Analysis of Web Wrinkling in an Accumulator

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Kimberly-Clark

GlobalNonwovens
The Fabric of Our Future

Overview

- Accumulators
- Finite Element Modeling
- Experimental Results
- Comparison of Results
- Summary
- Acknowledgments
- References
- Questions

Accumulators

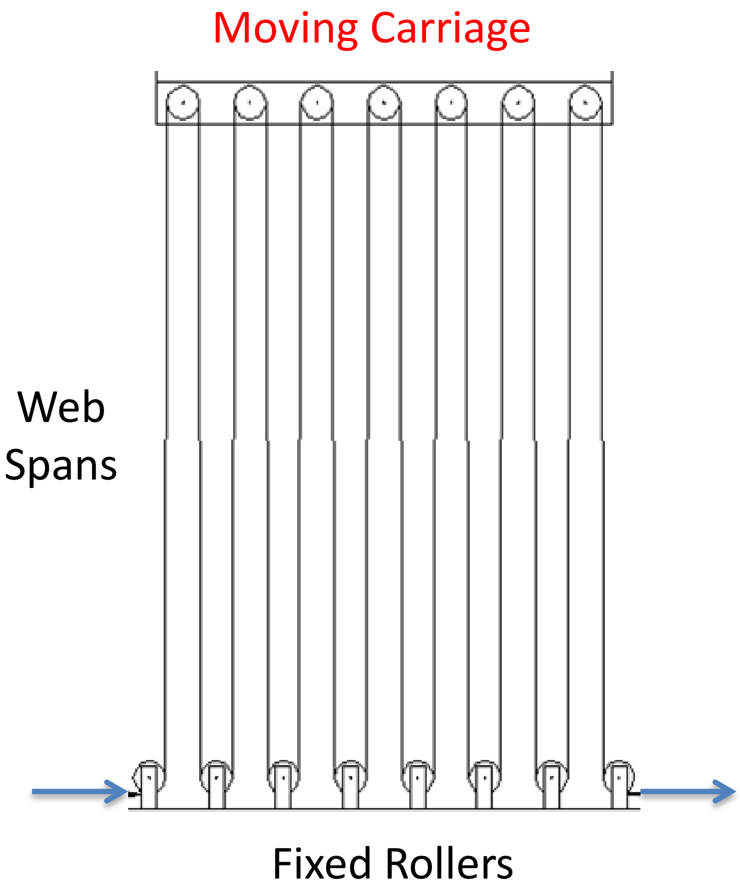
IWEB 2009 Info [1]

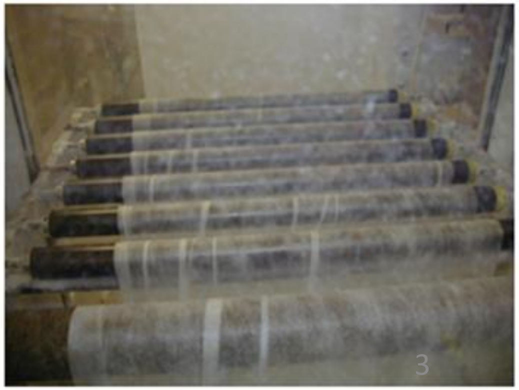
Definition

- Web storage device
- Winders / Unwinds
- Lower fixed rollers
- Moving carriage

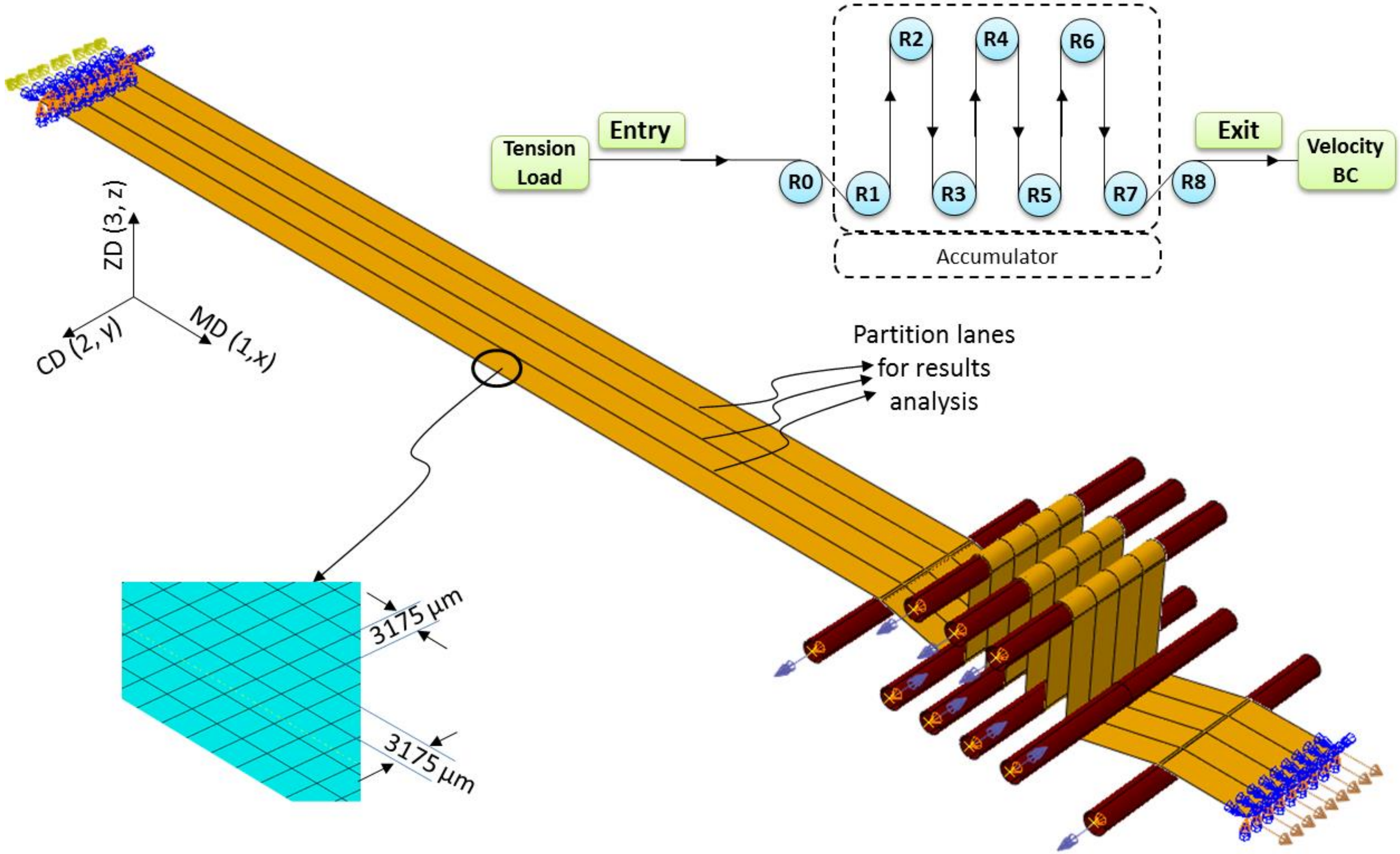
Top 10 Research Needs:

1. Validated computer models are needed
2. Air / web interaction within a accumulator
3. **Non-ideal webs in accumulators**
4. **Multi-span interaction: tension, wrinkles, lateral**
5. **Misalignment of a moving carriage**
6. High speed –vs- traction for a porous web
7. Larger rollers –vs- wrinkles –vs- roller mass
8. Should we drive rollers in the accumulator? How?
9. What is the best general arrangement?
10. How should the accumulator be controlled?





