Effect of Ethylene Content on Bowtie Trees and Wet Electrical Performance in Filled Insulation Materials

Amalendu Sarkar, Mark Easter, Ed Walcott, William Temple and John T. Smith, III.

Subcommittee A – Cable Construction & Design

Fall 2010 ICC Meeting

October 18, 2010

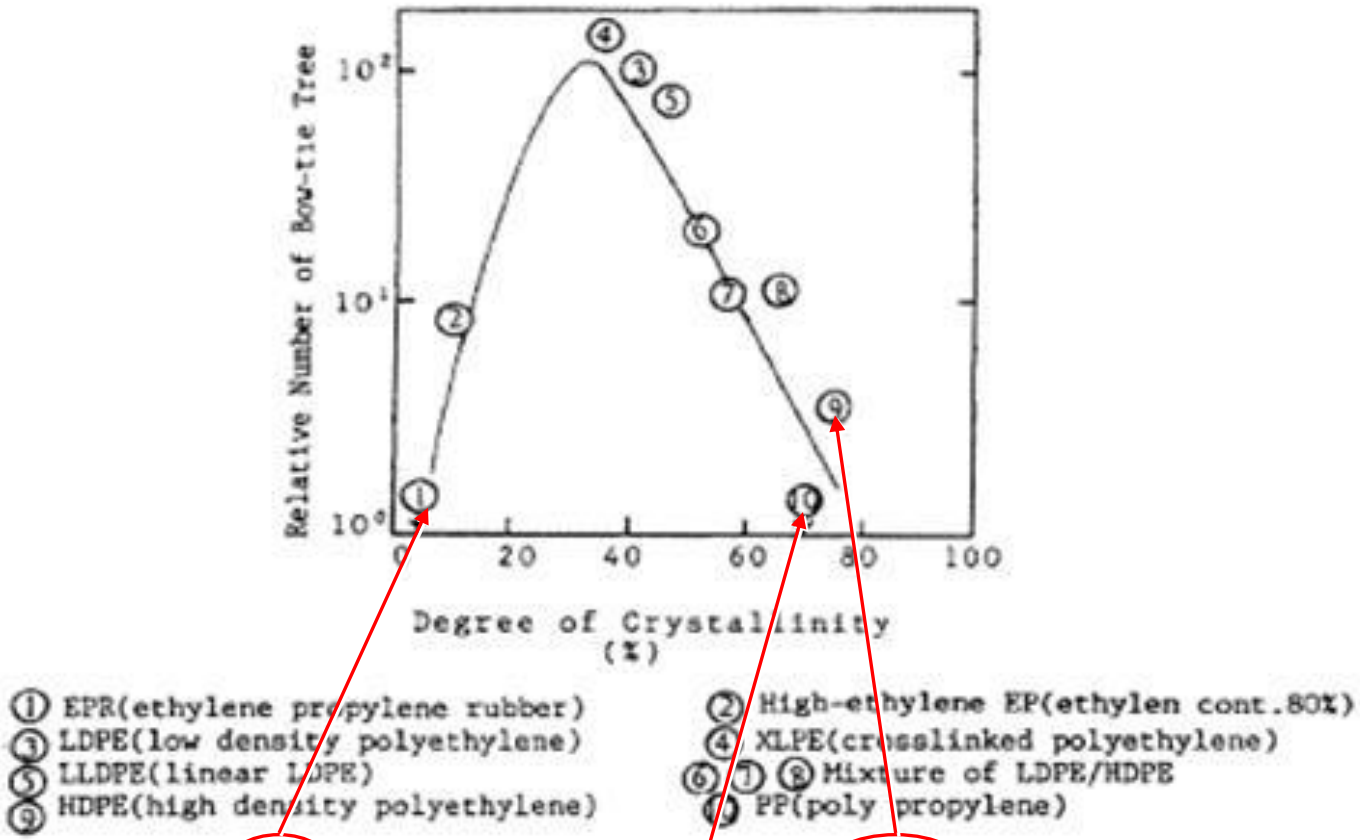
Fountain Hills, AZ

General Cable

Background

- There are two (2) types of Ethylene Propylene Rubber (EPR) medium voltage cable insulations used today
  - Amorphous EPR
  - Semi-Crystalline EPR
  - Primary difference is in ethylene content of the EPR
- Both have been successfully used for over 40 years
- Claims in the industry assert that percent (%) ethylene content of the insulation affects susceptibility to water-tree growth

Published Studies (Figure 1)



Amorphous **Unfilled** EPR, Highly Crystalline PP and HDPE grew the minimum number of bow-tie trees. Our Results Refute Claims of Increased Susceptibility of Semi-Crystalline EPR to Water-Treeing, and the Limiting of Ethylene Content of EPR Insulations to < 72%.

Study performed by Tohru et. al. at Fujikura Corporation at ambient temperature on unfilled resins and not on fully compounded filled EPR insulation used in MV cables

Ethylene Content in EPR <72 wt.%?

- **Based on this study some claim that the percent (%) ethylene content of MV EPR insulations should be limited to no more than 72%, and with no addition of low density polyethylene (LDPE) in the EPR insulation formulation**

- **This presentation will show data that refutes the claims of higher susceptibility to water-treeing of semi-crystalline EPR MV insulation formulations whose ethylene content is > 72Wt.%.**

