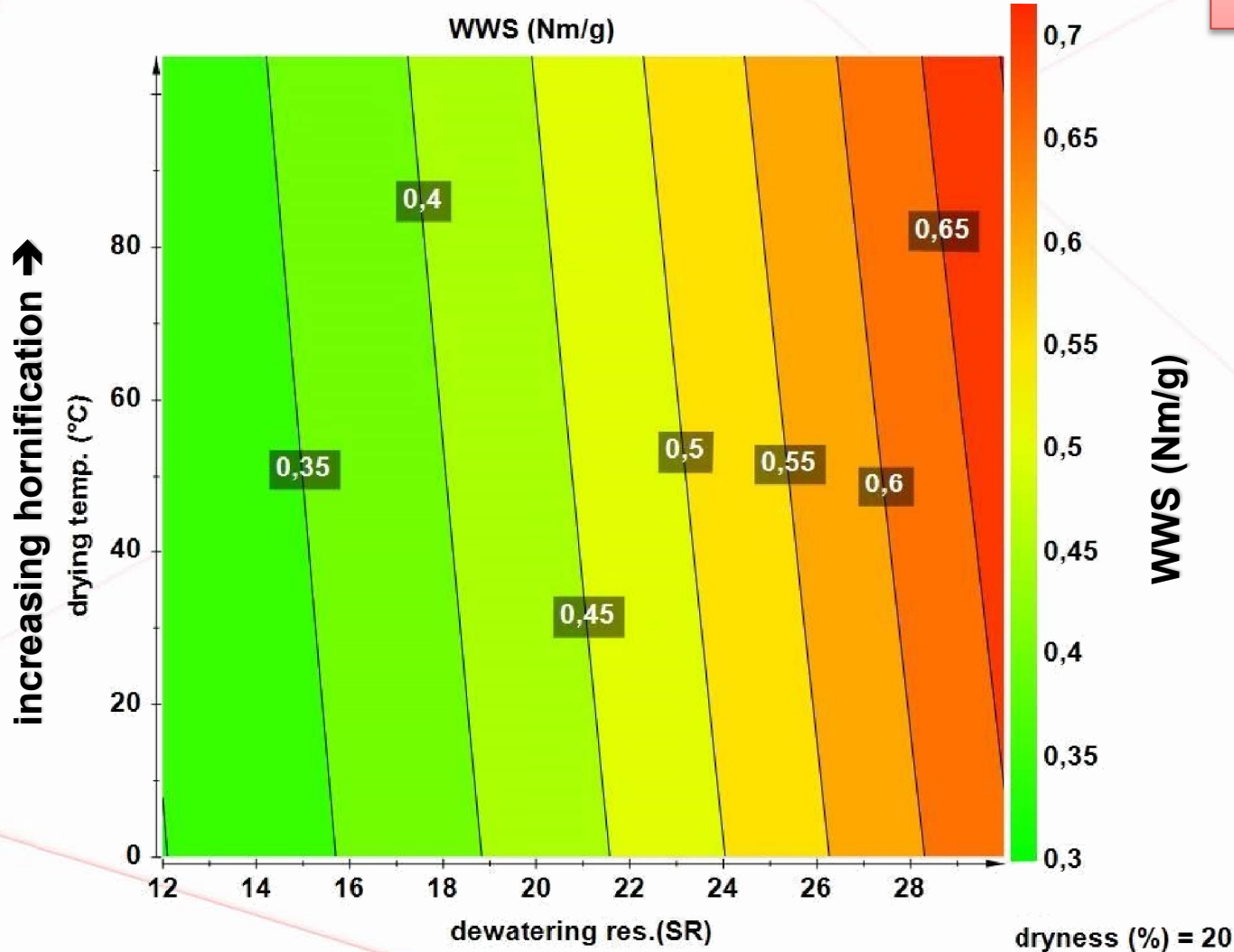


# SAMPLE PREPARATION FOR HORNIFICATION



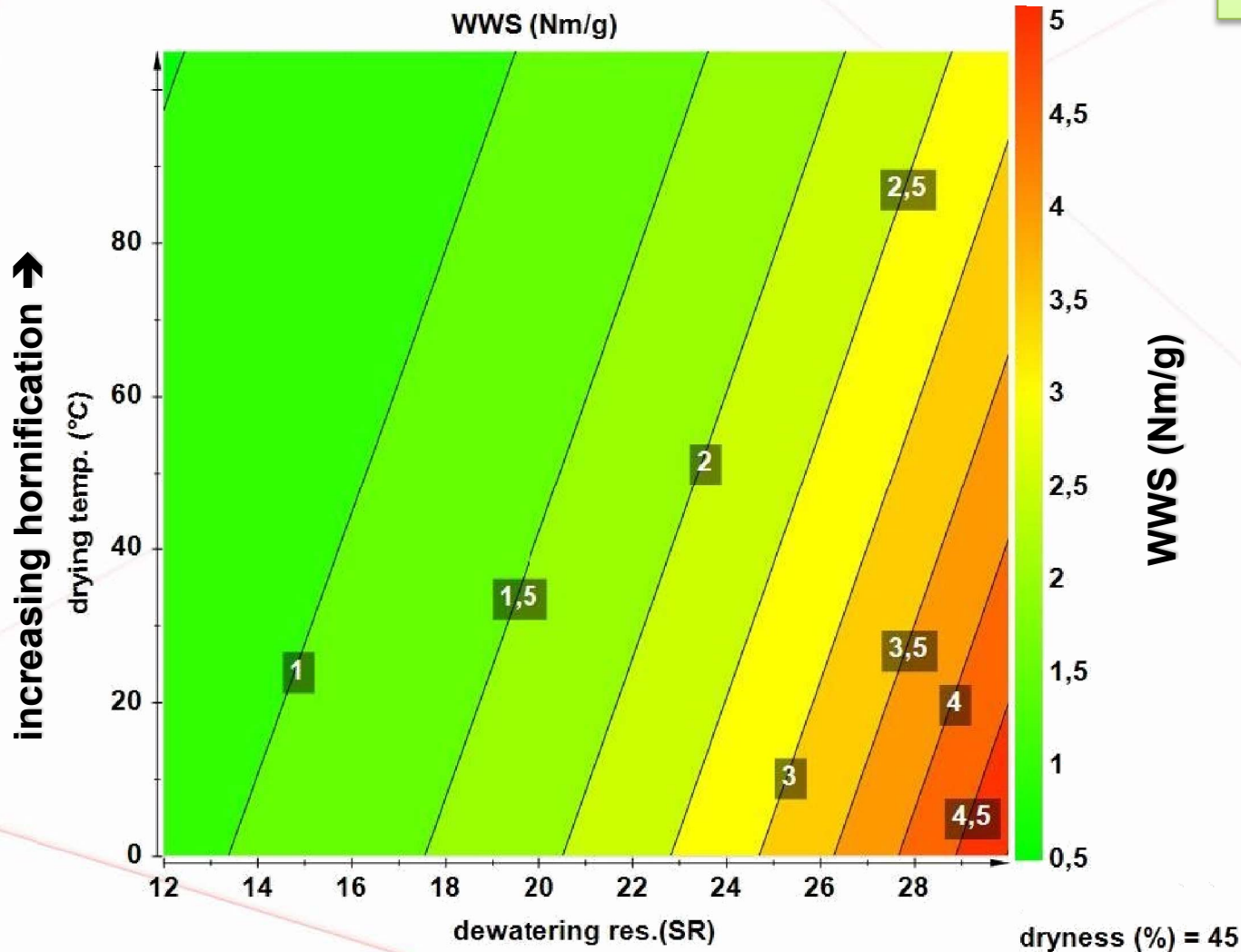
# HORNIFICATION vs. SR

Dryness  