Finite Element Model – Set Up



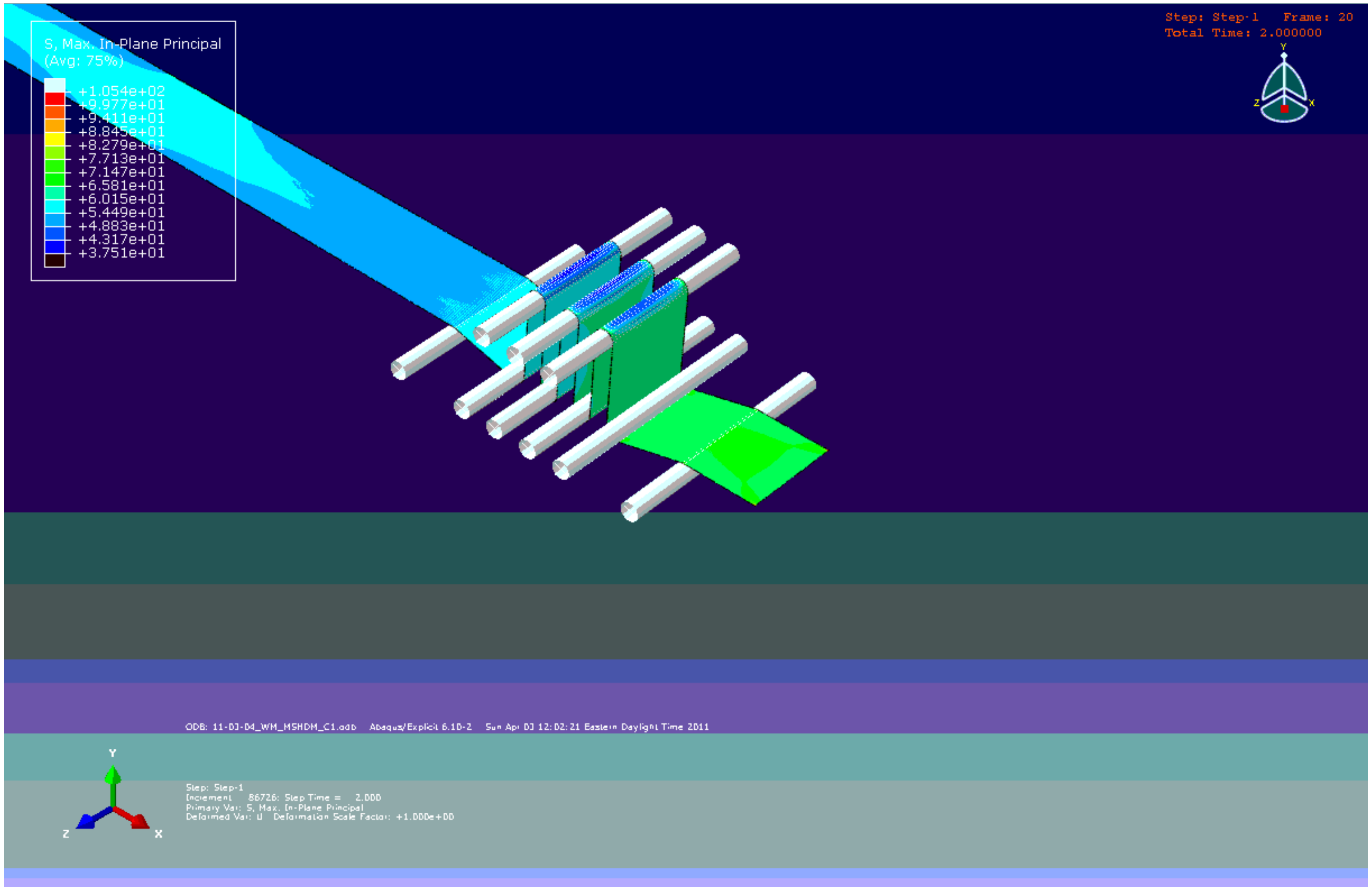
Number of Elements = 318,994
Number of Degrees of Freedom = 964,845

Simulation Cases

- Case 1: Perfect Web / Perfect Accumulator
- Case 2: Perfect Web / Imperfect Accumulator
  - Case 2B: Perfect Web / Individual Roller Misaligned
- Case 3: Imperfect Web / Perfect Accumulator
- Case 4: Imperfect Web / Imperfect Accumulator

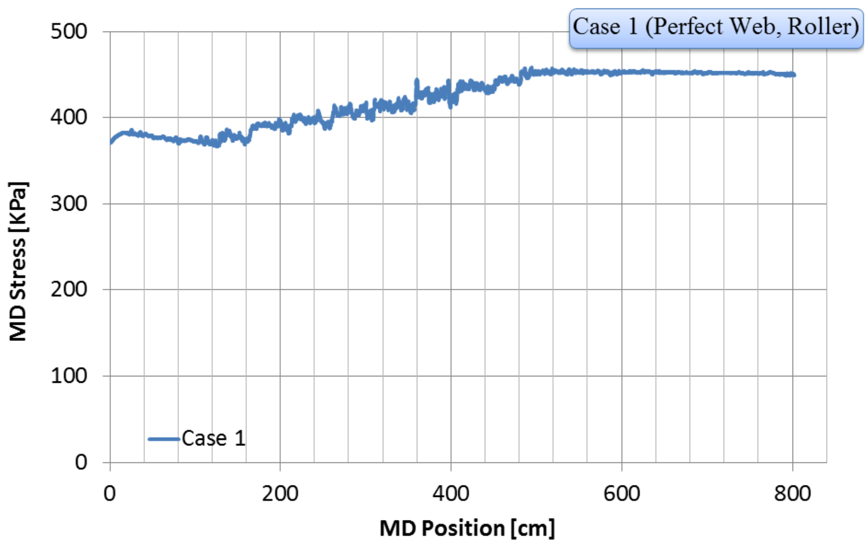
Basis Weight	17.0 gsm	Length	790.1 cm
Modulus MD	62.8 MPa	Width	40.64 cm
Modulus CD	14.3 MPa	Thickness	203.2 µm
Poisson's Ratio	0.4	Roller Diameter	7.62 cm
COF	0.22	Enter Tension	0.75 N/cm

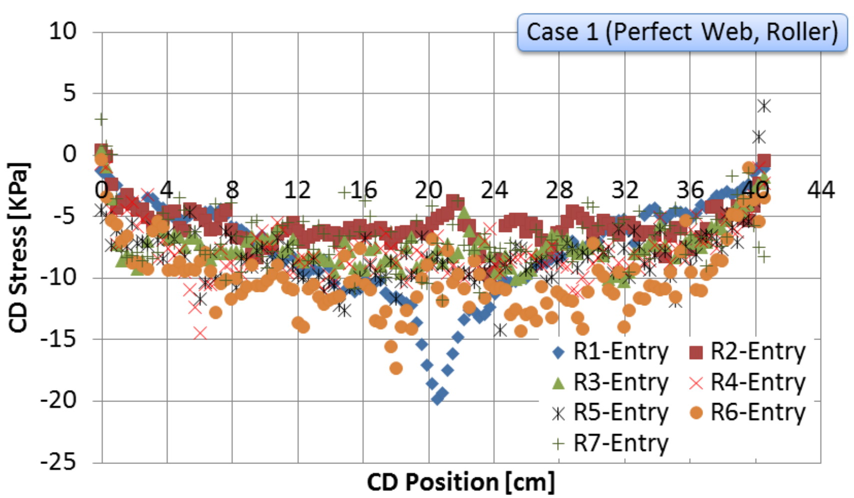
Case 1: Perfect Web / Perfect Accumulator