Published Studies

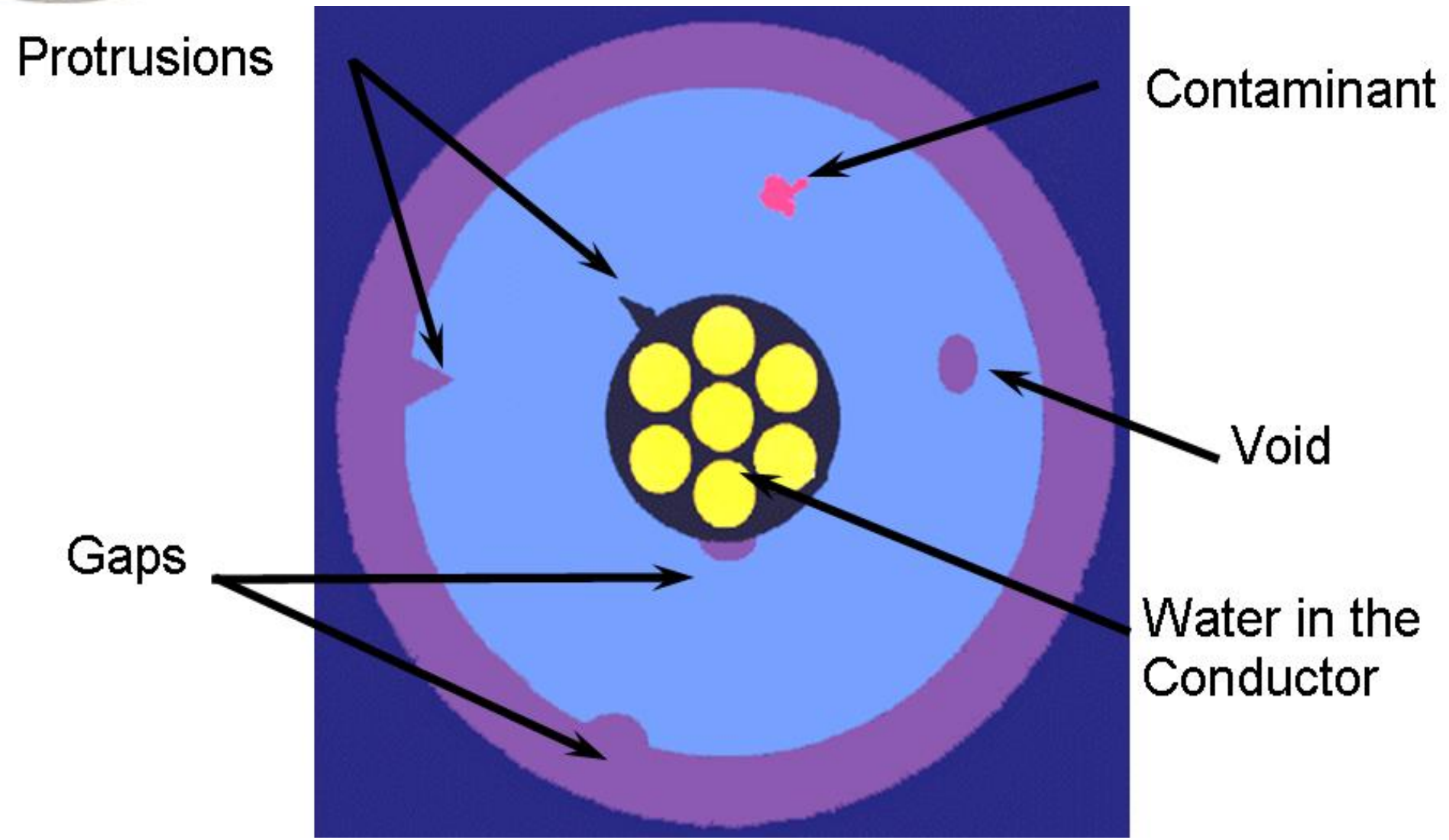
- Studies on the growth of water trees in Amorphous and Semi-Crystalline filled EPR by M. Brown, and another by R. Blodgett concluded that:
  - The presence of reinforcing clays and other compounding ingredients play an important role in reducing the tendency of EPR to develop trees
  - Low levels of crystallinity in EPR MV insulation materials do not guarantee superior cable life, compared to EPR Insulations of significantly higher ethylene content and crystallinity

- Issiki and his group studied water tree growth on LDPE, HDPE, XLPE, PVC, PS, PP, PC, EVA and polyamides and concluded that:
  - Water-Tree growth had very little dependence on the crystallinity and polarity properties of materials
  - Water-Trees tended to grow more easily in soft materials

Published Studies

- The Dow Chemical Company, The Southern Company and NEETRAC published data on actual field service cables in the same installation after 17 years of service which showed the following:
  - Longest bow-tie tree observed in an Amorphous EPR-Insulated cable was 26 mils
  - Longest bow-tie tree observed in a TRXLPE-Insulated cable was 12 mils
  - ac Breakdown and Impulse Strength of the TRXLPE cable was superior to that of the Amorphous EPR-Insulated cable
- These results also refute claims that higher % ethylene content increases susceptibility to water-tree growth

Potential types of defects



Other factors affecting water tree growth

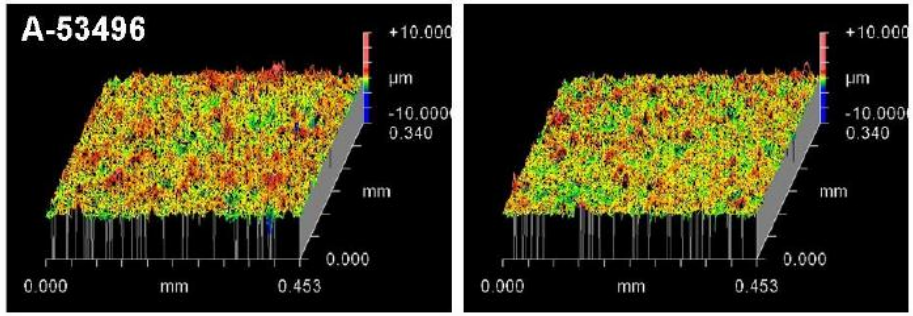
- Presence of Voids
- Contamination
- Ionic species
- Interfacial smoothness and imperfections
- Other factors are: Type of fillers, Quality of mix, Level of dispersion, Control of production process, Crosslink density, Design of Compound Formulation, Electrical stress, Operating stresses and Temperature exposures in service

