Review and comparison of methods to measure paper fracture energy

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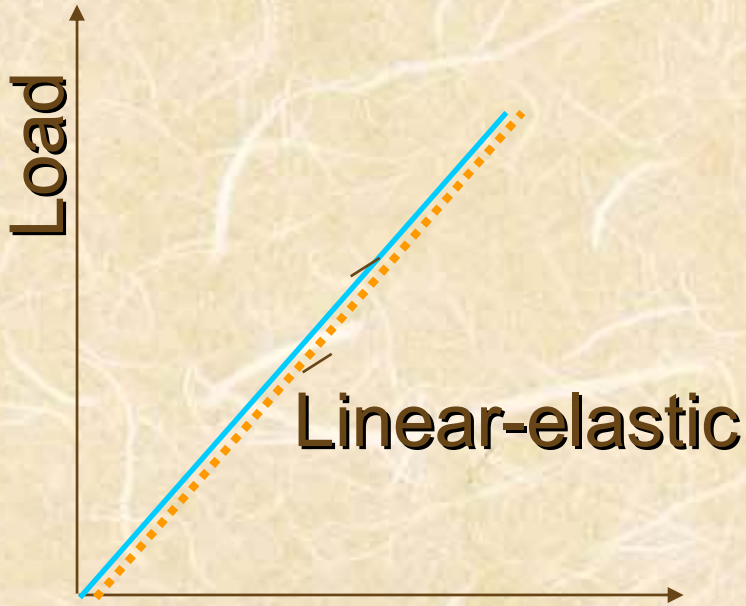
Outline

- Mechanical properties
- Current methods to measure fracture toughness
  - Liebowitz non-linear form of the J-integral technique
  - Essential Work of Fracture measurement
  - Cyclic Work of Fracture technique
  - Cohesive crack opening
- Comparison samples tested
- Results of comparison
- Discussion and conclusion

Mechanical Properties

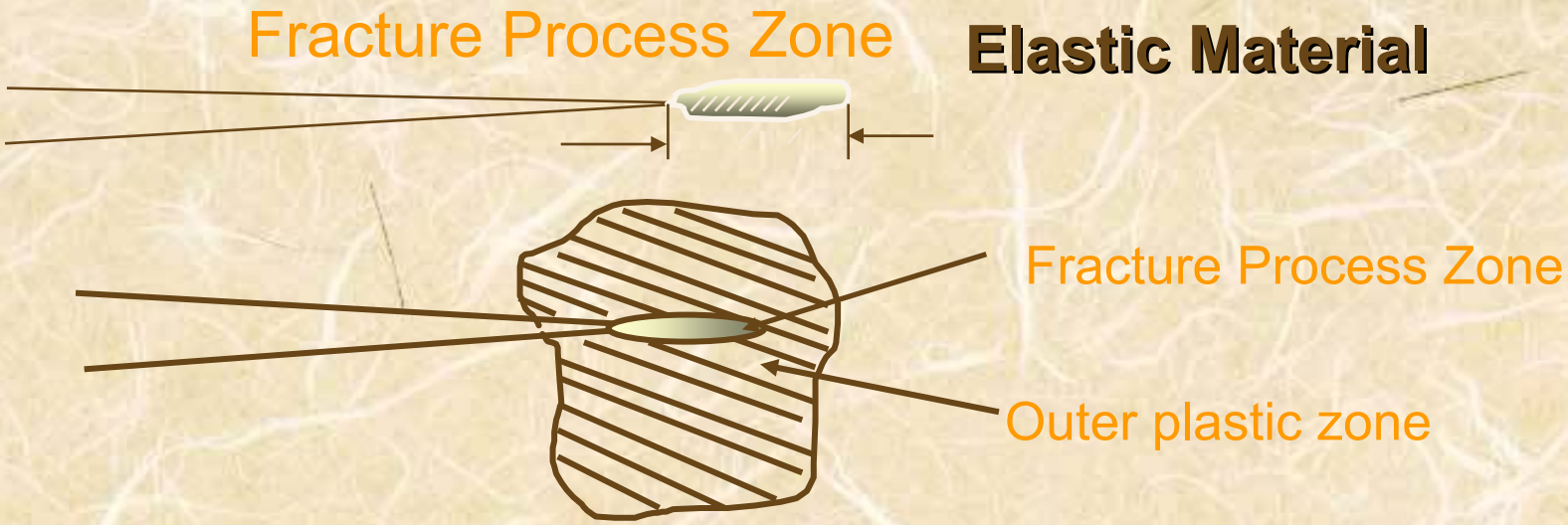
Paper: visco-elastic material- generally significant plastic deformation



Groundwood

All other furnishes

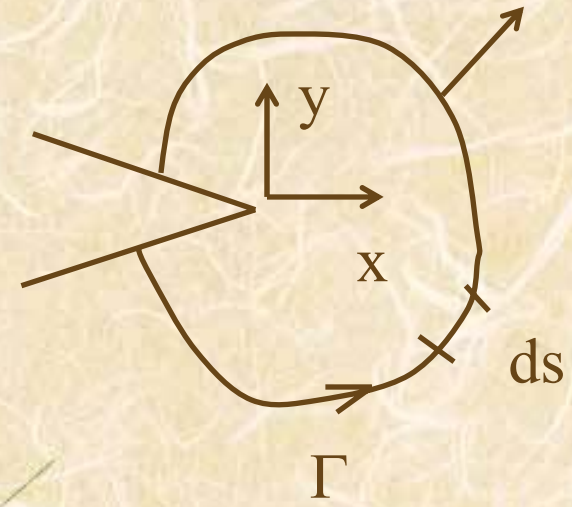
Fracture toughness



- Energy required to extend a crack a given distance
  - Independent of test geometry
- Linear elastic: work of failure only from fracture
- Elastic-plastic: measured work= work of fracture + plastic work in outer plastic zone.
- Want to separate work of fracture from other work

