Detecting Disc-Shaped Flaws by Impedance Spectroscopy

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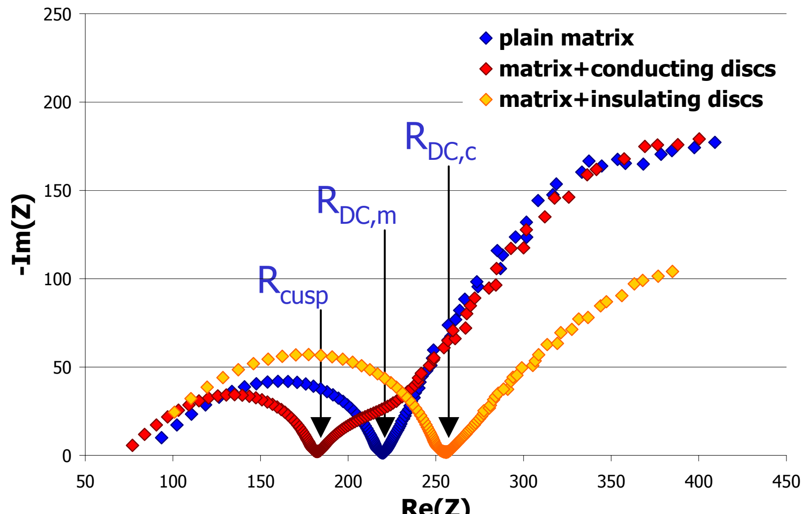
Model systems were made with right cylindrical discs in cement matrix and tested by AC impedance spectroscopy. The dual arc (conducting discs) and single arc (insulating discs) behaviors were analyzed for conductivity σ vs. disc volume fraction ϕ, based on the intrinsic conductivity approach:

$$\frac{\sigma_{composite}}{\sigma_{matrix}} = 1 + \underbrace{[\sigma]_{\Delta}}_{\text{Intrinsic Conductivity}}\phi + 0\phi^2, \quad \Delta \equiv \frac{\sigma_{disc}}{\sigma_{matrix}}$$

Typical Nyquist Plots (shown at ϕ=0.027, z-dir)



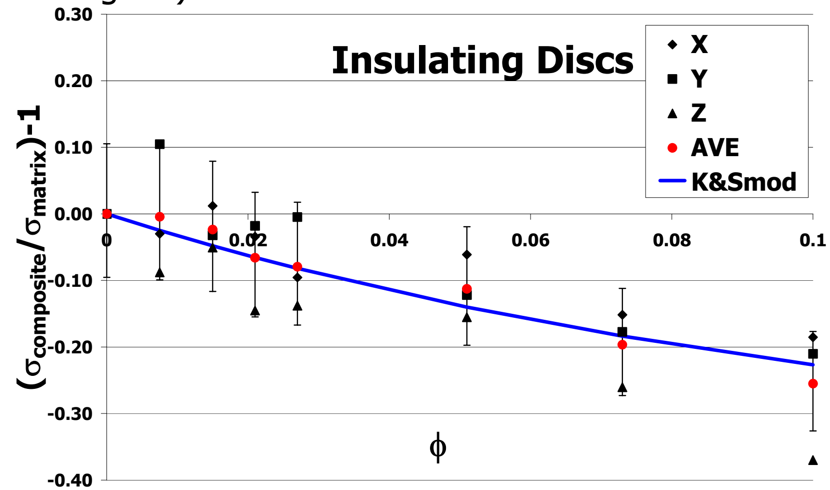
$$\frac{\sigma_{composite}}{\sigma_{matrix}} = \frac{R_{DC,m}}{R_{DC,C}}$$