Maximum In-Plane stress shown in the video

Case 1: Perfect Web / Perfect Accumulator

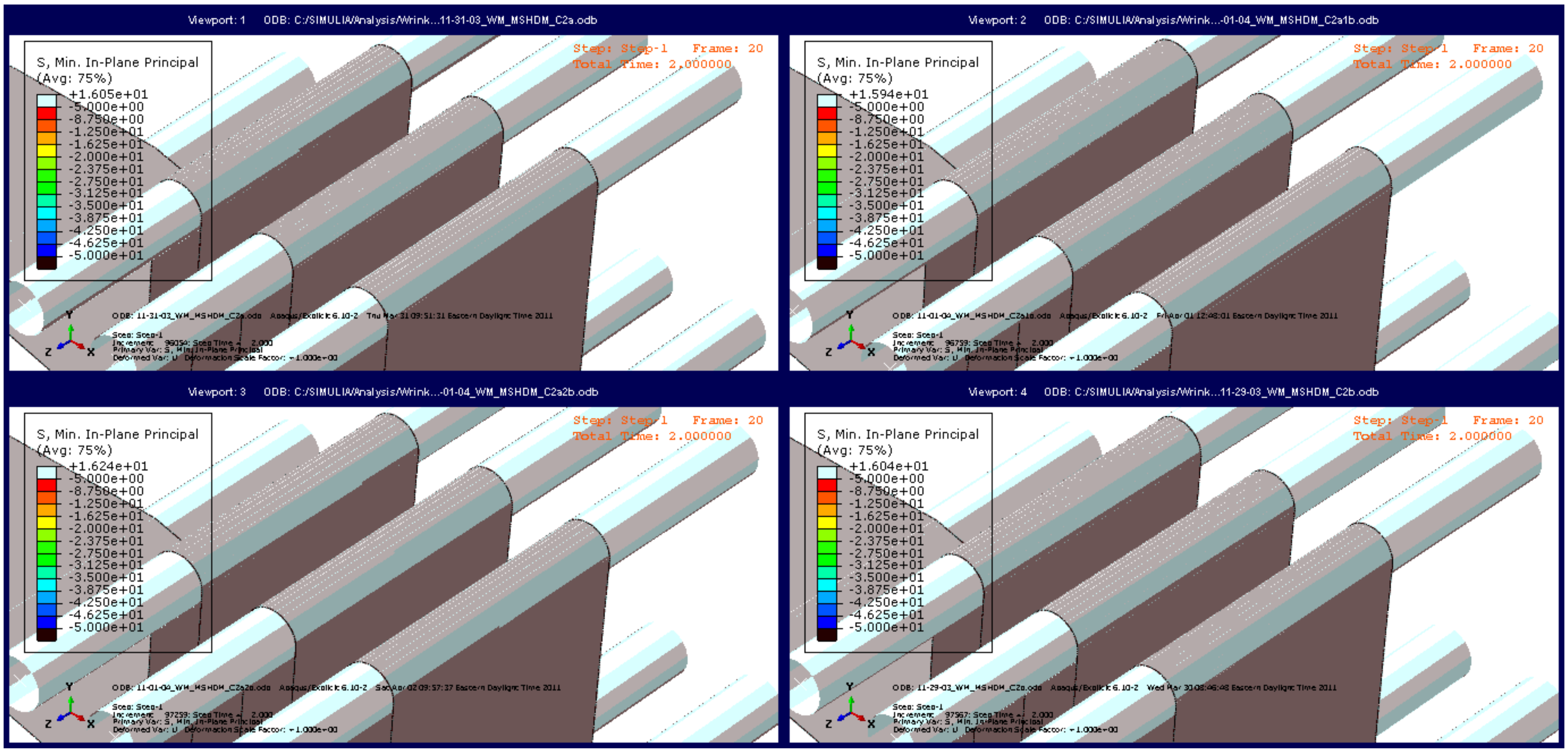




- MD Stress along the center of the web increases from 0.75 to 0.92 N/cm due to bearing drag from nine rollers
- CD in-plane stressed at the entry of each roller within the accumulator are shown
- The web is under compressive stress at each span due to Poisson contraction
- The critical stress required to form a wrinkles on the roller (Good et al [2]) is 94 Kpa according to the following equation

$$\sigma_{ycr} = -\frac{h}{R} * \sqrt{\frac{E_x \ E_y}{3\left(1 - \nu_{xy}\nu_{yx}\right)}}$$

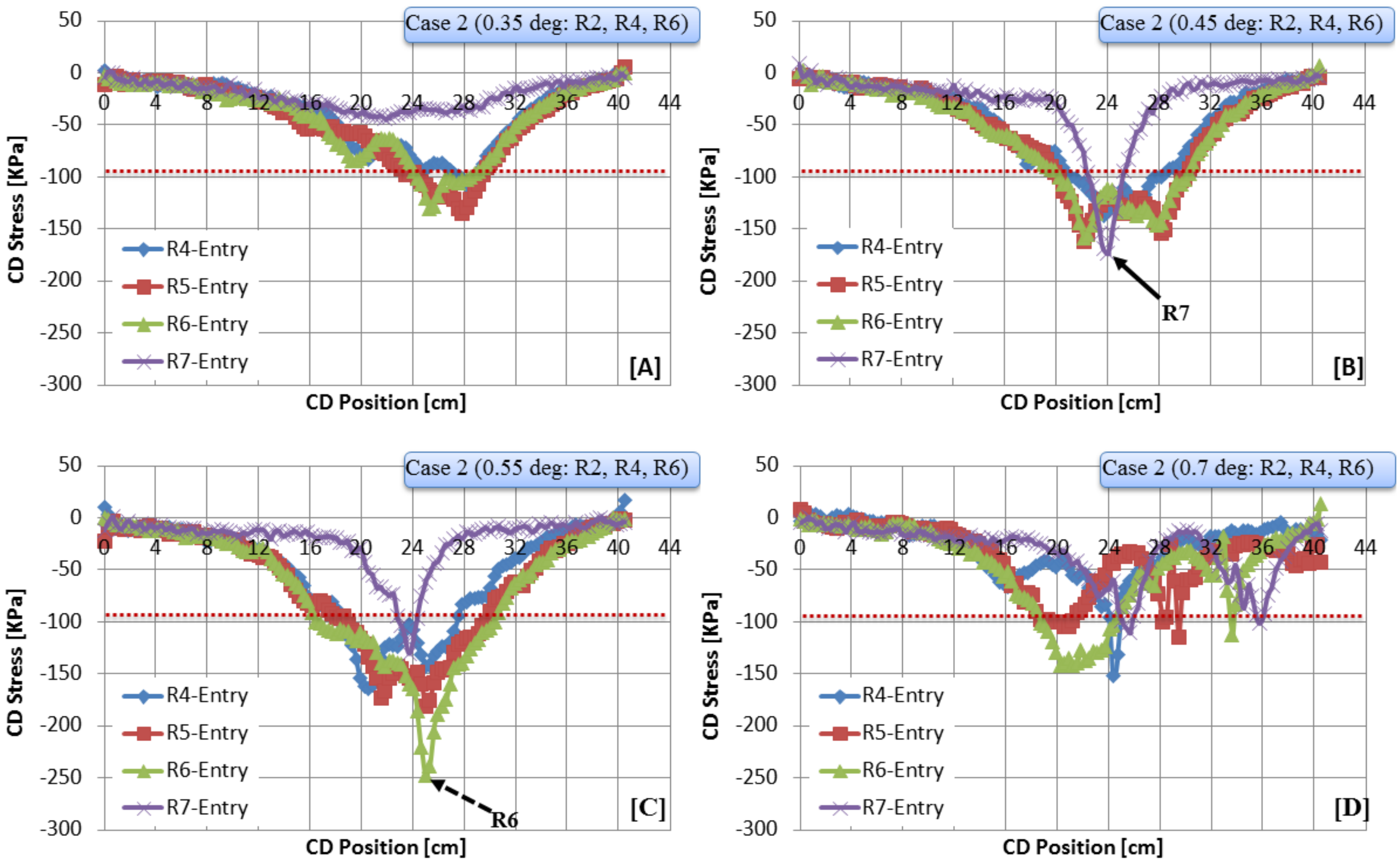
Case 2: Perfect Web / Imperfect Accumulator