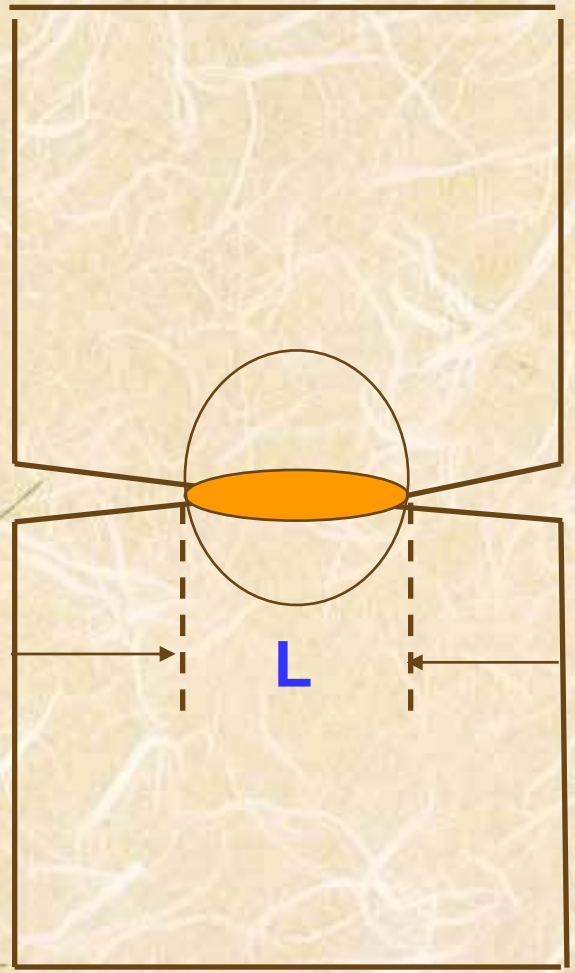
J-integral method

- Estimated from line integral
- Single specimen size technique:
  - Implemented in L&W Instrument
  - Measurements made on normal tensile plus MD and CD centre-notched specimens (50mm wide)
  - Unnotched tensile curve fitted
  - Fracture toughness calculated from point of maximum load
  - Technique has difficulties with tough papers



Essential Work of Fracture (EWF) method

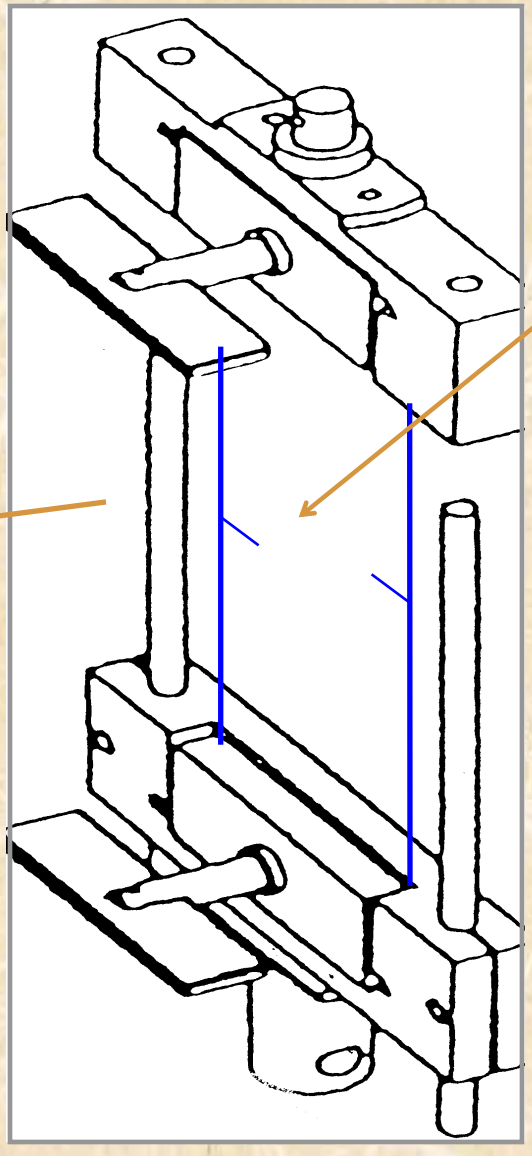
- Requires large number of samples of different sizes
- Separates the essential work of fracture from total by graphical interpolation
- Very time consuming
- DENT geometry