< 25%



# HORNIFICATION vs. SR

Dryness  
> 25%

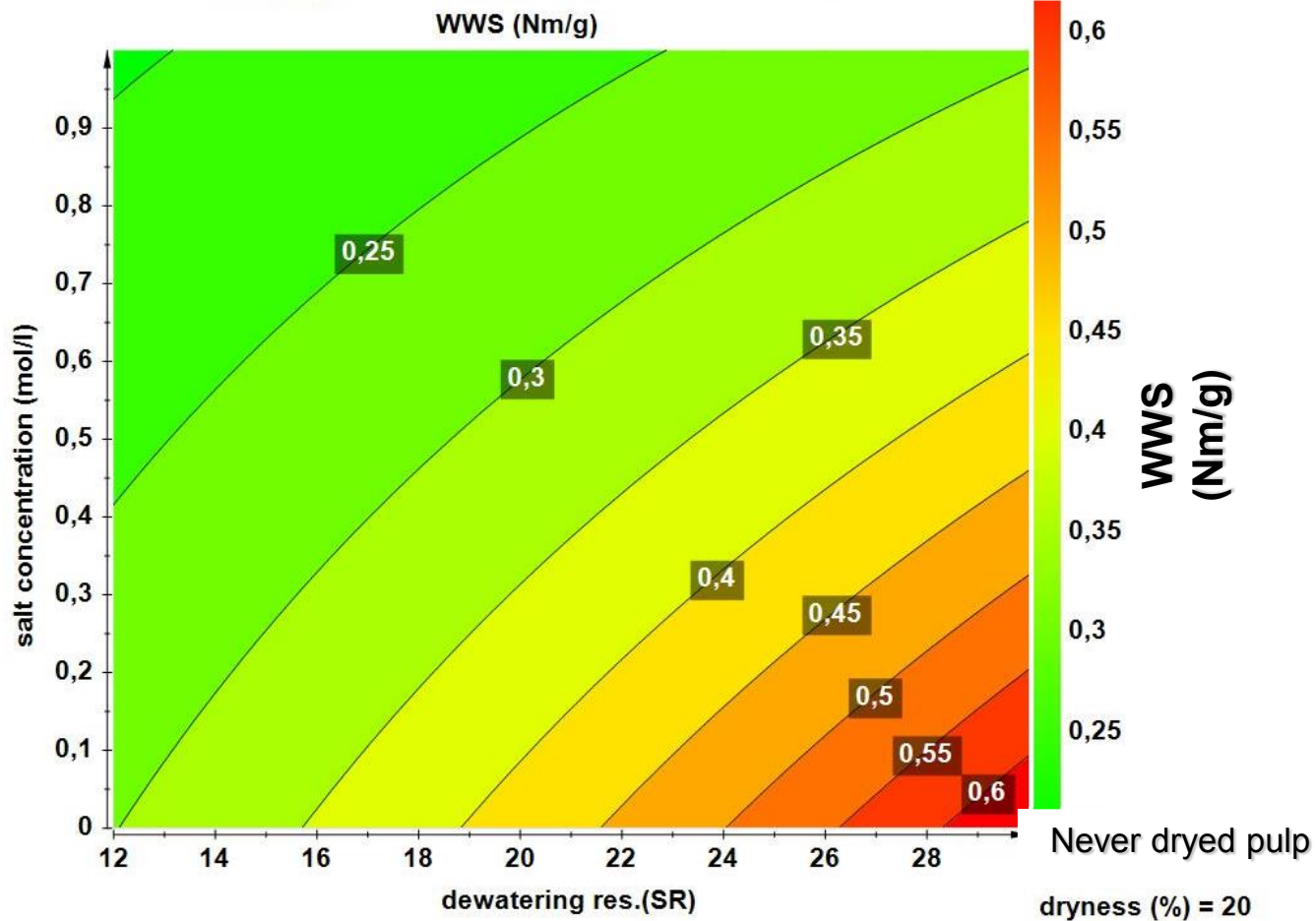


# INTERMEDIATE RESULTS: Hornification

- Hornification has a slightly positive effect on WWS at low dryness levels.
- Hornification has a negative effect on WWS at high dryness levels.