Materials & Dispersion Testing

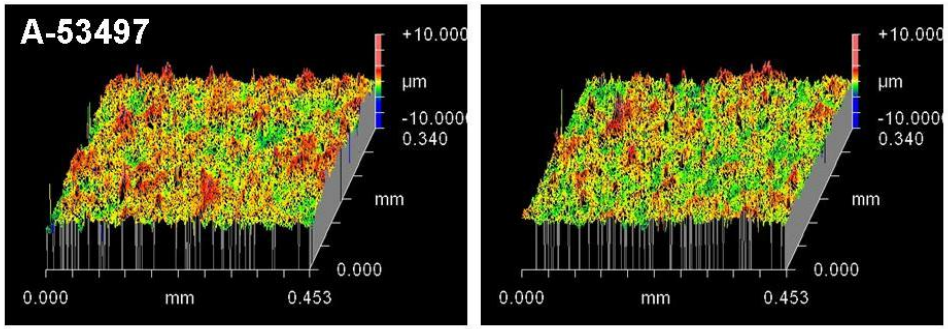
Insulation Material Type	Material A	Material B
Type of EPR	Semi-crystalline EPR	Amorphous EPR
Ethylene Content	>72 Wt. %	<72 Wt. %
Type of mixer	Buss Co-kneader	Banbury
Clay content	~30%	~50%
Dispersion Index* (Method ASTM D2663)	92.0	69.6
Total peaks observed*	313	790
Mean peak Dia (µm)*	11.8	14.3
RMS roughness (µm)*	0.52	0.80

***Results are average of ten determinations from ten different locations**

IFM topographic maps of Material A and Material B (Sample area 911µ x 760µ)