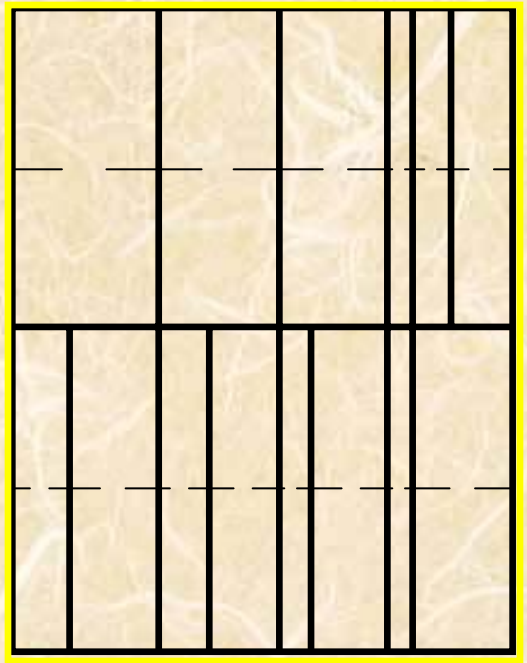
Physical Testing

Instron model 5566 universal testing machine

Line type clamps

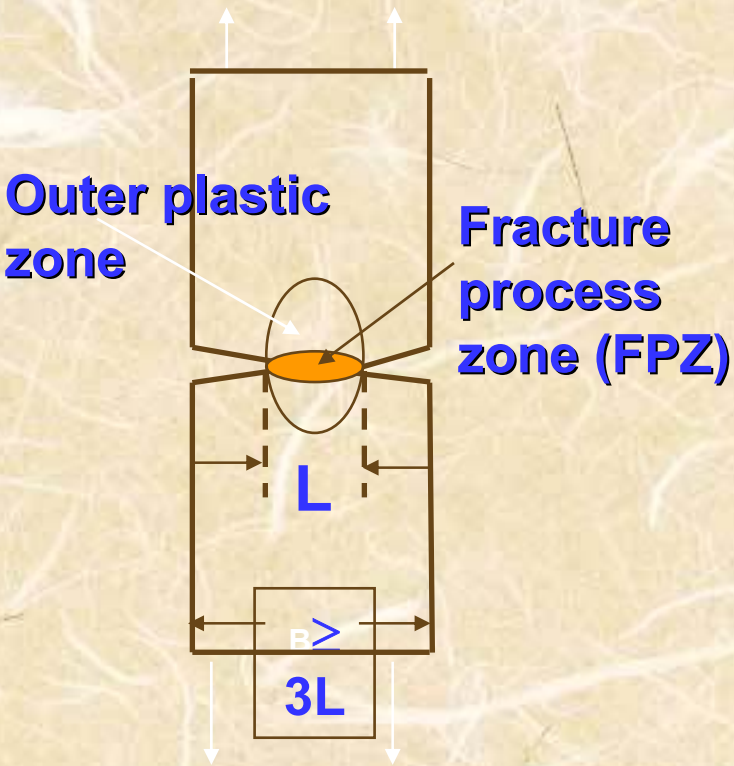


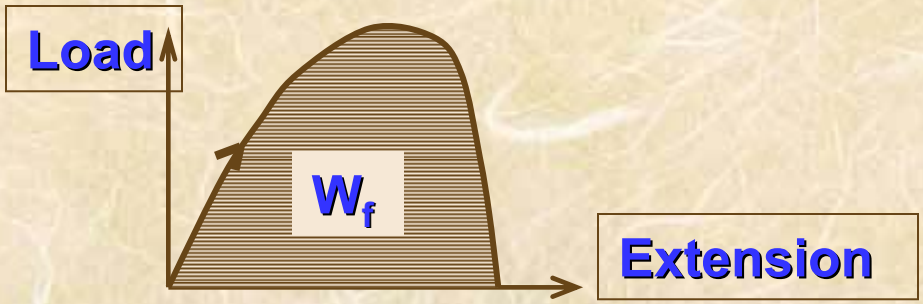
DENT Sample



Sample cutting die (top view)

