Influence of electrode configuration on impact damage evaluation of self-sensing hierarchical composites

G. Uribe-Riestra[a,b], J. Ocampo-Bello[a,b], F. Gamboa[c], F. Mendoza-Santoyo[d], C. Pérez-López[d], E.A. Franco-Urquiza[e], M. Preud'homme[f], A. Castillo-Atoche[b], F. Avilés[a,*]

[a] Centro de Investigación Científica de Yucatán A.C., Unidad de Materiales, Calle 43 No.130 x 32 y 34, Col. Chuburná de Hidalgo, C.P. 97205 Mérida, Yucatán, Mexico.
[b] Universidad Autónoma de Yucatán, Facultad de Ingeniería, Av. Industrias no contaminantes por Periférico Norte, Cordemex, C.P. 97310 Mérida, Yucatán, Mexico.
[c] Centro de Investigación y de Estudios Avanzados del IPN Unidad Mérida, Departamento de Física Aplicada, km. 6 Antigua Carretera a Progreso, A.P. 73-Cordemex, C.P. 97310 Mérida, Yucatán, Mexico.
[d] Centro de Investigaciones Óptica, Loma del Bosque 115, Colonia Lomas del Campestre. C.P. 37150, León, Guanajuato, Mexico.
[e]CONACYT-CENTA-CIDESI, Centro Nacional de Tecnologías Aeronáuticas. Carretera Estatal 200 Querétaro-Tequisquiapan km 23 No. 22547. C.P. 76270, Colón, Querétaro, Mexico.
[f]CENTA-CIDESI, Centro Nacional de Tecnologías Aeronáuticas. Carretera Estatal 200 Querétaro-Tequisquiapan km 23 No. 22547. C.P. 76270, Colón, Querétaro, Mexico.

Supplementary Material

S.1. Electrical resistance of plates before impacting

The distribution of electrical resistance of as-manufactured plates (before impact) for the IS, BS and TT configurations are shown in Fig. S1. Each figure has two scale bars for the identification of the color maps; the one at the left represents the initial electrical resistance before impact (R_0, in kΩ), and the one at the right representing the same initial electrical resistance but normalized with the electrode separation (L) for each configuration (R_0/L, in kΩ/mm). The values of L were 10 mm for the IS and BS configurations, and 1.7 mm for the TT configuration. During the VARTM manufacturing process, the resin infiltration point was placed close to the (0,0) location, the resin front flows along the x direction, and vacuum is drawn closer to the (60,0) corner. For the IS configuration (Fig. S1a) R_0 is between 2.96 kΩ and 36.9 kΩ, with maximum values occurring near the left edge of the plate. For the BS

*Corresponding author. E-mail address: faviles@cicy.mx (Francis Avilés).

configuration (Fig. S1b) R_0 is between 4.59 kΩ and 42.8 kΩ, with maximum values along the right edge of the plate. Finally, for the TT configuration (Fig. S1c) R_0 is between 2.64 kΩ and 28.4 kΩ, with the highest R_0 occurring again close to the edges of the plate. The higher values of R_0 close to the edges of the plate indicates that those regions present zones with less density of MWCNTs (or more disaggregated networks). This is because the GF weaves act as porous media, and CNT aggregates can be trapped at the inlet. These aggregates become less frequent as the resin flow front moves through the plate following the pressure gradient, letting better dispersed CNTs and smaller CNT aggregates pass through the fibers to the outlet region (Reia da Costa et al., 2012). At the outlet, the flow front speed is small (Hsiao et al., 2000), and consequently, less amount of CNTs may be present at the edge close to the resin extraction point. Aside from the higher values of R_0 in a few localized zones close to the panel edges, most of the plate area present a quite uniform initial electrical resistance, indicating a reasonable distribution of the conductive filler (MWCNTs) within the composite. Notice also that the initial differences in R_0 are smeared out by the electrical resistance technique when using the fractional changes in electrical resistance ($\Delta R/R_0$) as the actual metric for damage assessment.

With respect to R_0/L, similar values are found for the IS and BS configurations, since the electrode spacing (L) is the same for both configurations. However, for the TT configuration R_0/L is up to four times higher than the values measured for IS and BS. This is because R_0 is similar for the three configurations, but the TT configuration has a smaller value of L (the plate thickness, ~1.7 mm). The higher values of R_0/L for the TT configuration suggests that the electrical conductivity is higher in the plane of the panel, i.e. with preferential electro-conductivity along the fiber direction (x,y). The electrical conductivity in the z-direction is

dominated by fiber contacts, which form less effective conductive pathways. This behavior can also be attributed to the flow of the CNT-modified resin during the VARTM process (Viets et al., 2014).

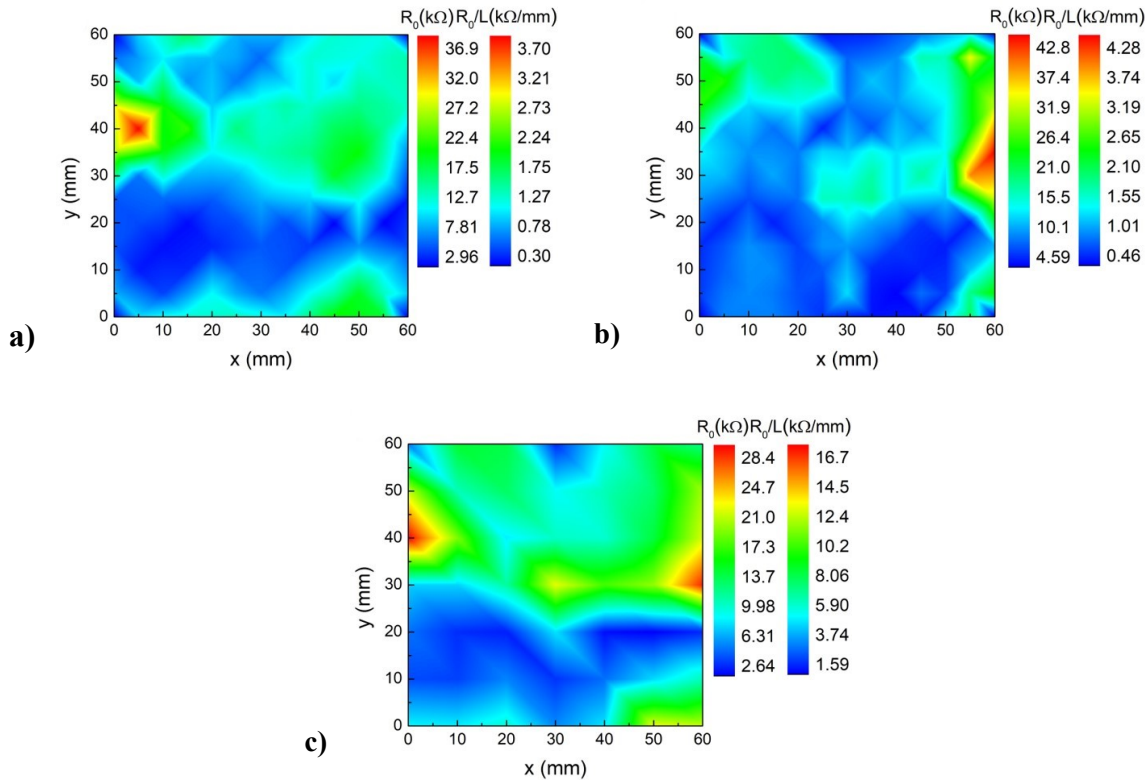

Fig. S1. Electrical resistance mapping of an as-manufactured composite plate. a) IS configuration, b) BS configuration, c) TT configuration.

References

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