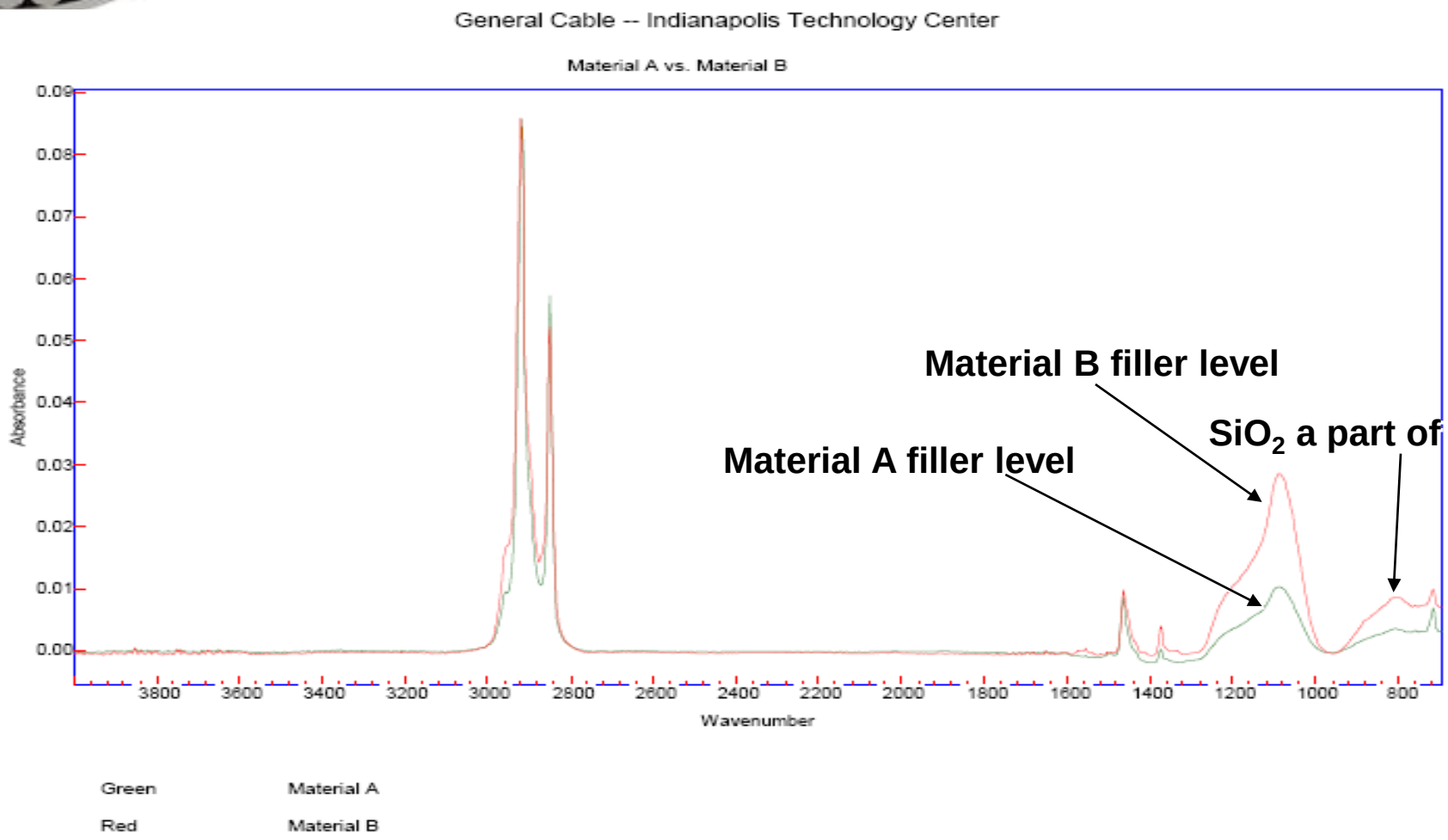
Material A



Material B

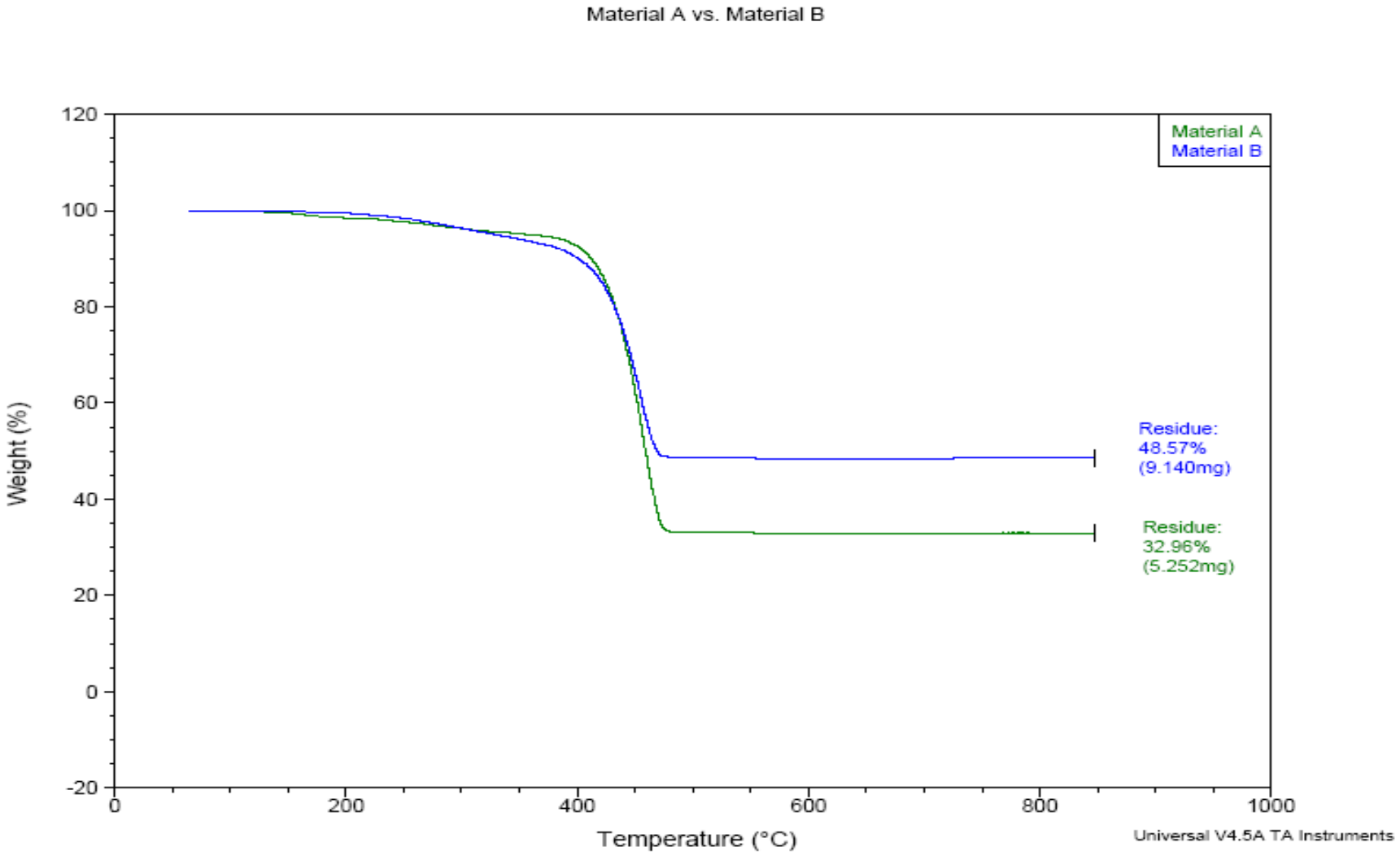
All images are scaled to the same height scale

FTIR Scan of Amorphous EPR (Material B) and Semi-Crystalline EPR (Material A)