EWF technique



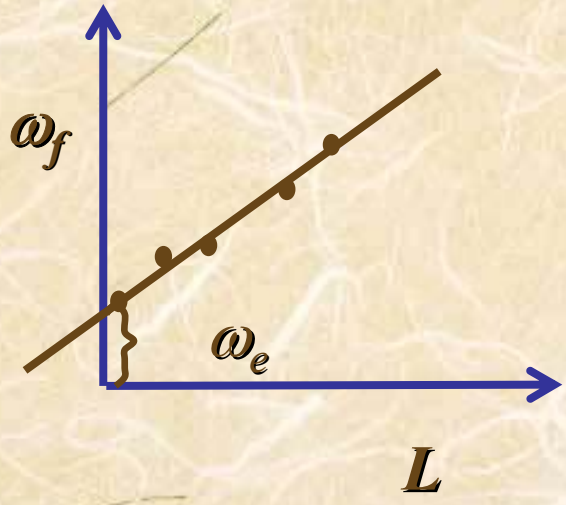


$$W_f = W_e + W_p$$

If $W_e \propto L$ and $W_p \propto L^2$

$$W_f = \omega_e L t + \beta L^2 t \omega_p$$

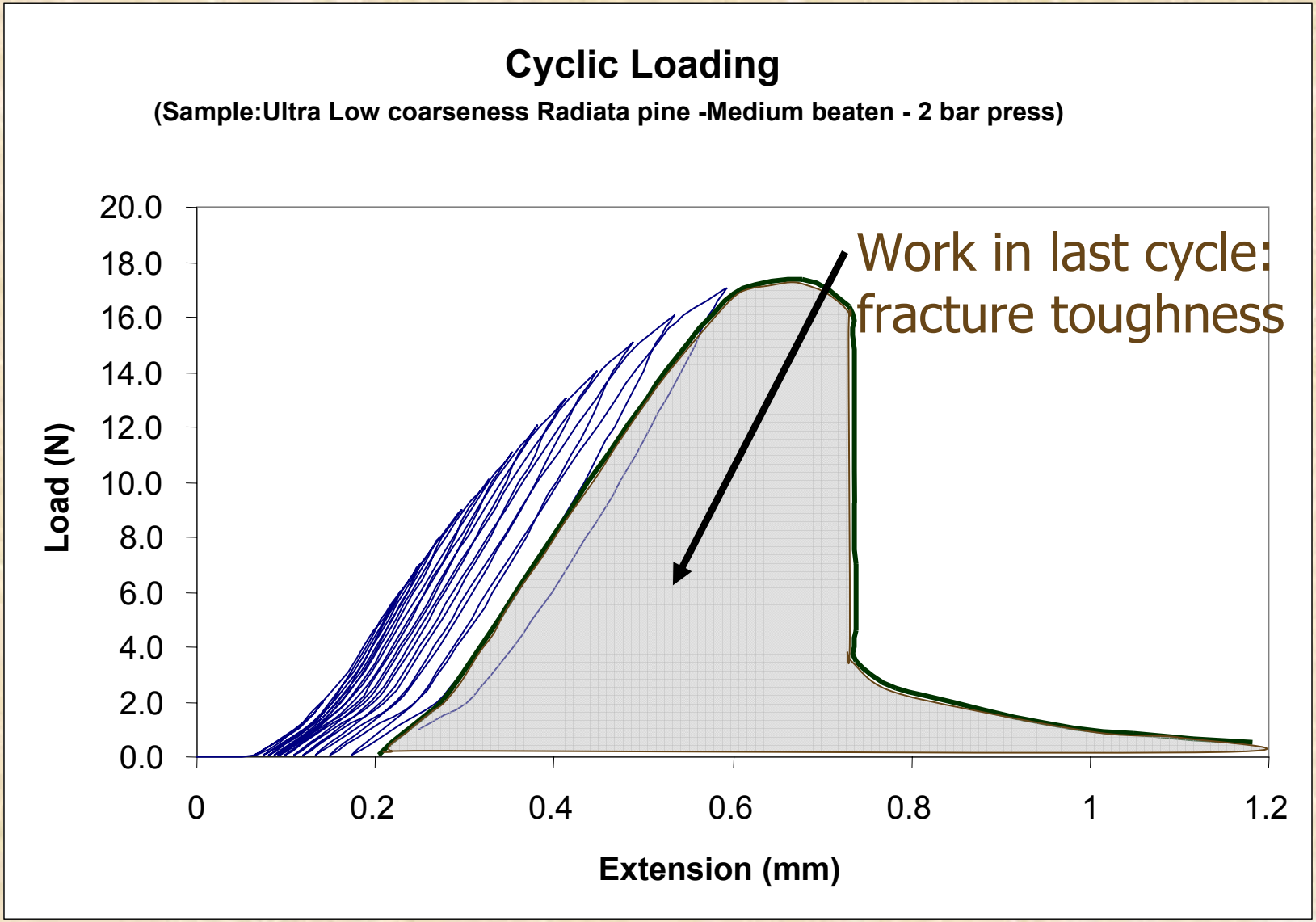
$$\omega_f (= W_f / Lt) = \omega_e + \beta \omega_p L$$



New Cyclic Technique

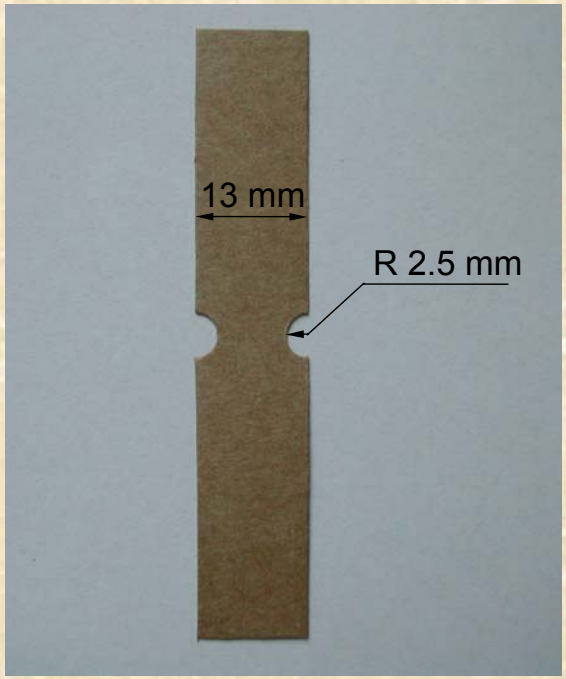
- Based on EWF technique, EWF sample geometry
- Instead of monotonically increasing load, cycle load
- Maximum load increases each cycle
- Work of last cycle: Fracture toughness
- Advantages over EWF fracture toughness
  - One sample size
  - Quick and simple
- Preconditions- same as EWF
  - *B>3L*
  - Sample yields fully before failure