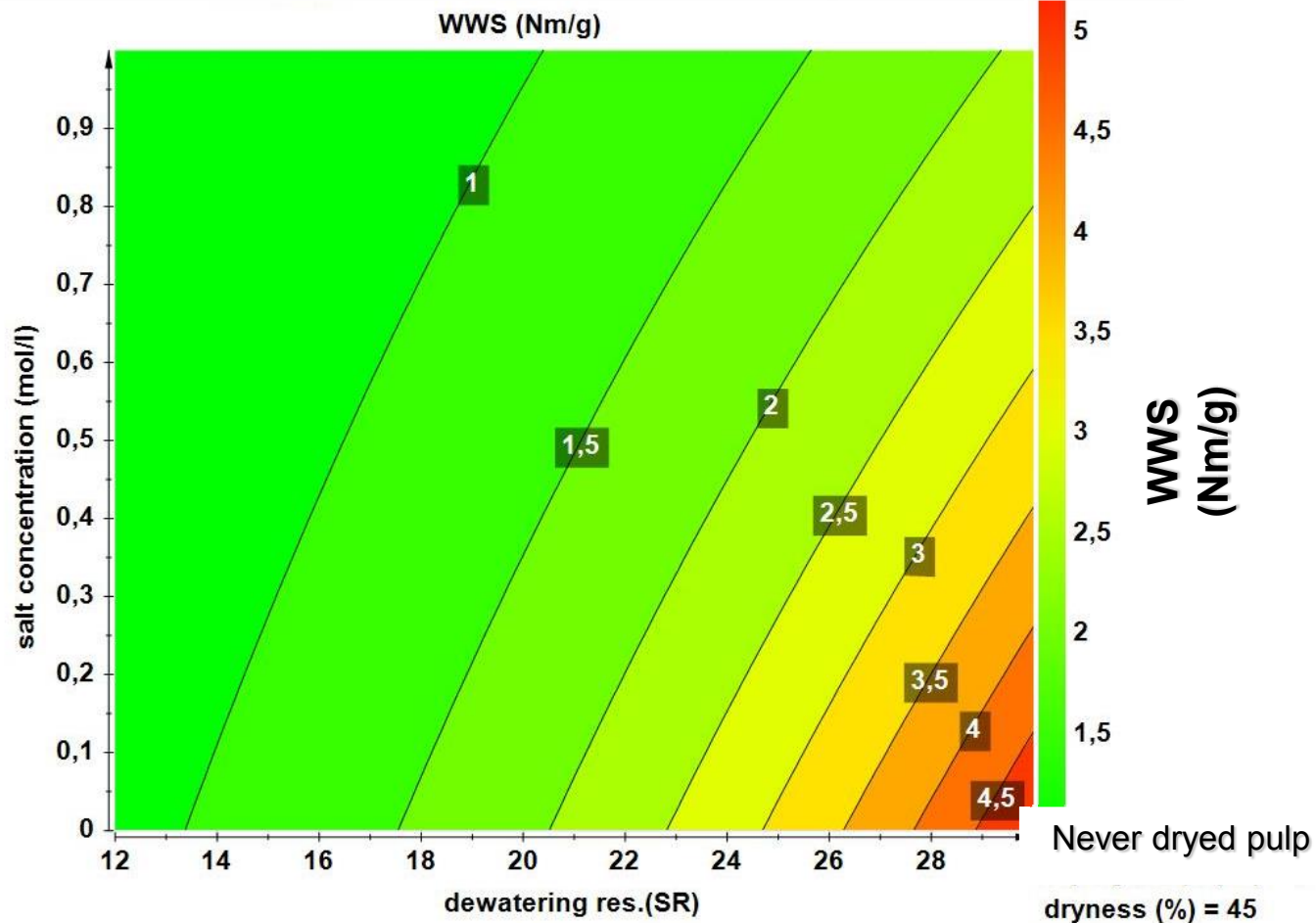
# SALT CONTENT (NaCl) vs. SR

Dryness  
< 25%



# SALT CONTENT (NaCl) vs. SR

Dryness  
> 25%



# INTERMEDIATE RESULT:

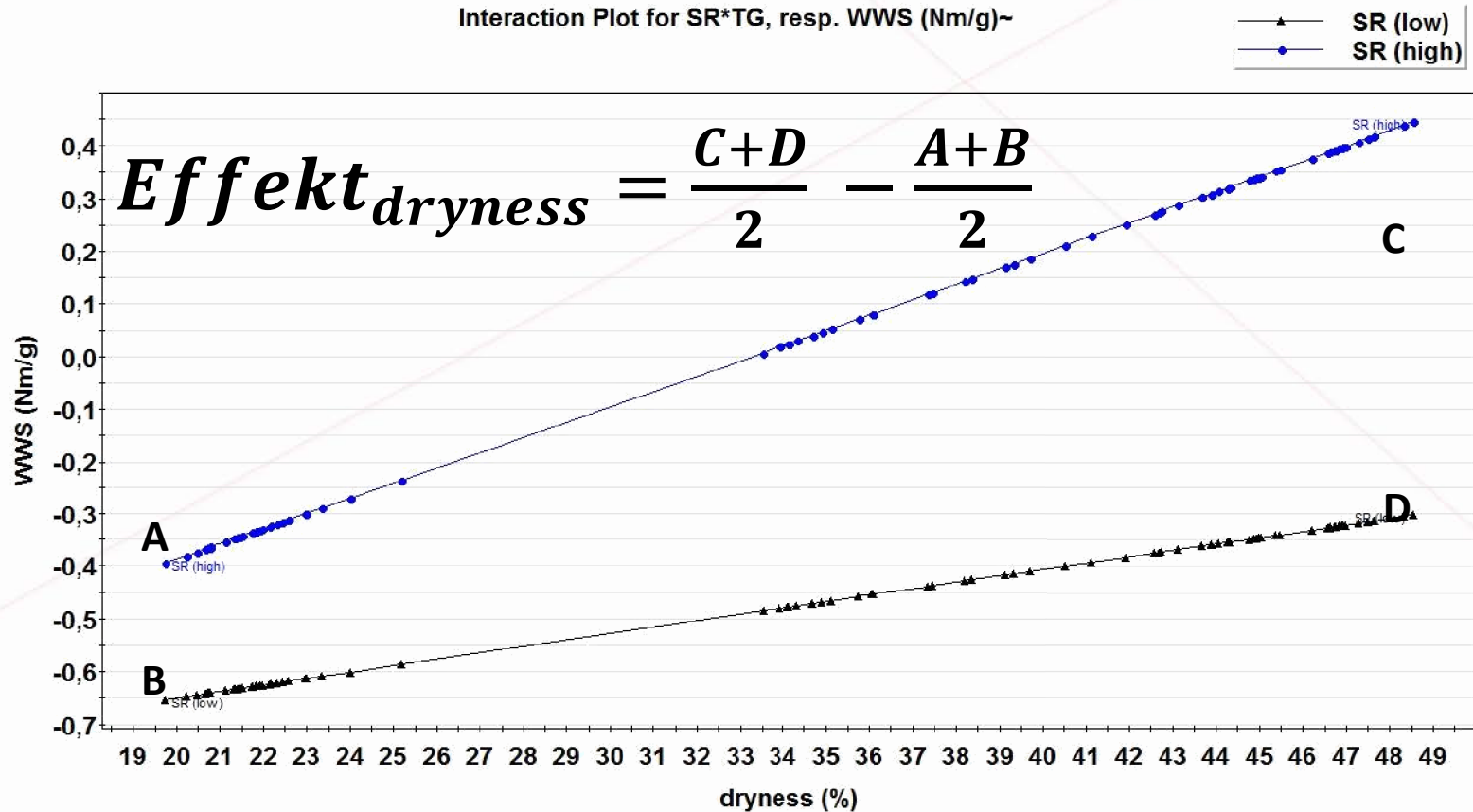
## Salt Content / Conductivity

- Salt concentration / conductivity has in any case a negativ effect on WWS.
- There is no significant effect on capillary forces.