Minimum In-Plane stress shown in the video

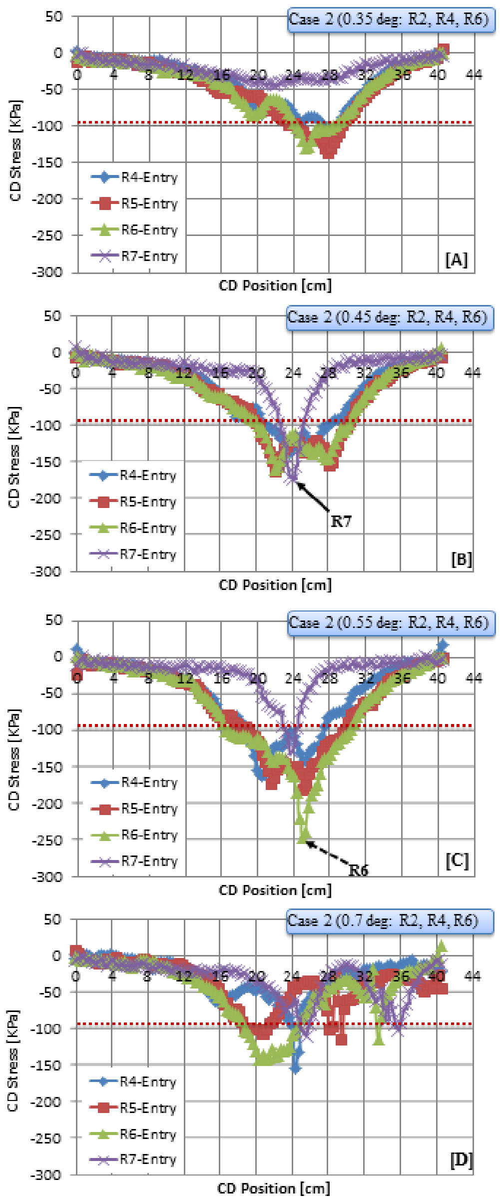
Case 2: Perfect Web / Imperfect Accumulator

Misalignment: 0.35˚, 0.45˚, 0.55˚, & 0.70˚



Graphs are shown for the last time step

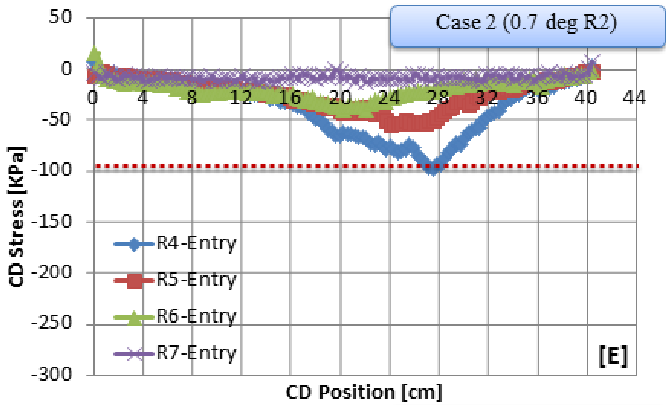
Case 2: Perfect Web / Imperfect Accumulator

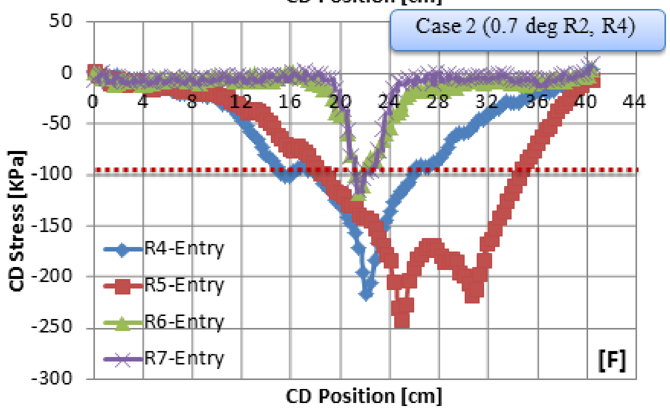


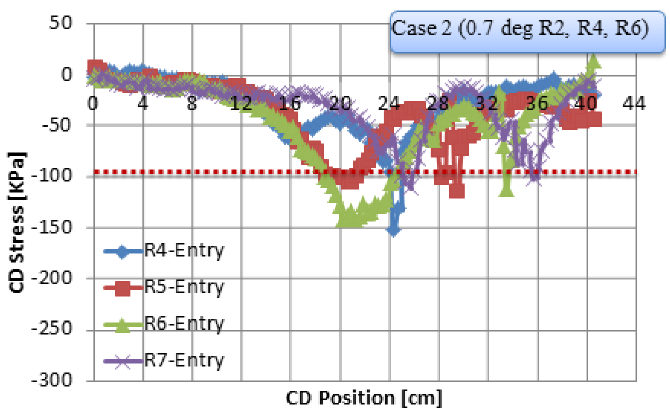
Case 2: Summary

- The web steers toward the slack side.
- [A] 0.35˚ - the CD stress [140 Kpa] is well above the predicted 94 Kpa critical stress
- [B] 0.45˚- Intermittent wrinkles flow thru the accumulator but disappear later
- [C] 0.55˚- Wrinkles last longer.
  - Wrinkles about to form on R6. CD stress is ~250 Kpa.
  - Wrinkles observed on R7. CD stress is ~175 Kpa.
  - Once the instability occurs, the CD stresses drop.
- [D] 0.7˚- Persistent walking wrinkles on R4-R6. Note that the CD stress is even lower than at 0.55˚ [C]

