Effect of Additive Concentration on the Dielectric Properties of Extruded HVDC Cable Insulation

M. Niittymäki[1*], S. Lähteenmäki[1], K. Lahti[1], I. Rytöluoto[2], M. Mulakkal[2], B. Diban[3], G. Mazzanti[3]
[1]*Tampere University,* Finland, [2]*VTT Technical Research Centre of Finland*, Finland, [3]*University of Bologna,* Italy
*minna.niittymaki@tuni.fi

Introduction

- Under high DC field stress, **mitigation of space charge accumulation in extruded HVDC cables is a necessity**.
- A **promising method for space charge mitigation** in cable insulation material could be **adding grafted additives into insulation matrix,** e.g. maleic anhydride grafted PP (PP-g-MAH).
- This paper studies the **effects of different concentrations (0.5 wt-% to 8.0 wt-%) of grafted maleic anhydride (PP-g-MAH) in PP cable insulation** material by investigating their material and dielectric properties.

Studied materials

- The studied PP insulation blend consists of:
  - i) 60 wt-% homophasic PP random copolymer (RACO) with ethylene content of <5wt-%
  - ii) 40 wt-% heterophasic PP copolymer (HECO) essentially comprising PP homopolymer matrix with dispersed ethylene-propylene rubber (EPR) phase
- For the additivated blends, **0.5 wt-% to 8.0 wt-% PP-g-MAH** (Sigma Aldrich) was added without further modification.
- **SEM analysis**: PP-g-MAH has good dispersion in the PP blend.
- **DSC** 2nd melting endotherms showed melting enthalpies in the range of 59-65 J/g and peak melting temperature of ~149.6 °.C Adding up to 8 wt-% of PP-g-MAH did not affect these values markedly
- **FTIR:** all the studied PP copolymer blends show similar FTIR spectra.
  However, increasing the additive amount up to 8.0 wt-% forms free carboxylic acid groups which can be associated with formation of new (deep) charge traps.
- **Mechanical properties**: adding small amounts of PP-g-MAH has only minor effect on the mechanical properties (e.g. making the compound less rigid).

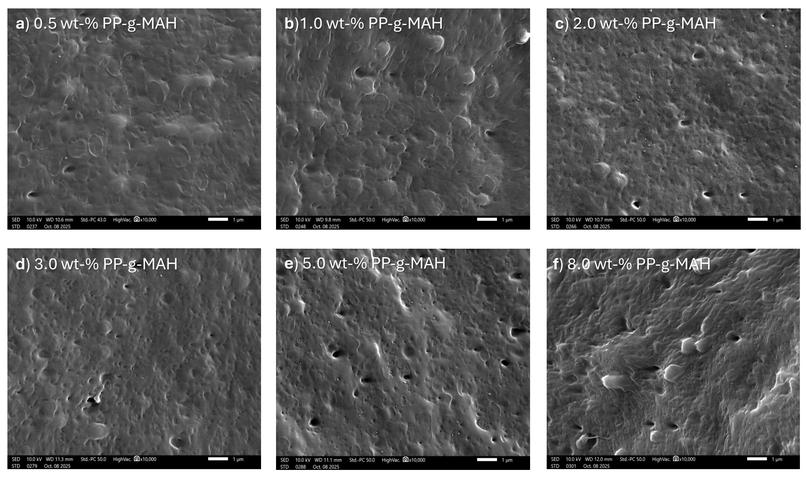


Fig. 1. SEM cross-sectional images of additivated PP blend compounds (10,000X magnification).

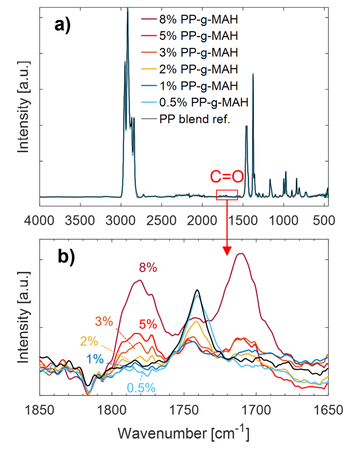


Fig. 2. a) ATR-FTIR spectra of the studied PP blends. b) Zoomed-in portion of the IR spectra in a) between 1650-1850 cm-1 (carbonyl range), showing the effect of increasing amount of PP-g-MAH.