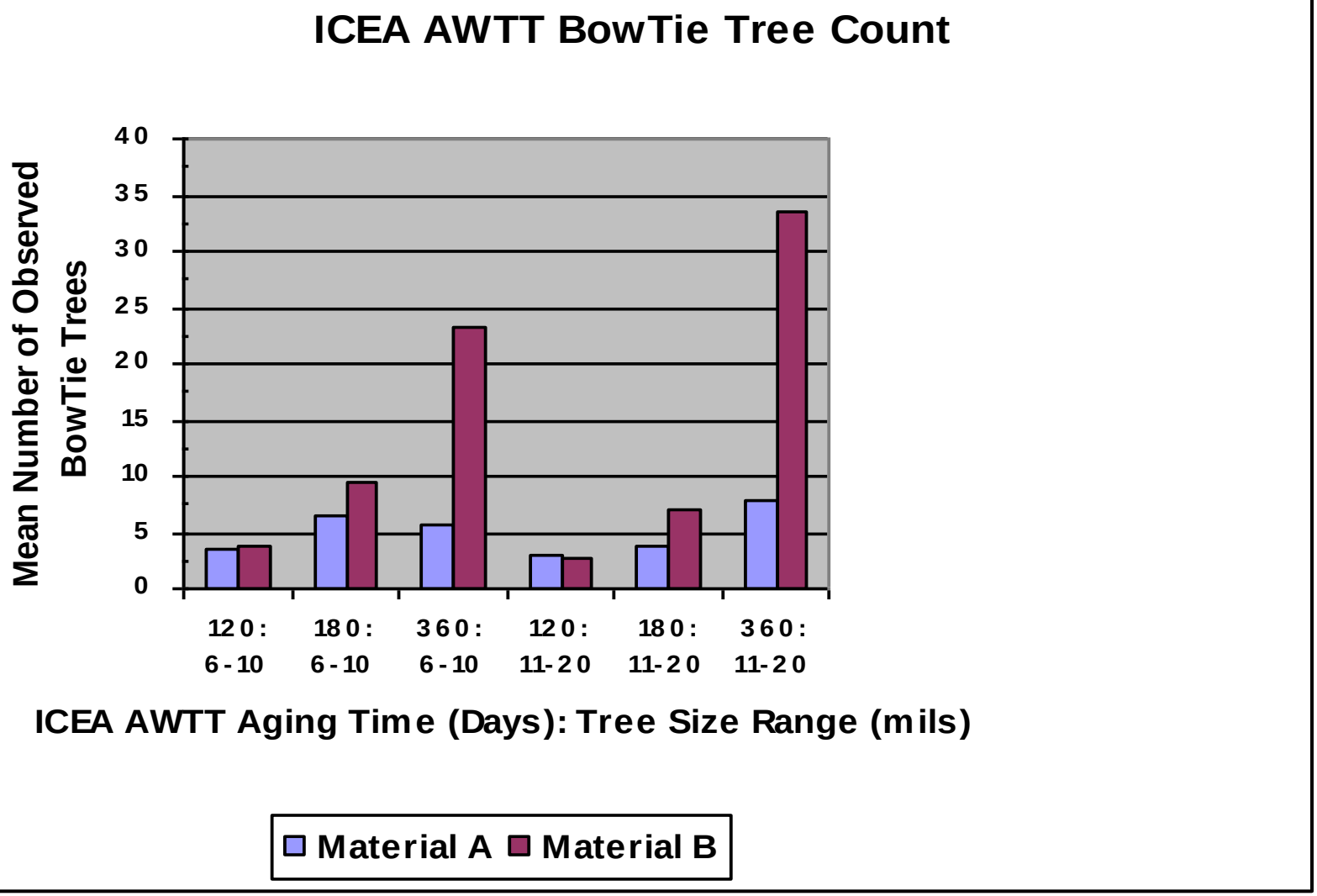


Virtually No Difference in the two Materials Except in Clay Filler Level

Thermogravimetric Analysis of Semi-Crystalline Material A and Amorphous Material B