# CALCULATION OF EFFECTS

Interaction Plot for SR\*TG, resp. WWS (Nm/g)~

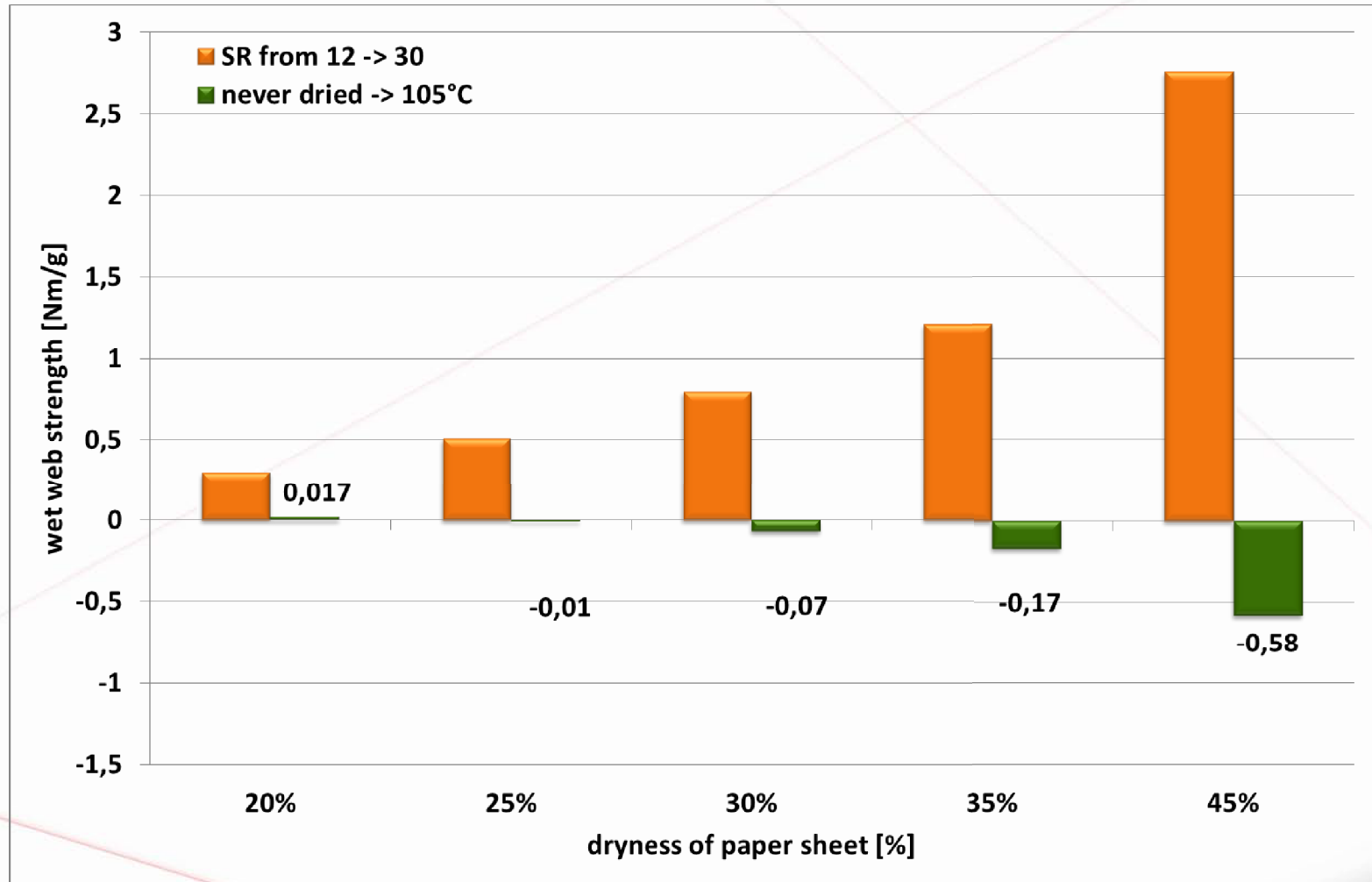


N=86  
DF=75

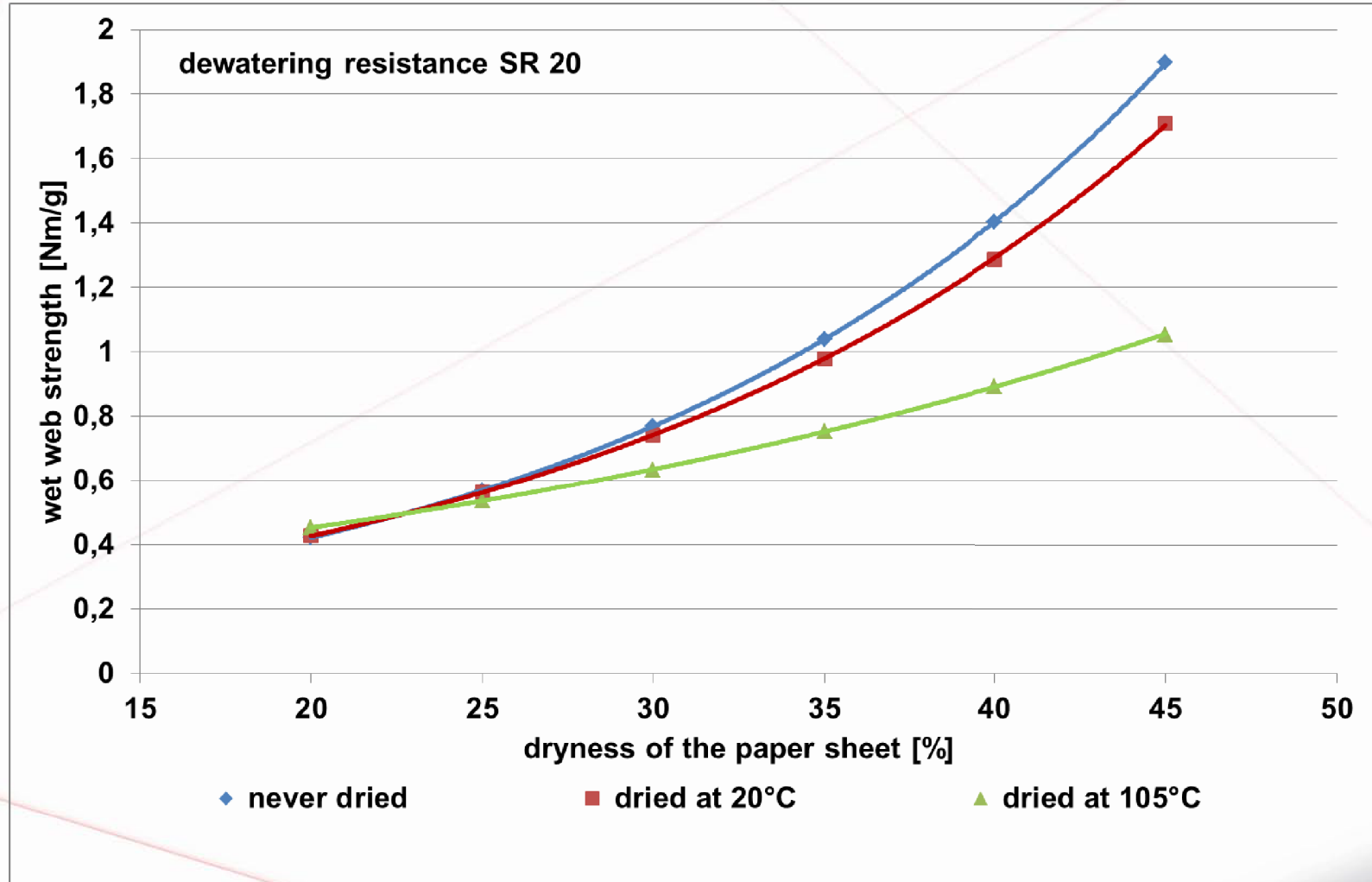
R2=0,984  
Q2=0,979

RSD=0,05596

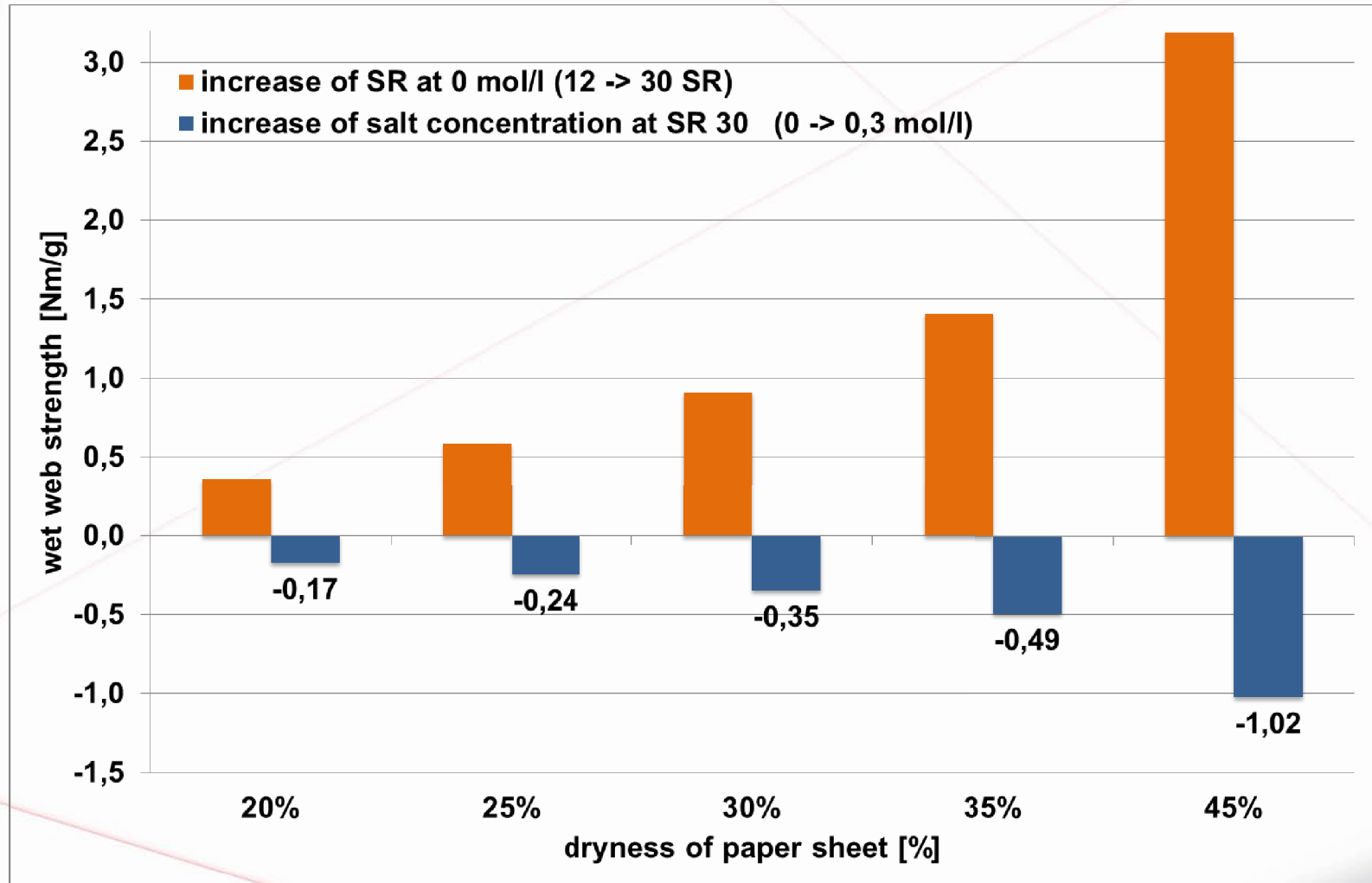
# WEIGHING OF HORNIFICATION



# DRYNESS LEVEL vs. HORNIFICATION



# WEIGHING OF SALT CONTENT



# HYPOTHESIS AND RANKING

## 1. Dry content < ~25 %

(Kendall 2001,  
Paavilainen 1993, Weise 1996)

1. frictional connection and form fit of fibers,
2. capillary forces between fibers,
3. fiber collapse is starting and
4. initial approach of fibers.