Case 2B: Perfect Web Individual Rollers Misaligned

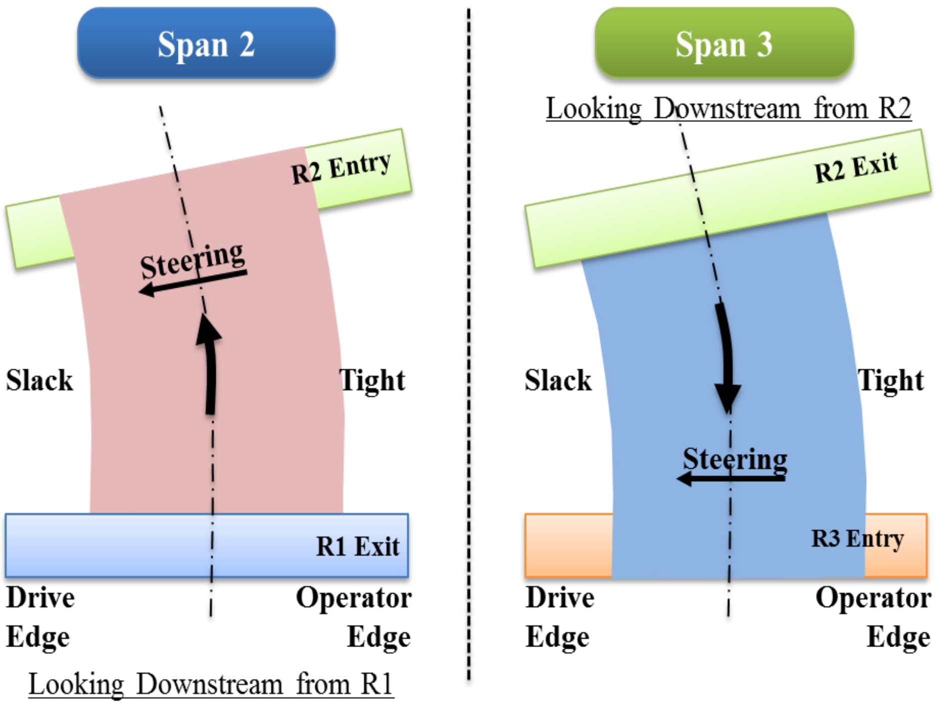






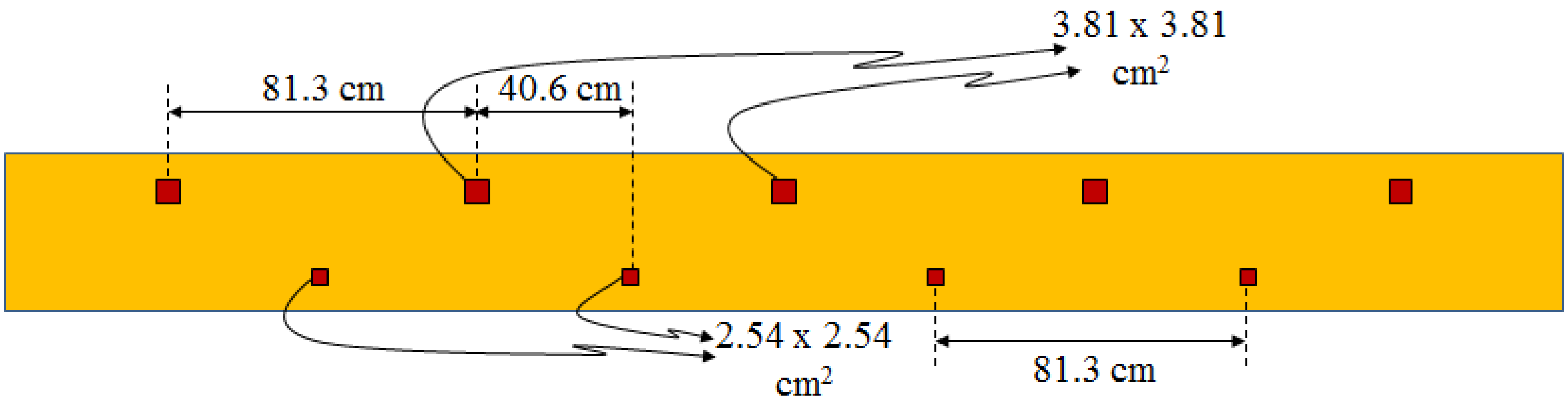
- Individual Rollers are consecutively misaligned
- When only R2 is misaligned 0.7˚, wrinkles do not form
- When both R2 and R4 are misaligned, wrinkles are present on R6 and R7
  - Observe stresses in R6, R7 < R4, R5
- When R2, R4 & R6 are misaligned - wrinkles form on R4 – R7 (previously discussed)
  - Stresses continue to drop post wrinkling

Misalignment & Steering Behavior



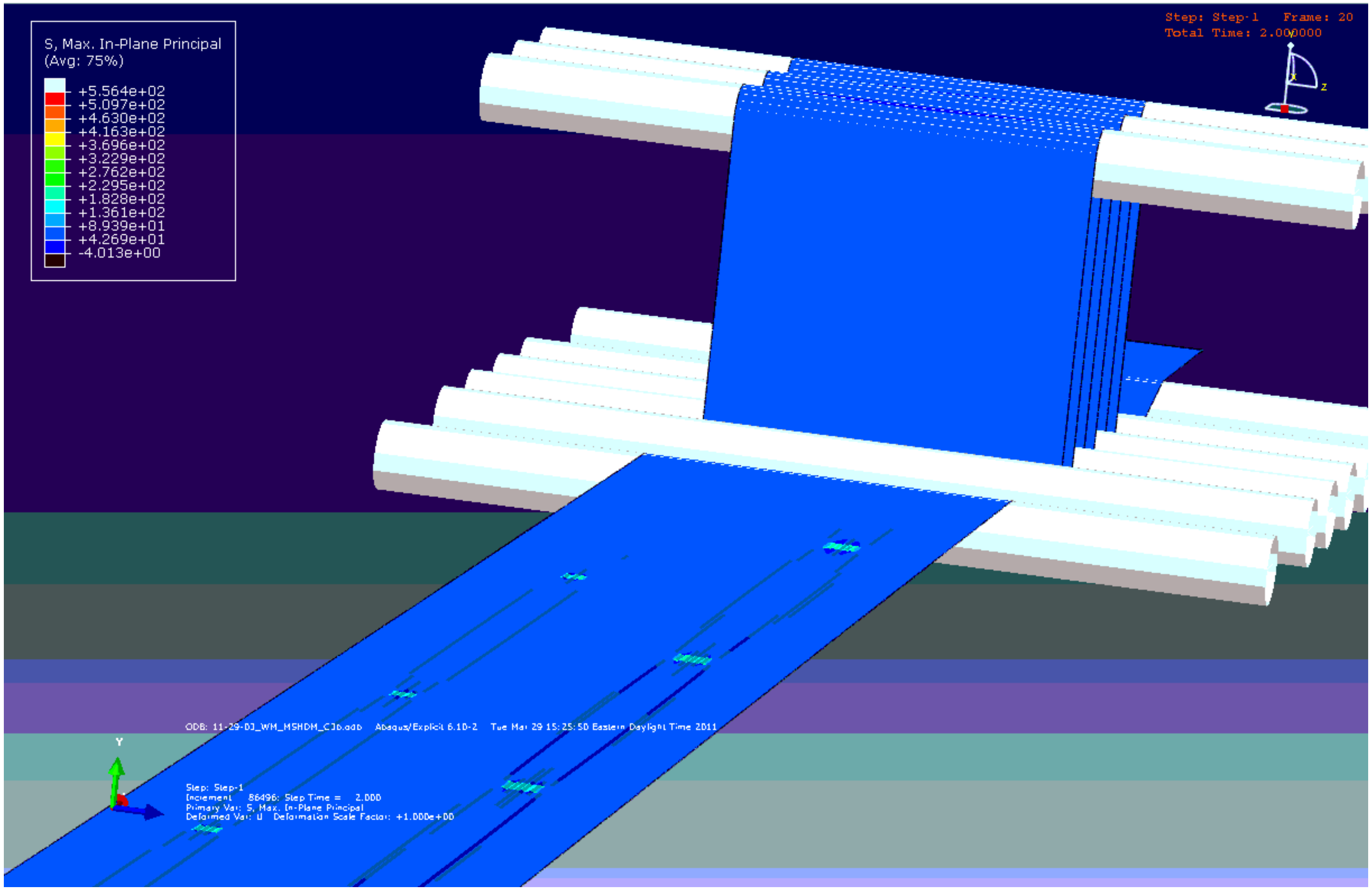
- When the carriage is misaligned the web sees a misaligned roller in every span
- The misalignment is in the same direction for each span
- The web seeks perpendicular entry according to Shelton [4]
- There is a compounding effect of multispan misalignment

Imperfect Web Set Up



- Intermittent imperfections are 1/4th the thickness [50.8 versus 203.2 microns]
  - Five large imperfections are 3.81 x 3.81 cm
  - Four small imperfections are 2.54 x 2.54 cm
- Web imperfections are located in the entry span before the web begins to move

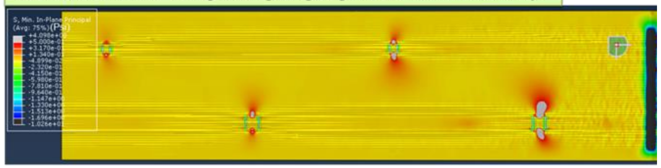
Case 3: Imperfect Web / Perfect Accumulator



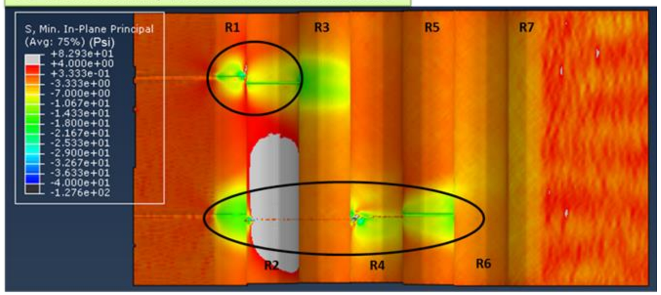
Maximum In-Plane stress shown in the video

