AN INDEX FOR THE INDENTATION SENSITIVITY OF COMPOSITE LAMINATES

Giancarlo Caprino, Valentina Lopresto, Claudio Leone

Department of Materials and Production Engineering, University of Naples “Federico II”,
Piazzale Tecchio, 80, 80125 Naples (Italy)
e-mail: caprino@unina.it, lopresto@unina.it, leone@unina.it

Keywords: impact damage, indentation depth, impact energy, composite laminates.

Summary. Many factors, impactor shape and energy, constraint conditions, target thickness and laminate stacking sequence, may influence the permanent indentation of a composite panel subjected to low velocity impact [1]. Using a hemispherical tup 12.7 mm in diameter, $D_t$, in [2] the evolution of indentation depth, $I$, as a function of impact energy, $U$, was measured CFRP laminates of various lay-ups and thicknesses. As expected, $I$ increased with increasing $U$ and larger indentations were measured for lower thicknesses. The previous experimental data were then re-examined [3] and the effect of panel thickness can be eliminated if the ratio of the impact energy, $U$, to the perforation energy, $U_p$, is considered. Plotting the indentation depth against $U/U_p$ all the $I$-$U$ curves pertaining to different laminate thicknesses converged to a single master curve having equation:

$$I = I_0 \cdot \left( \frac{U}{U_p} \right)^\beta$$

where $I_0$, $\beta$ are material constants to be experimentally determined. It was shown that the two parameters actually influencing $I_0$ and $\beta$ are the fibre type and content. Additional indentation results were generated in a subsequent work [4] where a more effective formula, given by:

$$I = k \cdot 10^{\gamma(U/U_p) - 1}$$

was find to better describe the trend for higher $U/U_p$ values. In equation 2, the constants $k$, $\gamma$ has to be experimentally determined. In this work, the effectiveness of a new empirical model, aiming to predict the indentation depth resulting in a composite laminate from a hemispherical tup impacting it at low velocity, is verified:

$$I = \alpha \cdot D_t \cdot \frac{U}{U_p} \left( \frac{1}{1 - \frac{U}{U_p}} \right)$$
with \( \alpha \) being a material-dependent parameter. The advantages of eq. (3) compared with eqs. (1) and (2) is that the effect of the tup diameter is explicitly accounted for. Furthermore, a single material constant has to be experimentally determined. Since larger \( \alpha \) values result in larger indentation depths for a given impact energy, this constant can be assumed as an index for the indentation sensitivity, on the basis of which different materials can be ranked. Of course, in principle \( \alpha \) may depend on various parameters, such as the constraint conditions or the laminae orientation and stacking sequence in the laminate. This highlights the significance of the present work, whose objectives were: a) to assess equation (1); b) to verify the dependence of \( \alpha \) on the laminate type and constraint conditions.

To reach the above mentioned scopes impact tests were carried out in a Ceast Mk4 instrumented testing machine on three different composite systems in different stacking sequences, thickness and \( V_f \): a) a glass/epoxy prepreg; b) a graphite/epoxy prepreg; c) basalt/epoxy dry plain-wave fabrics. The samples were simply supported on a steel plate and struck at the centre by a hemispherical steel nose having 16 mm and 19.8 mm diameter. After impact, indentation was measured according to EN 6038 standard. The CFRP indentation data were drawn from a database: about 200 test records, generated by various researchers were individuated. As example, to demonstrate the effectiveness of equation (3), in Figs. 1, \( I/D_t \) was reported against \( U/U_p \) for the carbon fibre system. As anticipated, all the experimental points sensibly converge to a single master curve.

Figure 1: Non-dimensional indentation, \( I/D_t \), against non-dimensional energy, \( U/U_p \). Material: CFRP.

REFERENCES