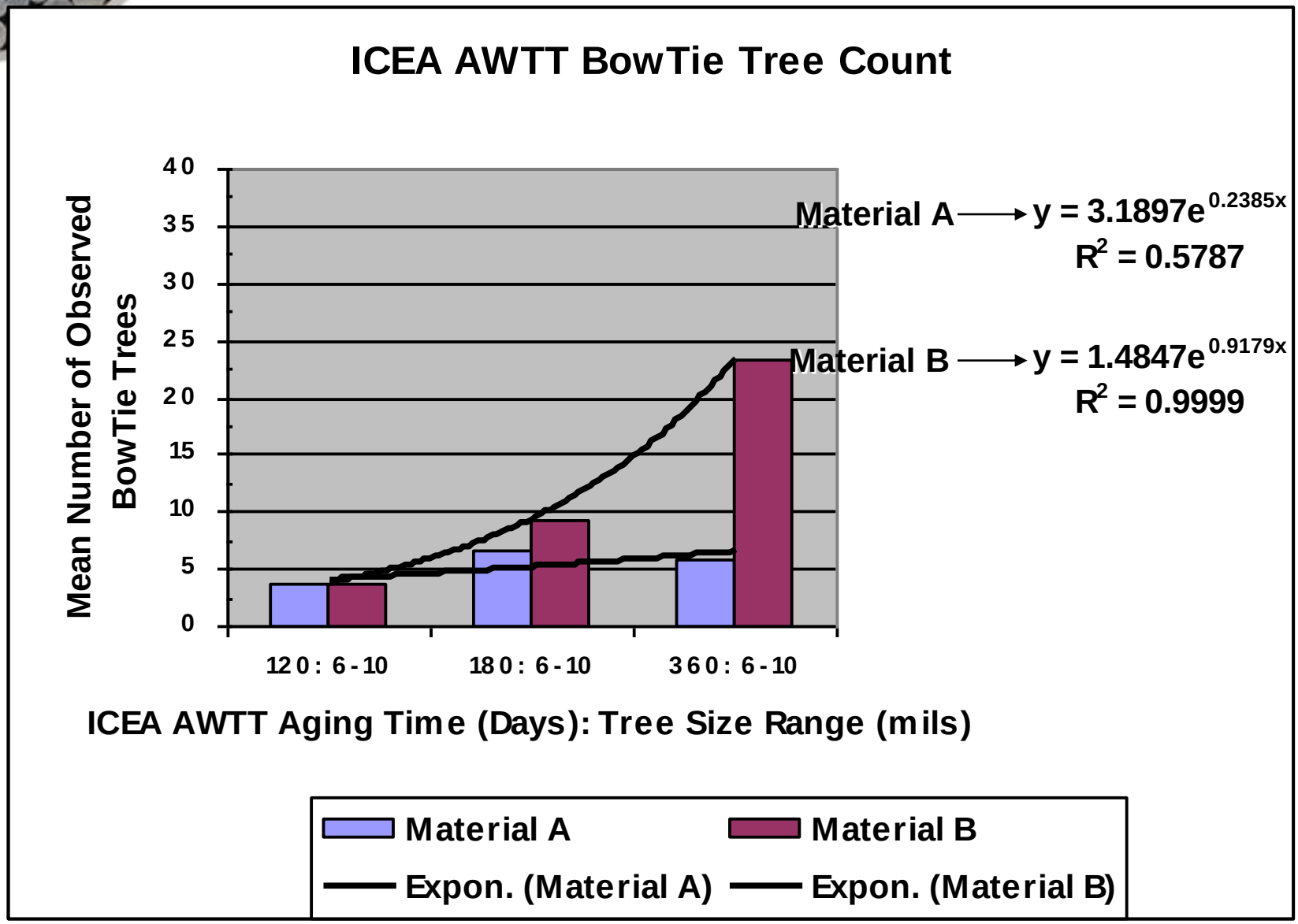


Bowtie Water Tree Count After ICEA Standard AWTT

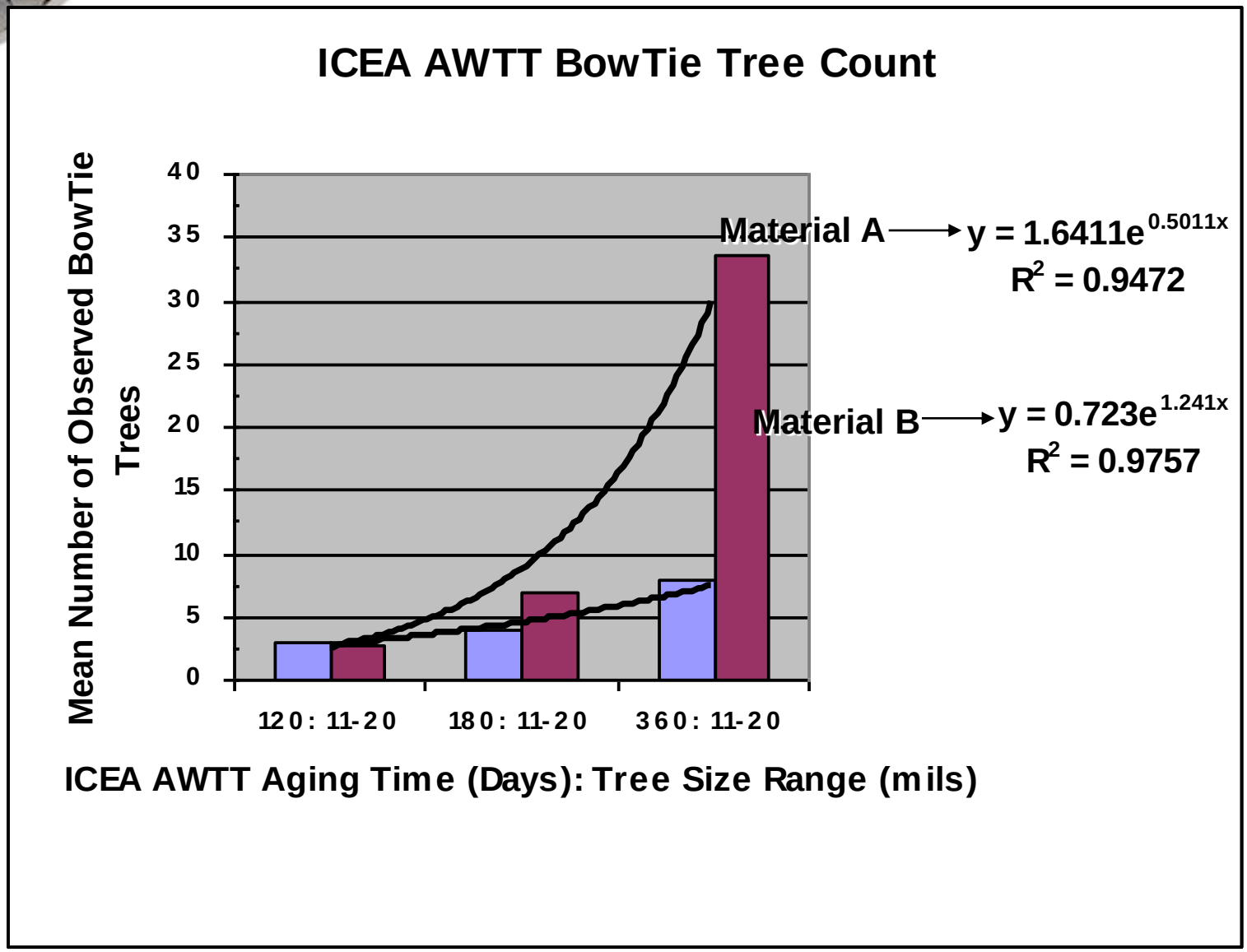


Material A is Semi-Crystalline EPR and Material B is Amorphous EPR. Trees more prevalent in Amorphous EPR than EPR with higher percent (%) ethylene content

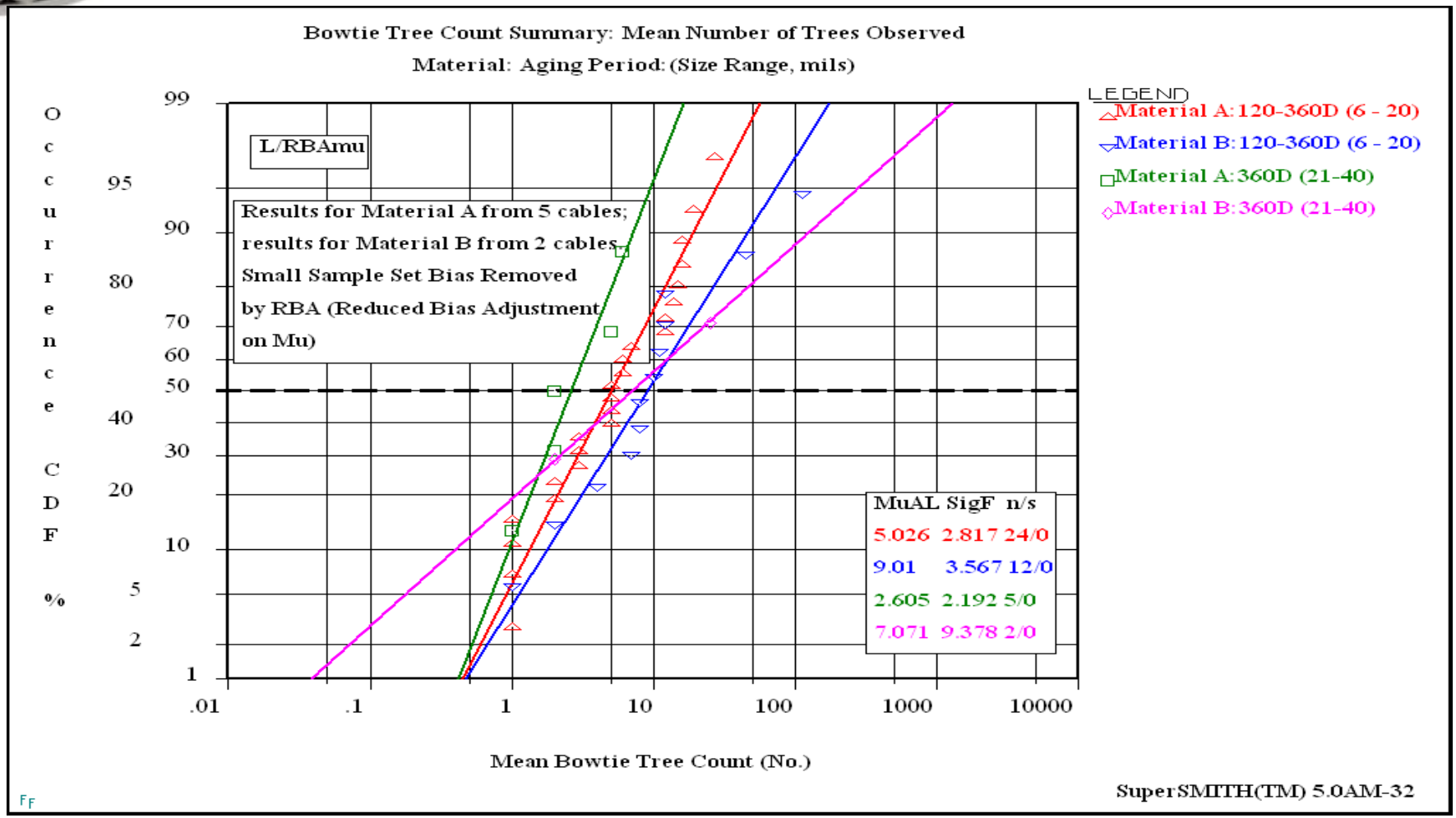
Bowtie Water Tree Count After ICEA Standard AWTT