Dielectric properties

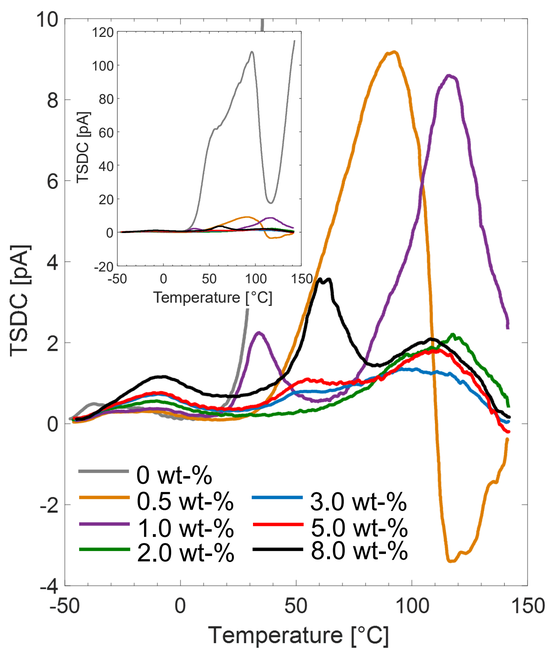


Fig. 3. Thermally stimulated depolarization current (TSDC) results for the studied blends. In the inset the low temperature region is given.

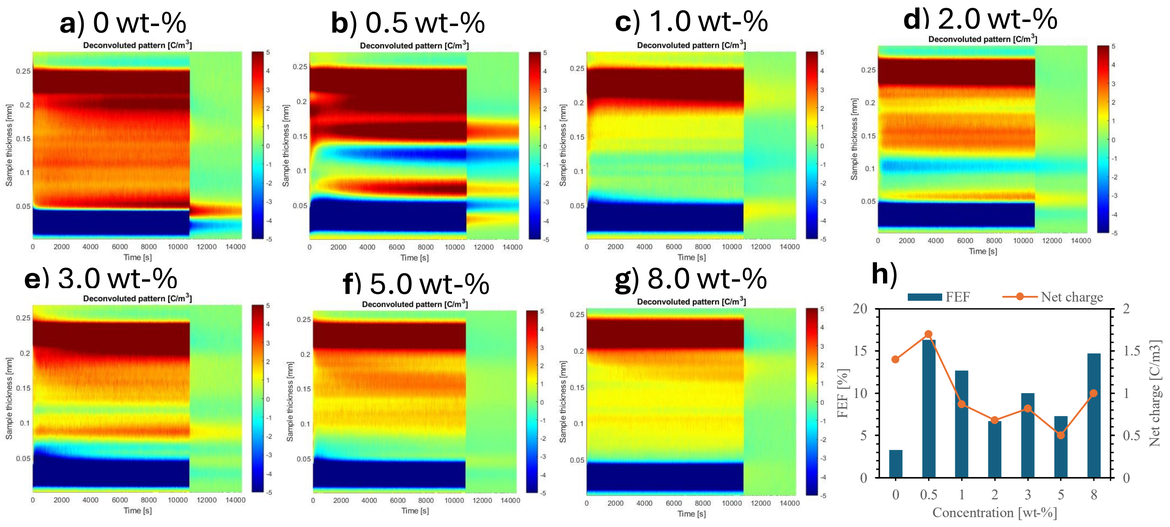


Fig. 4. a) – **g**) Space charge patterns for the PP blends with different concentrations measured by utilizing PEA method. Polarization was made under 30 kV/mm at 70°C. Polarization and depolarization durations were 10800 s and 3600 s, respectively. The color bar indicates the amount of charge in C/m³. **h**) Field enhancement factor (FEF) and net charge measured by PEA measurement at different additive concentrations.