Minimum In-Plane stress

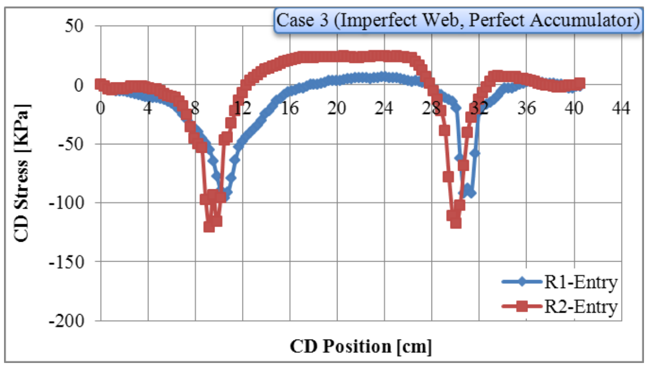
CD stress contours; Troughs in open span prior to accumulator entry

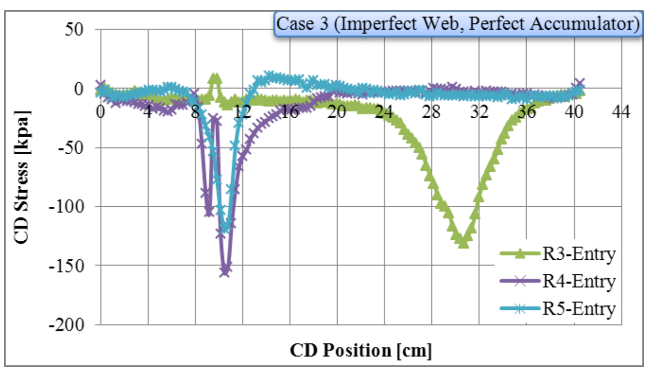


CD stress contours; Wrinkles within accumulator



Circles in the figure indicate the presence of a wrinkle on one or more rollers

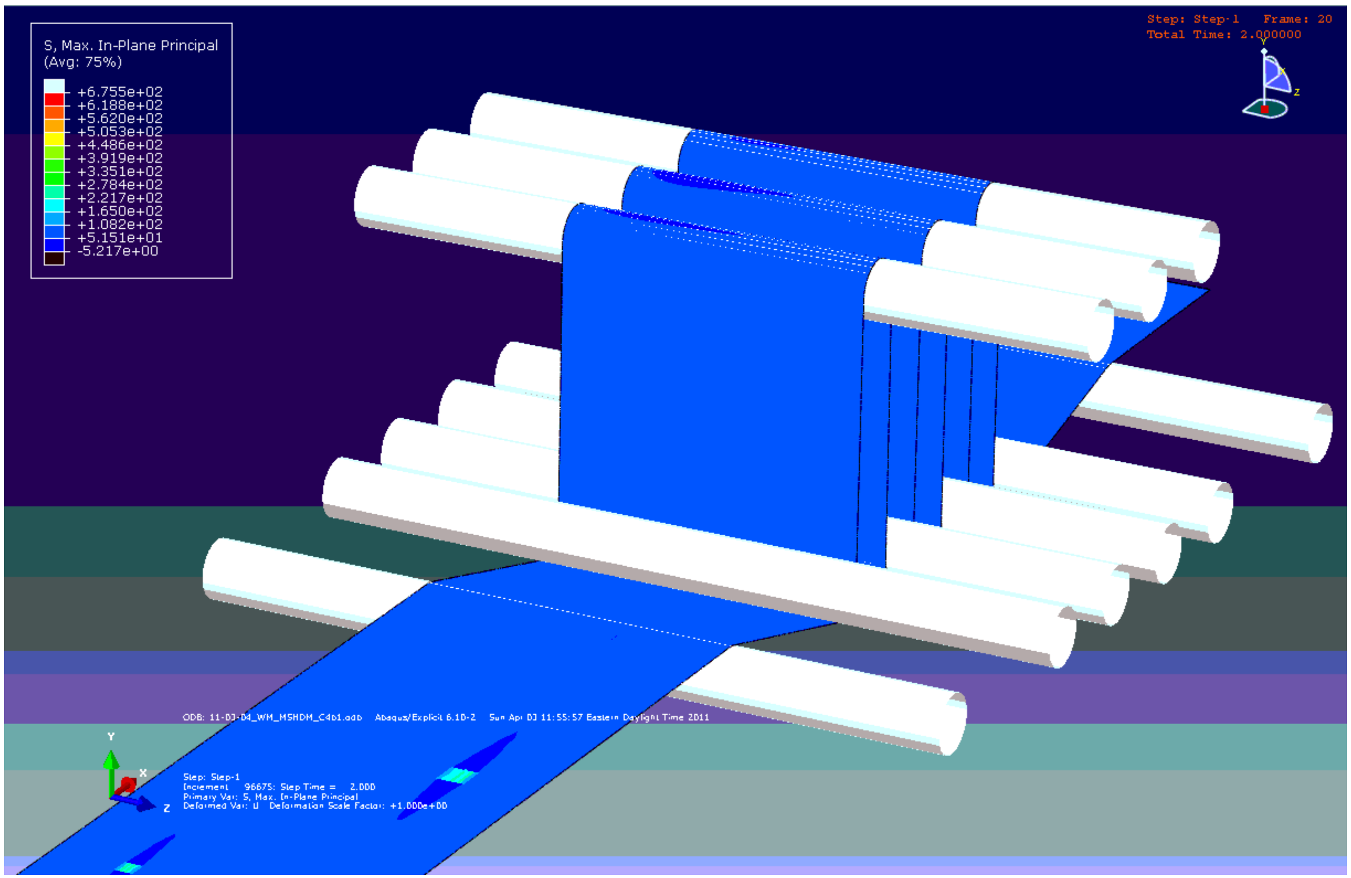




Case 3: Imperfect Web Perfect Accumulator

- Webs with holes studied previously by Good et al [2]
  - A hole in the web causes CD compressive stresses to reach a maximum value on either side of the imperfection.
  - This causes troughs to form that run parallel to MD on either side of the imperfection
- Our model studied imperfections that have reduced thickness compared to the rest of the web
  - Model results agree with Good et al [2]
  - As the imperfection nears the roller, wrinkles form on the roller ahead of the imperfection reaching the roller
- Imperfect webs can form wrinkles despite perfect alignment in accumulator

Case 4: Imperfect Web / Imperfect Accumulator

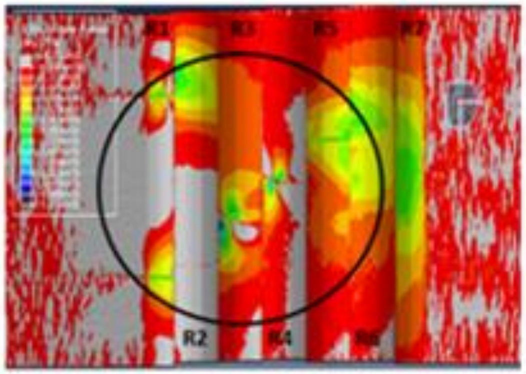


Maximum In-Plane stress shown in the video

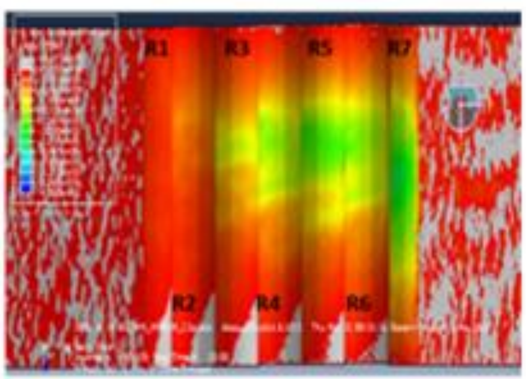
Case 4: Imperfect Web / Imperfect Accumulator