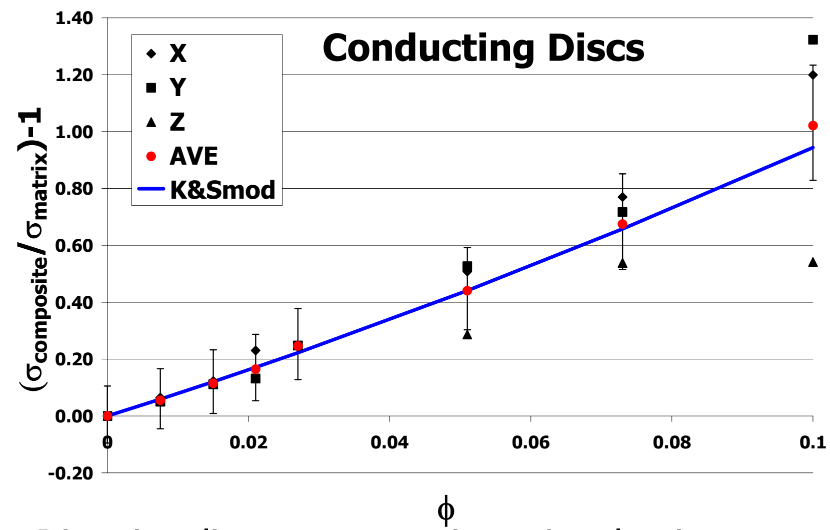
insulating discs

$$\frac{\sigma_{composite}}{\sigma_{matrix}} = \frac{R_{DC,m}}{R_{cusp}}$$

conducting discs

Results (averages) are in excellent agreement with existing mixing laws in semi-dilute regime, once suitably modified for difference in shape (right cylinders vs. oblate spheroids) and alignment (random vs. aligned).

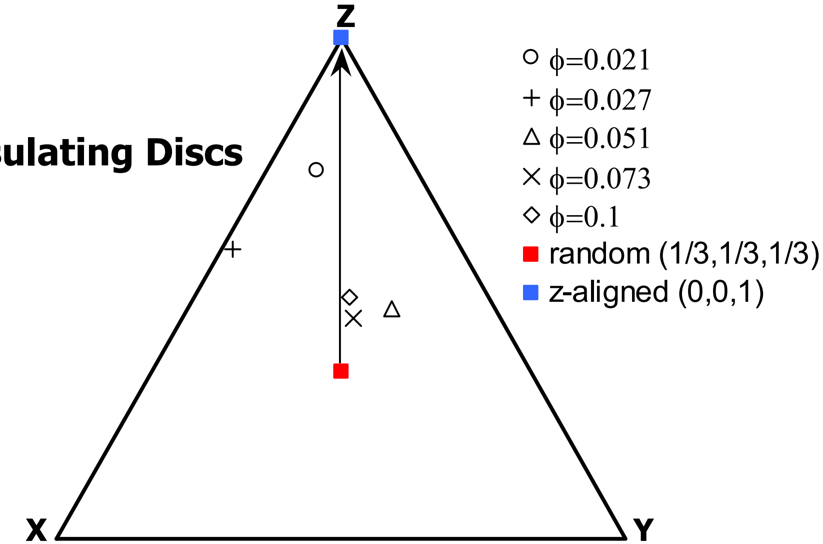




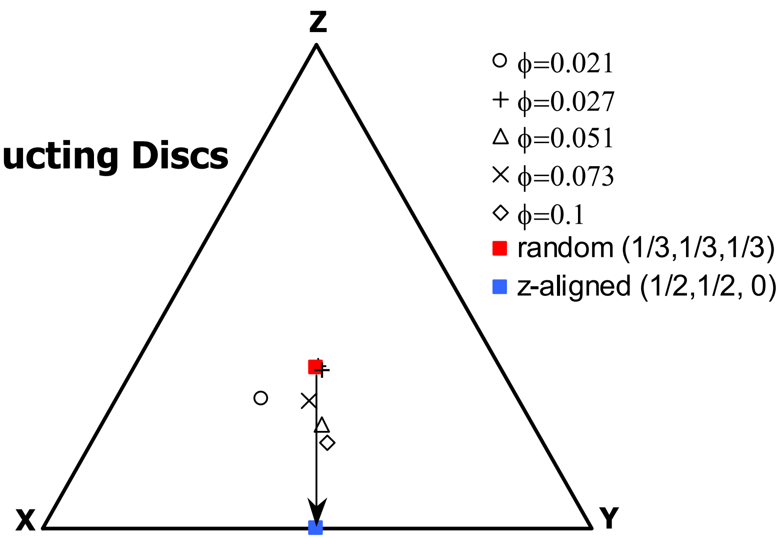
Directionality suggests orientational anisotropy →