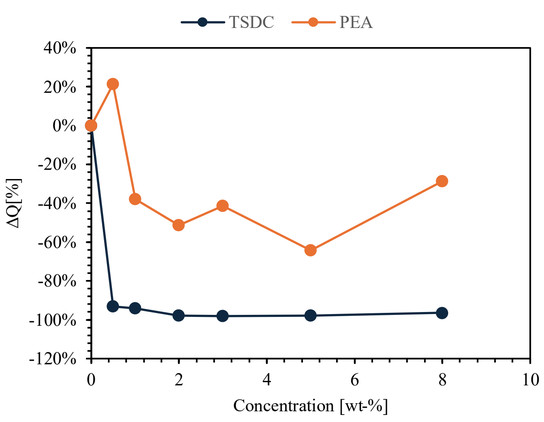
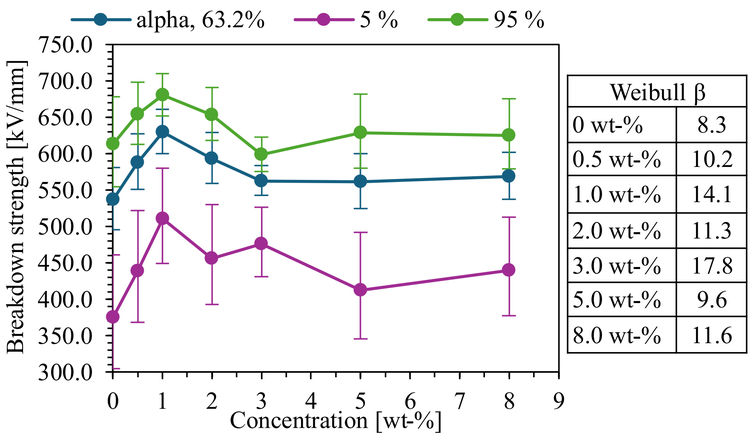


Fig. 5.. The relative charge from TSDC and PEA measurements as a function of additive concentration. ΔQ is the change between additivated PP blend compared to reference PP blend.



Weibull β	
0 wt-%	8.3
0.5 wt-%	10.2
1.0 wt-%	14.1
2.0 wt-%	11.3
3.0 wt-%	17.8
5.0 wt-%	9.6
8.0 wt-%	11.6

Fig. 6. Breakdown strength of the PP blends as a function of the additive concentration. The error bars present the 95% confidence bounds.

- **Charge relaxation properties** (i.e. thermally stimulated detrapping) show that a small amount of PP-g-MAH decreases TSDC current, see **Fig. 3.**
- Space charge mitigation can be observed from **space charge density profiles** presented in **Fig. 4**.
- Low FEF and net charge are observed at the concentrations of 2.0 wt-% and 5.0 wt-%.
- **A comparison between** net charge obtained from **PEA** and total charge of **TSDC** shows that 0.5 wt-% is too low concentration for space charge mitigation, see **Fig. 5.**
- Short-term **breakdown strength** (BDS) is at high level (Weibull α is 536 – 569 kV/mm), see **Fig. 6.**
- BDS increases slightly when the concentration is 1.0 wt-%, but the changes are quite small.

Conclusions

- Low concentrations of PP-g-MAH effectively mitigate space charge in PP-based cable insulation.
- The optimal PP-g-MAH concentration was studied.
- **No significant changes in morphological characteristics** are observed with PP-g-MAH contents up to 8.0 wt-%.
- According to TSDC and PEA, **the optimal concentration could be in the range of 1.0–5.0 wt-%.**
- The **concentration** of additive **does not have significant effect on the breakdown strength.**
- In the next phase, the most promising additivated PP blends will be studied more thoroughly, e.g. long-term properties are examined.

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