## 2. Dry content ~25 - ~50%

(McKenzie 1984, Pelton 1993,  
Wagberg 1997, Nilsson 2000)

- ✓ A flexible, visco-elastic and soft fiber is needed for inter fiber bonding
  - ✓ diffusion of microfibrils, polymer chains and polyelectrolytes from wood polysaccharides, especially from xylan
- ✓ H-bridge-bonds
- ✓ Van der Waals bonds

# CONCLUSION

## Paper strength at dryness levels

- **< 25 %** is mainly influenced by means of the fiber morphology.
  - Promoted by rigid and hornificated fibers with low water retention value.
- **> 25 %** is mainly influence by the fiber flexibility.
  - Increasing the amount of fiber contact points for H-bridge-bond generation.

# APPLICABILITY

Important questions to be answered before and during the optimization process:

- What dryness levels are reached at the first open draw?
- Which mechanism should/must be addressed for optimization?
- Pay attention to possible interactions in the process e.g.
  - Fiber swelling and drying efficiency.
  - Conductivity and additive efficiency.
  - ....

# COOPERATION MATRIX – BFS INF 1000\_11



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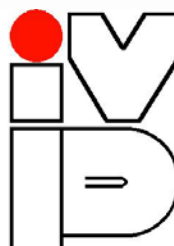


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