Overall disc orientation characterized by $[\sigma]_{\Delta(i)}$, $i = x, y, z$ in a triangular representation with coordinates $([\sigma]_{\Delta(x)}/\Sigma, [\sigma]_{\Delta(y)}/\Sigma, [\sigma]_{\Delta(z)}/\Sigma)$

Insulating Discs

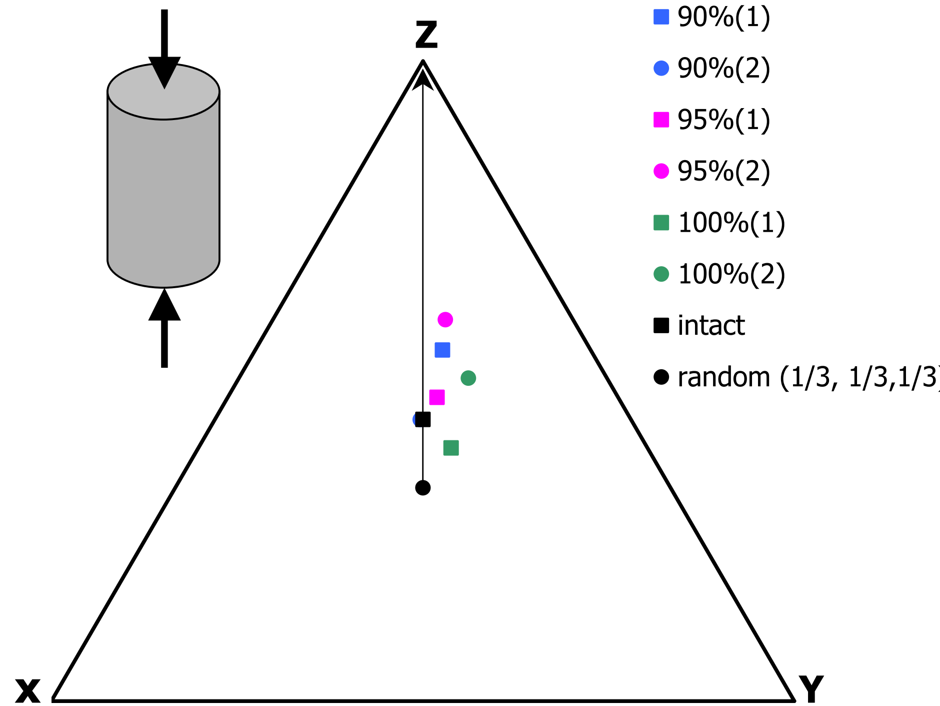


Conducting Discs



Lower z-axis conductivities (than for random distribution) suggests that greater than random fraction of discs were z-aligned (plane of discs || to x-y planes)

<u>Actual Composite Damage Studies</u>:
These results are completely general, with potential uses for composites with flakes or cracks. Once the role of cracks in the overall electrical properties is fully understood, it could lead to a novel non-destructive evaluation method, structural health monitoring, and the development of truly "smart" materials.



Example: Triangular representation for a series of cement-matrix composites (0.5 vol% steel fiber, 2 mm length x 30 μm dia.) subjected to different percentages of the peak compressive stress. Cracks were saturated by conductive solution.