Bowtie Water Tree Count After ICEA Standard AWTT

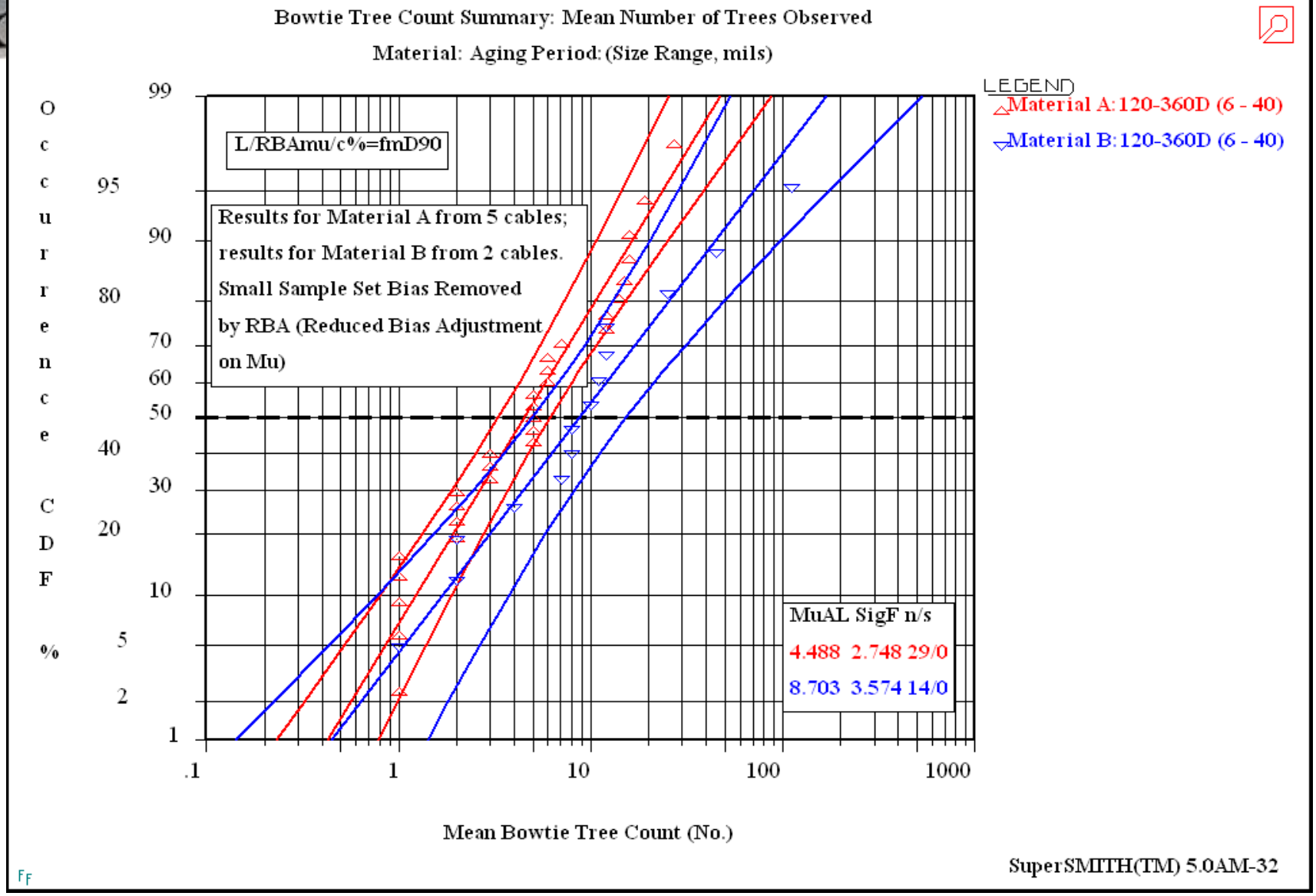


Bowtie Water Tree Count After Several ICEA AWTT Test Samples



Summary of the number of trees observed over the entire 1-year aging period for the indicated tree size categories for Material A and Material B