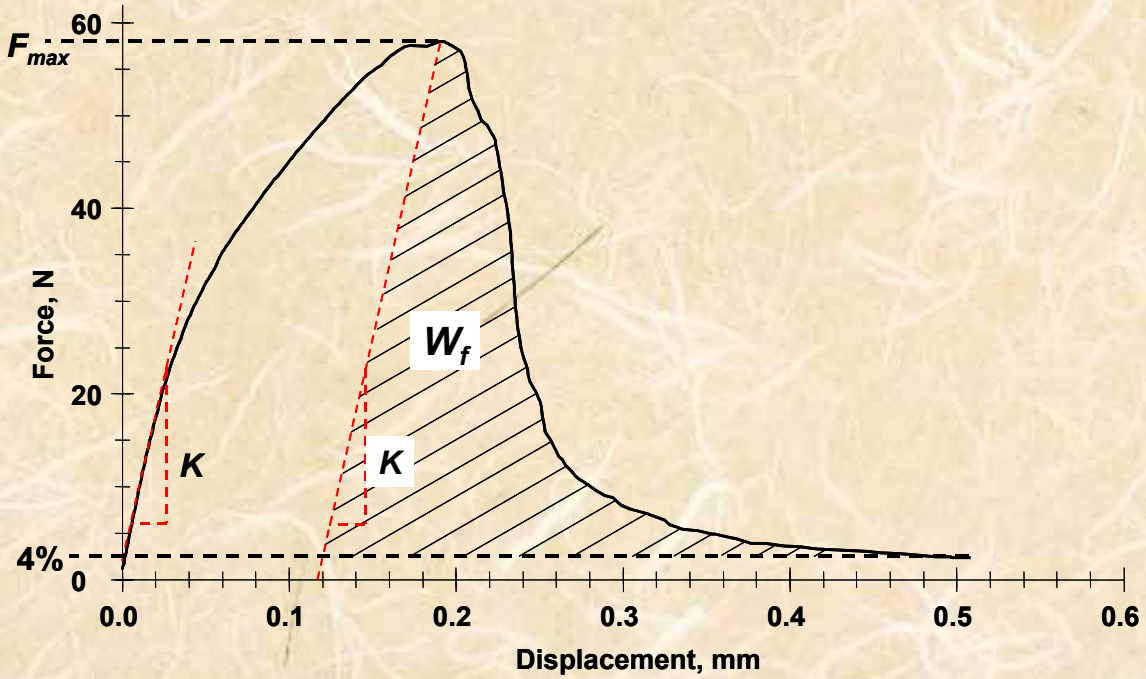
Cyclic method



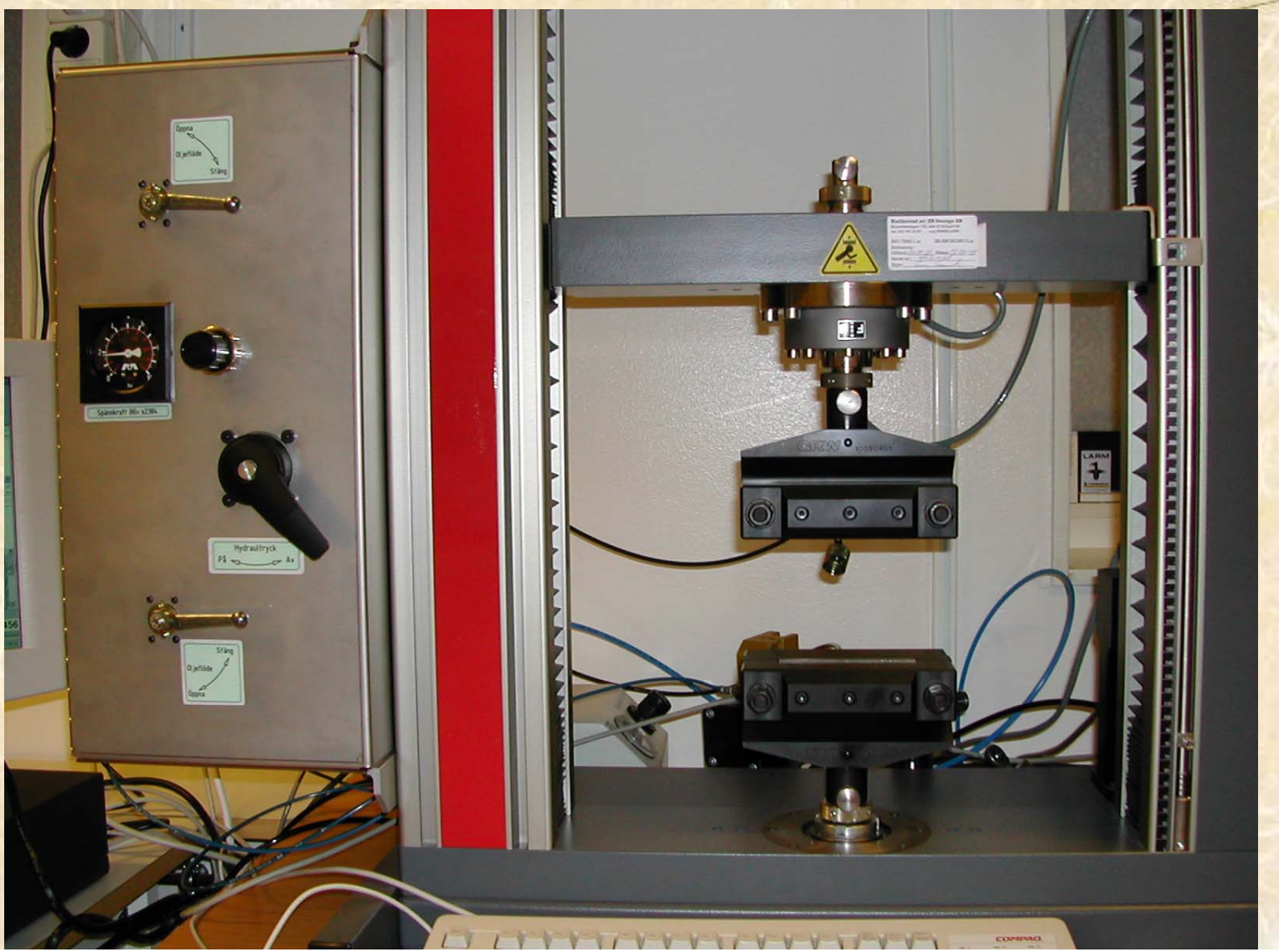
Cohesive crack opening measurements

- Clamped length 5 mm
- Shaded area gives fracture energy





Test rig



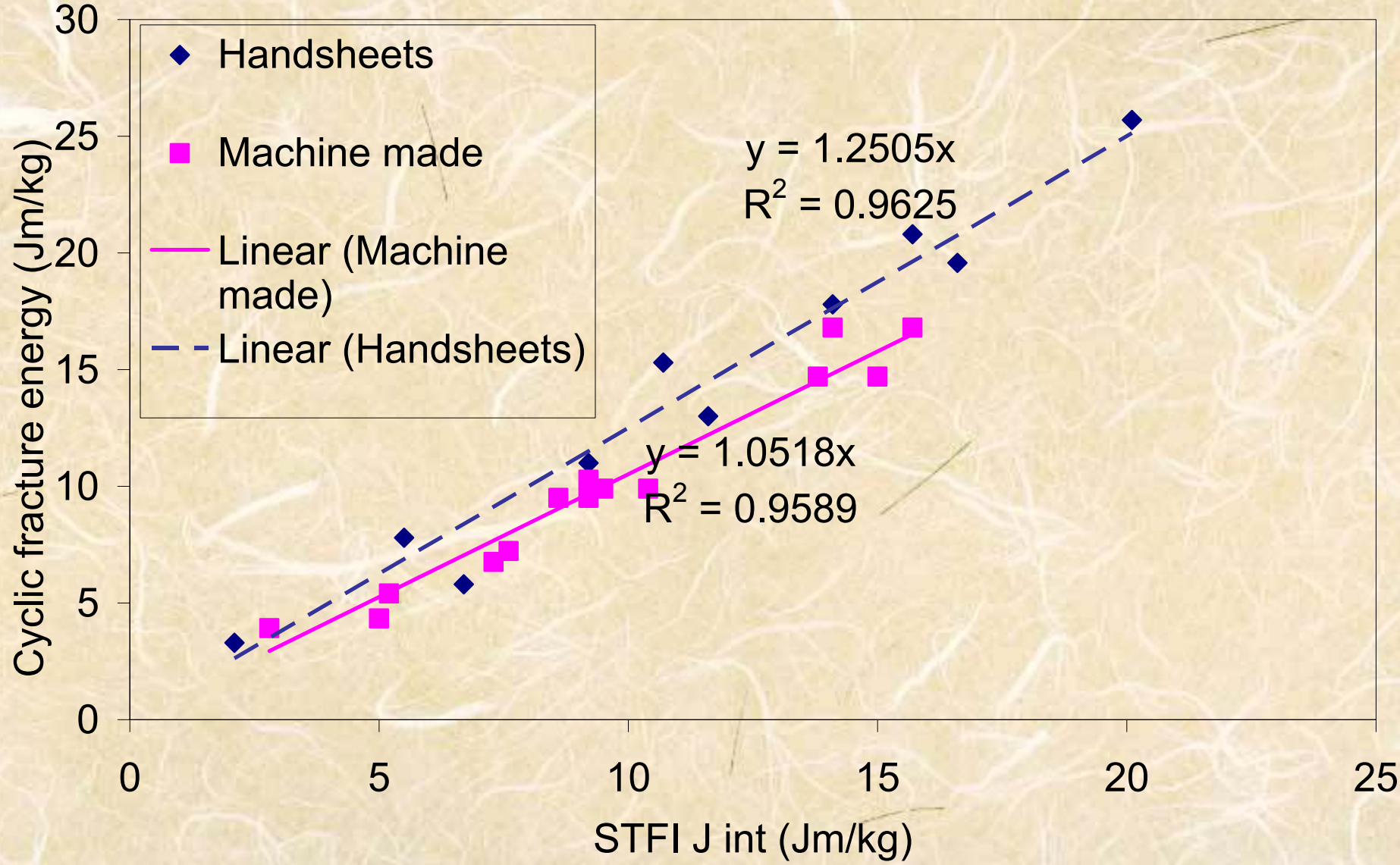
Test materials

- Handsheets
  - Bleached Scandinavian long fibre kraft
  - Unbleached radiata pine kraft
    - Unrefined, 50 min, 80 min (Valley)
  - Unbleached eucalypt kraft
    - Unrefined, 20 min, 40 min (Valley)
  - Blend of radiata pine and eucalypt kraft
    - 25:75, 50:50, 75:25; euc: 22 min, pine 55 min (Valley)
- SCA machine made papers (Tested MD and CD)
  - Newsprint
  - Coating base paper
  - SC grade paper
  - Testliner
  - Kraftliner