Minimum In-Plane stress

Case 4: Imperfect Web
0.35˚ R2, R4, R6



Case 2: Perfect Web
0.35˚ R2, R4, R6

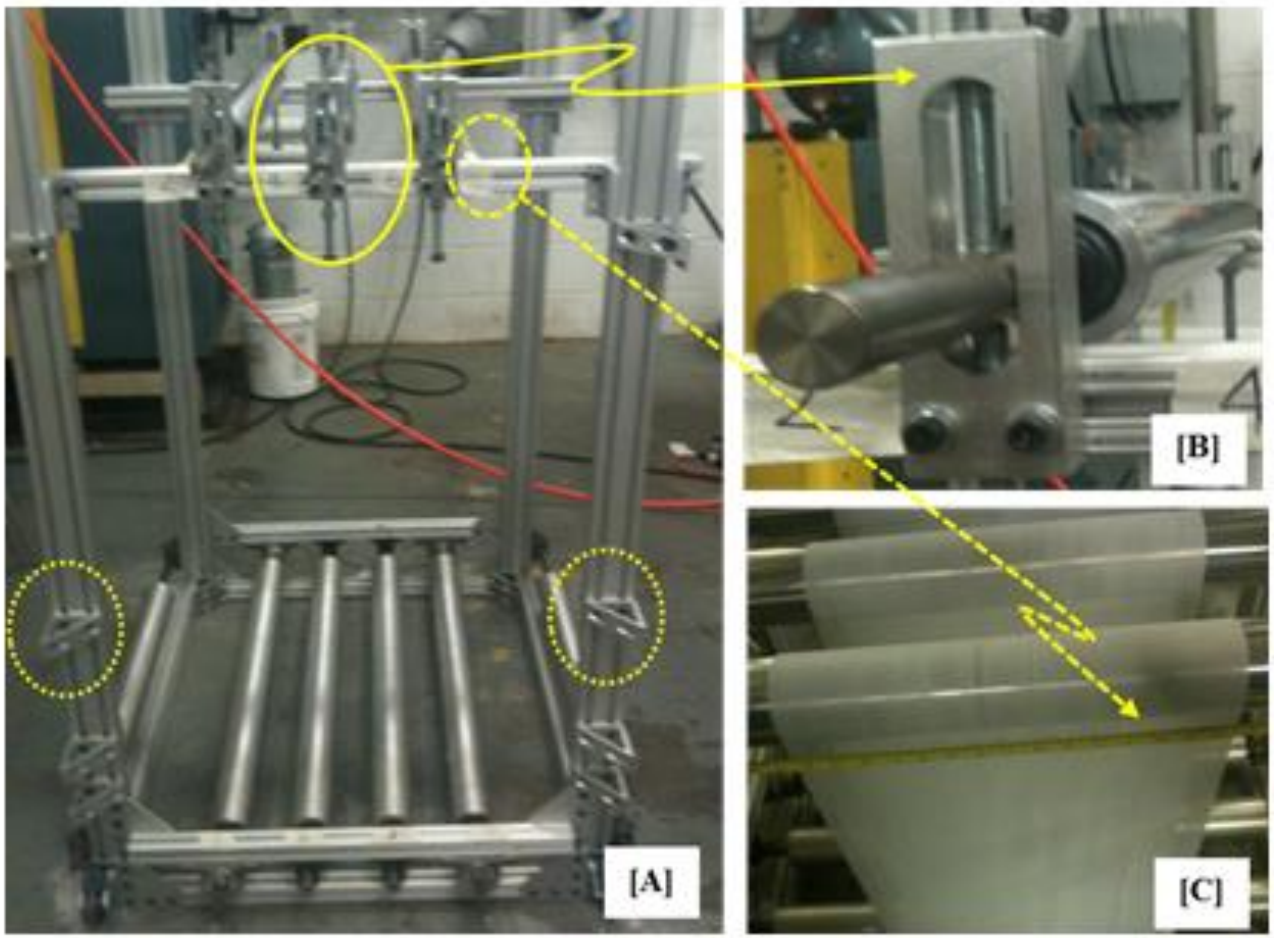


- For this case, the imperfect web will wrinkle at one half of the misalignment required for a perfect web

- Improved formation that is more consistent will reduce wrinkles for nonwovens

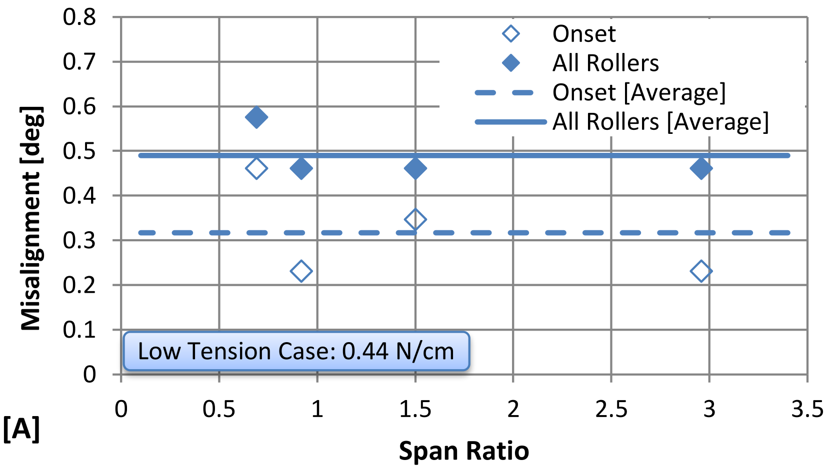
- Nonwoven webs are imperfect by nature and will require better alignment of rollers

Experimental Set Up

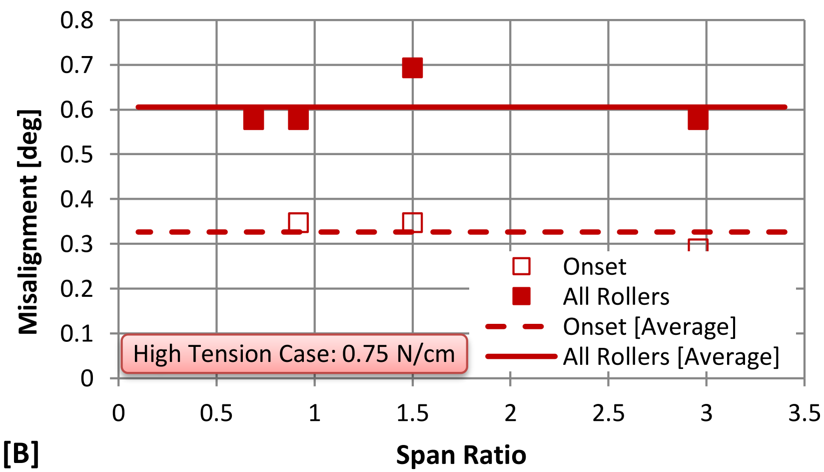


Solid circles – Misalignment bracket
Dotted circles – Hard stops
Dashed circles – Width measurement tapes

Experimental Results



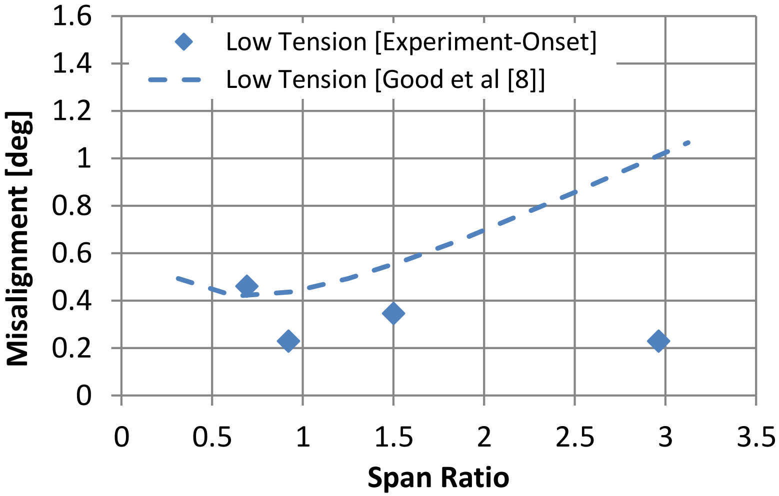
[A]