Bowtie Water Tree Count After Several ICEA AWTT Test Samples

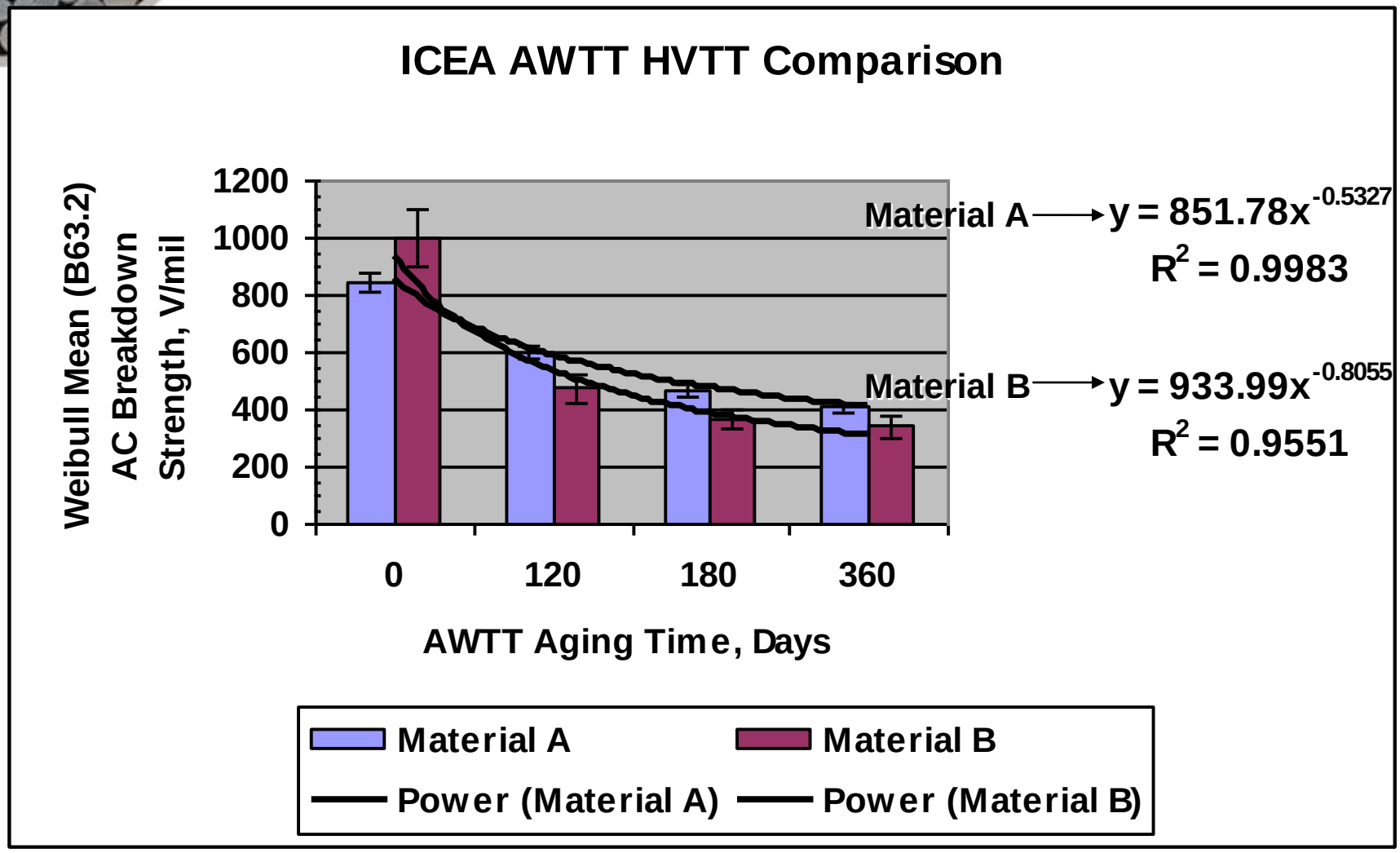


Summary of Bow-tie Water Tree Performance After ICEA AWTT

- **Number of observed Bow-Tie trees for Material A (ethylene content > 72%) in the 6 – 20mils size range for all aging time periods is statistically equivalent to Material B (ethylene content < 72%) at 90% confidence bounds**
  - **Number of observed Bow-Tie Trees for Material A are numerically lower than (or equal to) number of observed Bow-Tie trees for Material B**
- **Bow-Tie tree growth rate (as measured by power of exponential fit) is lower for Material A**
  - **For 6 – 10 mil Size range by ~ 4:1**
  - **For 11 – 20 mil Size range by ~ 2:1**

- **Trees are more prevalent in Amorphous EPR Material B (< 72% Ethylene Content) than Semi-Crystalline EPR Material A (> 72% Ethylene Content)**

AWTT HVTT AC Breakdown Strength Comparison



AWTT HVTT AC Breakdown Strength Comparison Summary

- **Material A semi-crystalline EPR (> 72% ethylene content) insulated cable has statistically higher retained ac breakdown strength after ICEA Accelerated Water Treeing Test (AWTT) than Material B Amorphous EPR (< 72% ethylene content)**

- **Material A (Semi-Crystalline) EPR insulated cable has statistically lower rate of degradation (by 34%) of ac breakdown strength after ICEA AWTT than Material B Amorphous EPR (< 72% ethylene content)**

Conclusions

- **EPR polymers when filled with reinforced clay in a suitable insulation compound do not show the same characteristics that work of Tohru, et. al showed in unfilled EPR polymers.**

- **The mean number of Bow-tie trees in a higher ethylene content EPR filled insulation system is numerically lower than (but statistically equivalent) to a lower ethylene content, more Amorphous EPR insulation material after ICEA S-94-649-2000 AWTT.**

Conclusions Cont'd

- **High ethylene content (>72 Wt.%) EPR Material A shows statistically higher ac breakdown strength than lower ethylene content (< 72 Wt.%) Material B after wet electrical testing**

- **This test data clearly indicates that limiting ethylene content in EPR to 72% by Wt. (or disallowing addition of a small amount of LDPE) does not correlate with susceptibility to treeing and corresponding cable failure**

- **Data to date has supported the Opposite. Higher crystalline EPR compounds are equivalent to more Amorphous EPR compounds, and show improvements in wet-aged electrical performance in some areas such as tree growth rate and retained ac voltage breakdown**

Thank you!