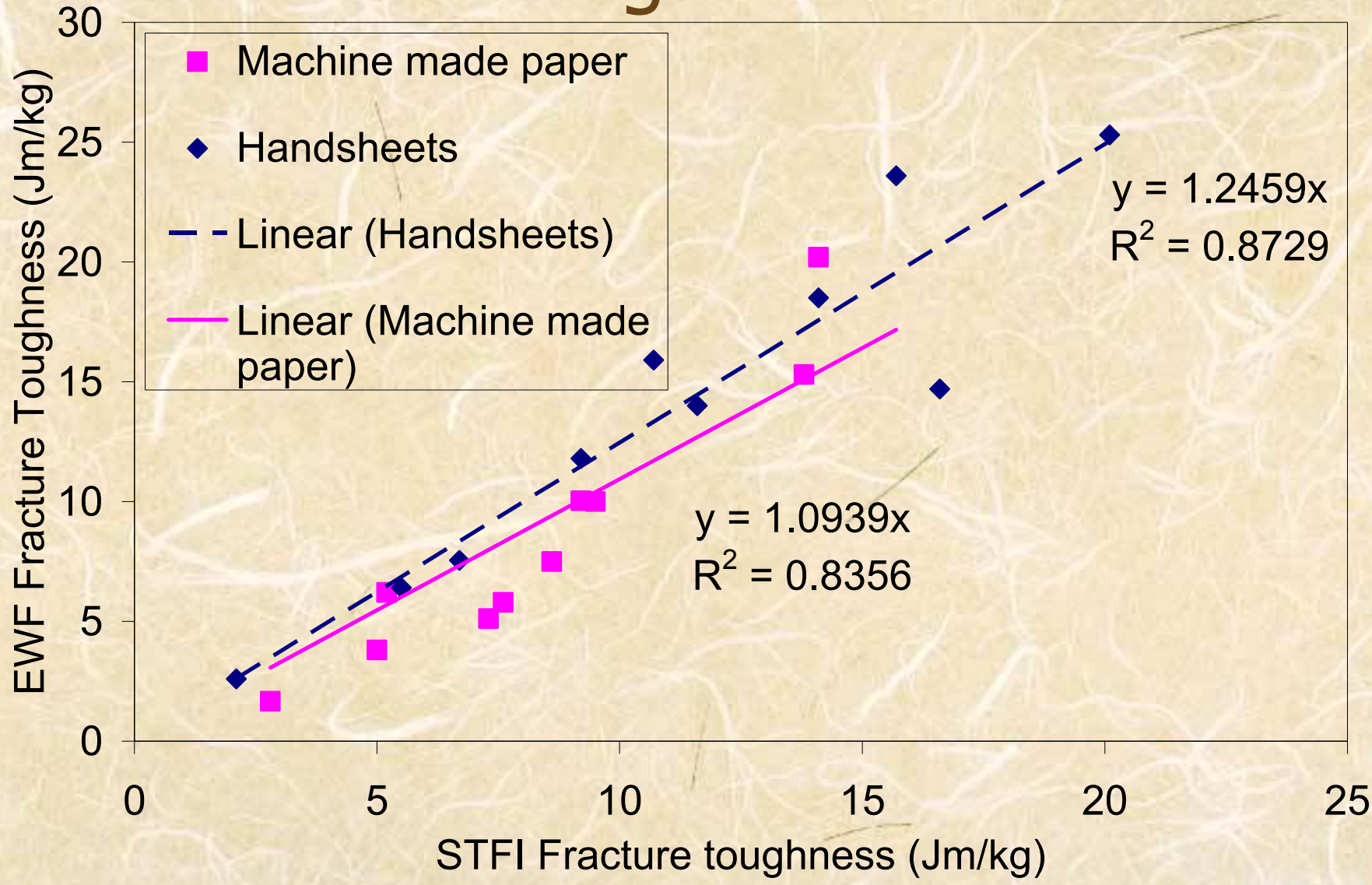
Comparison plots

- EWF vs STFI J integral fracture toughness
- Cyclic vs STFI J integral fracture toughness
- Cyclic vs EWF fracture toughness
- Cohesive crack opening vs STFI J integral fracture toughness
  - All results in fracture toughness index (Jm/kg)