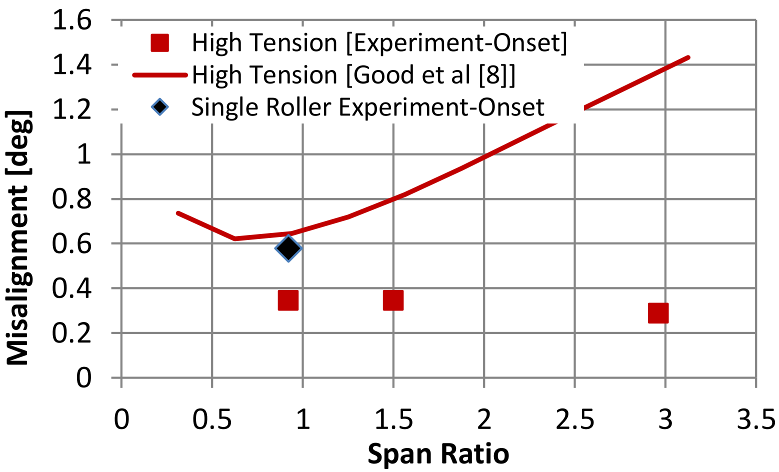


[B]

- Two tensions: 0.44 N/cm, 0.75 N/cm
- Average misalignment required to initiate a wrinkle/s on one roller within accumulator is ~ 0.3° for both tension levels (Onset)
- More misalignment is required to form wrinkles on all rollers
  - 0.5° for low tension
  - 0.6° for high tension
- Misalignment to cause wrinkles on all rollers was independent of span ratio and to a lesser extent independent of tension
  - This is inconsistent with previous findings [2]
  - Also note that the web to roller COF used in the study was 0.22

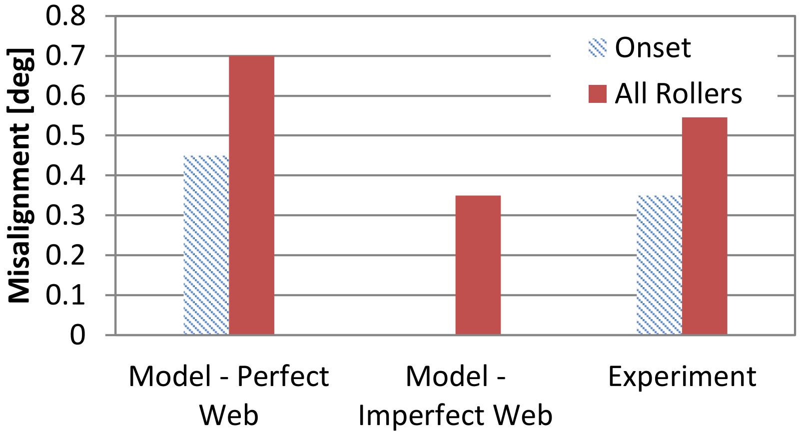
Comparison: Closed Form Solution –vs- Experimental Results



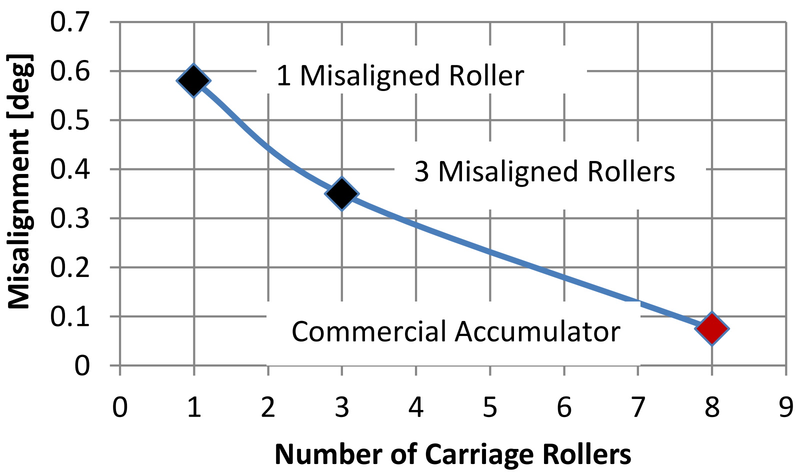


- Wrinkling criteria developed by Good et al [2, 3] for single roller misalignment is shown in graph (observe the red solid and blue dashed lines) → $\theta_{Wrinkle} = 2 \times \theta_{Troughs}$
- Good et al solution predicts misalignment required to wrinkle for a single roller.
  - Experimental data for R2 being misaligned compares well with Good et al's solution.
- Experimental results shown for misalignment carriage with 3 rollers do not agree with Good et al's solution.
- Good et al solution thus over estimates critical misalignment to form wrinkles for accumulators.

Comparison of Results: FE Model –vs- Experimental Results



- The FE model only looked at high tension and L/W = 0.9
- Model results agree reasonably well with experimental data
- The average experimental values fall between the model results for perfect & imperfect web scenarios



- Comparison of 1 –vs- 3 misaligned rollers in the carriage with commercial accumulator with 8 rollers indicate that the critical misalignment required to cause wrinkling appears to be inversely proportional to the number of rollers

Summary (1/3)

- FE Model:
  - When a wrinkle forms, CD stresses drop immediately after the instability occurs.
  - An imperfect web will wrinkle at smaller angles of carriage misalignment as compared to a perfect web.
  - Misalignment required to form severe wrinkling within accumulator decreases with increase in number of rollers
  - Explicit finite element modeling is a powerful tool to better understand wrinkling mechanics for non-ideal webs and accumulators.
  - Misalignment required to form severe wrinkling within accumulator decreases with increase in number of rollers

Summary (2/3)

- Experimental Results:
  - Wrinkles will first appear at the exit of an accumulator due to misalignment.
  - More misalignment is required to form continuous wrinkles across all of the rollers within the accumulator.
  - For the nonwoven web studied herein, the critical angle of carriage misalignment required to cause wrinkles is independent of length / width ratio.
  - The critical angle of misalignment required to cause wrinkles is almost independent of tension.

Summary (3/3)

- Comparison:
  - Experimental results are in general agreement with FE model results.
  - Existing closed form solution for a single roller over estimates the critical misalignment required to cause wrinkles in accumulators.
  - The critical angle for carriage misalignment appears to be inversely proportional to the number of rollers in the carriage for an imperfect nonwoven web.

- Application:
  - Non woven material uniformity is critical for better convertibility
  - Accumulators require better alignment to avoid wrinkles as compared to a single misaligned roller.
  - The required precision appears to be linear with the number of rollers within the accumulator.

Future Work for Industry Needs

- **Understanding the fundamental mechanical behavior of these delicate nonwoven webs**
  - Formation variations
  - Poisson's ratio > 2
  - Nonlinear material behavior
  - Viscoelasticity & plasticity
  - Web imperfections – camber, baggy lanes, floppy edges
- Analytical solutions for multi-span systems with web imperfections
- Understanding the air/web dynamics within an accumulator
- Impact of basis weight and imperfect formation on web dynamics
- Understanding traction within accumulators at higher speeds
- Validated computer models are needed for low modulus webs and accumulators

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- Dr. Keith Good, Dr. Prabhakar Pagilla, Dr. John Shelton, Bruce Feiertag, Ron Markum & Dr. Karl Reid

References

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2. Good, J. K., Biesel, J. A., and Yurtcu, H, “Predicting Web Wrinkles on Rollers”, Proceedings of the Tenth International Conference on Web Handling, Web Handling Research Center, Stillwater, Oklahoma, 2009.
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4. Shelton, J. J., “Lateral Dynamics of a Moving Web,” PhD Thesis, July 1968.

Questions ?

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