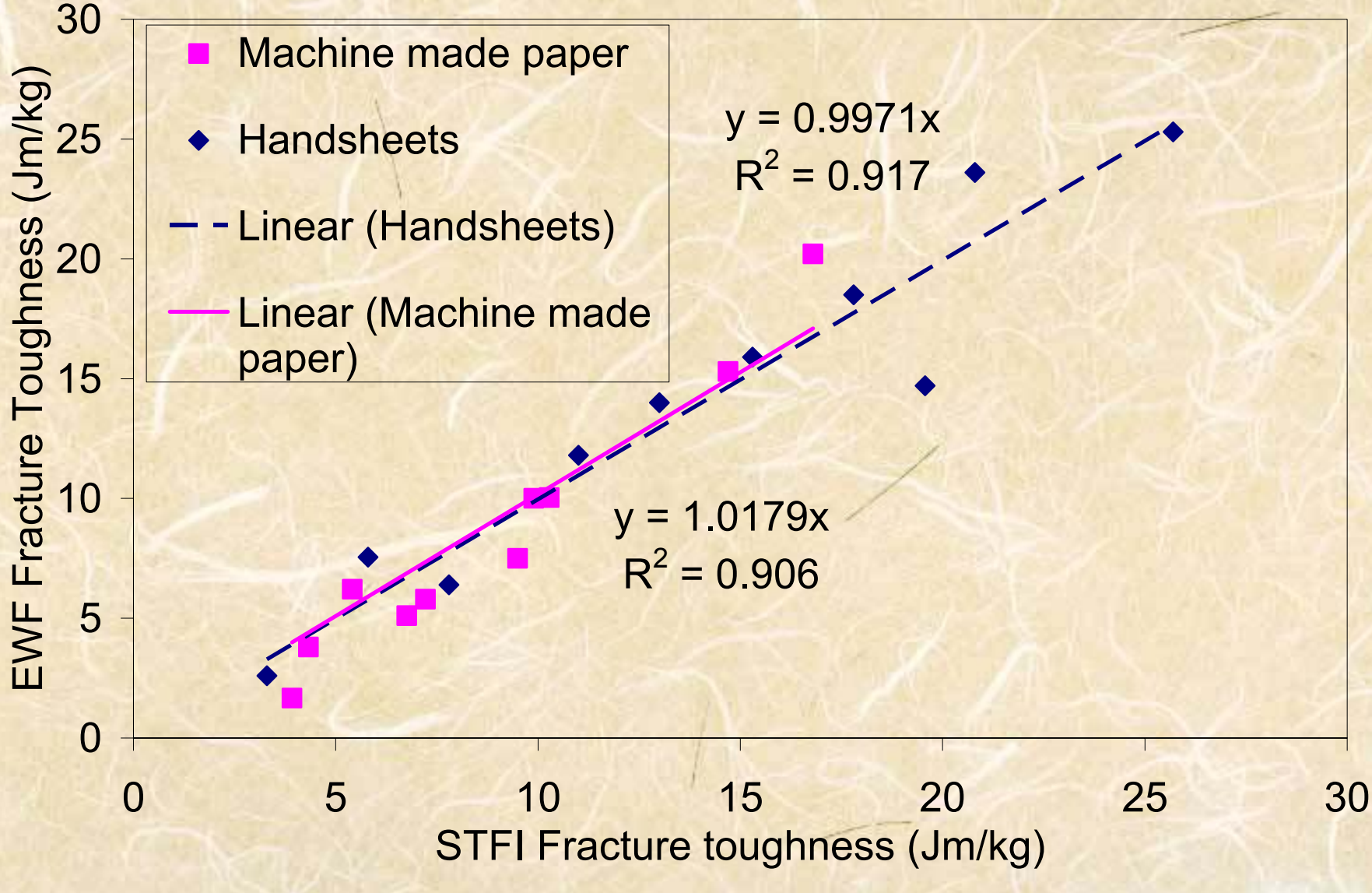
Cyclic vs. STFI J Integral



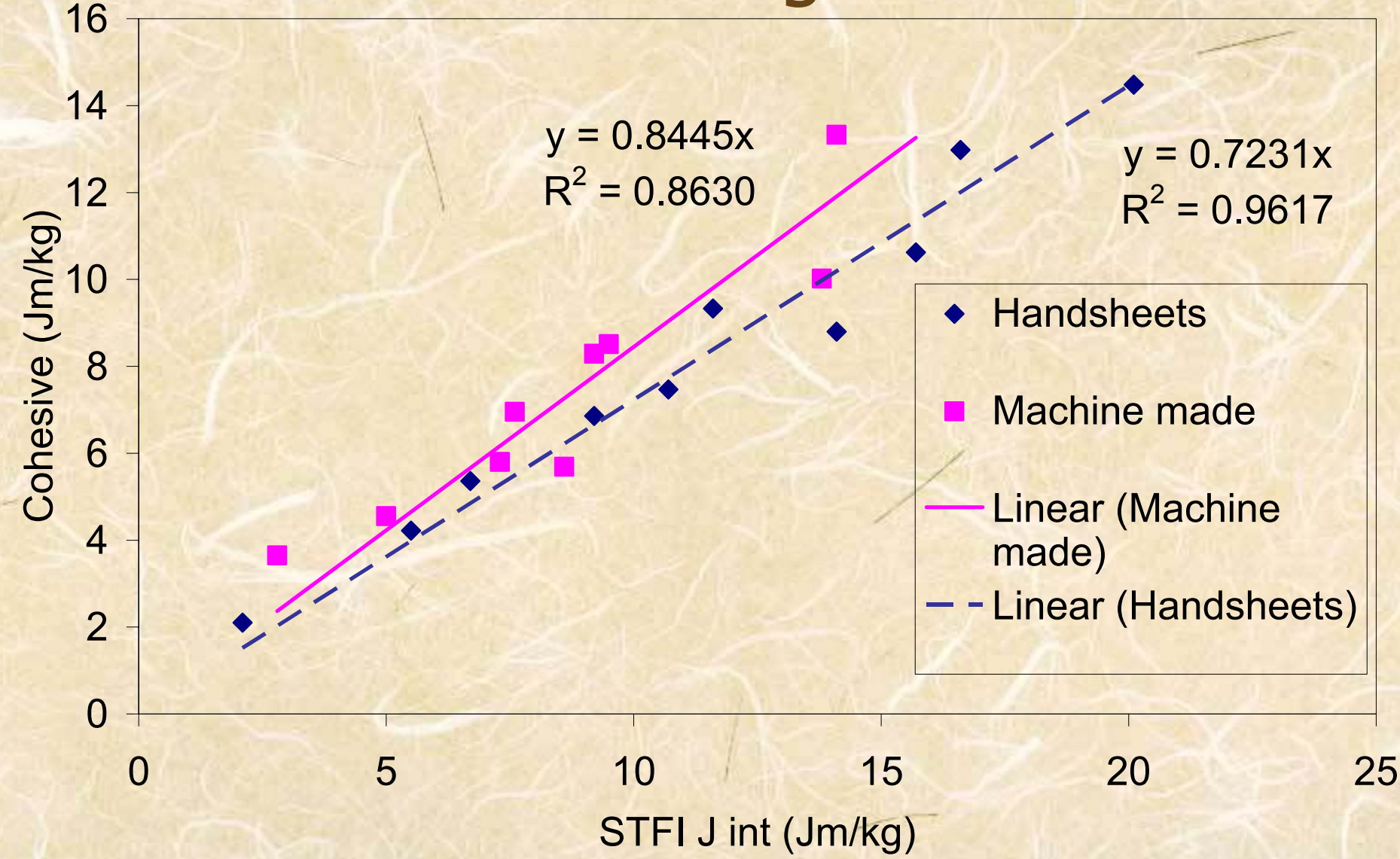
EWF vs STFI J integral Fracture Toughness



EWF vs Cyclic Fracture toughness



Work of Cohesive crack opening vs STFI J-integral FT



Summary

- All methods linearly related to each other
  - Both machine made and handsheets
- EWF comparable to Cyclic fracture toughness all papers
- Machine made papers
  - EWF and cyclic FT 5% higher than STFI.
  - Cohesive work of fracture 17% lower than STFI
- Handsheets
  - EWF and cyclic FT 25% higher than STFI.
  - Cohesive work of fracture 17% lower than STFI

Discussion

- Outside of scaling differences all tests seem to be measuring essentially the same thing
- No deviation from linear relationship seen
  - Previous comparison measurements probably used too large a sample size for EWF.
- Can scaling differences in measurements be explained from first principles?

Acknowledgements

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