Parametric Study of ENF Bonded Composite Joints Using Design of Experiments and CBBM Method

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Due to their wide applications and advantages, composite bonded joints have presented promising results compared to traditional techniques, such as bolting, welding, and riveting [1], [2]. Joint strength is the key property in evaluating the capability of the adhesive joint. However, due to the manufacturing process, mechanical and geometrical variations are factors that must be taken into account in the design of bonded joints, since there are intrinsic or epistemic uncertainties [3]. So, this work aims to evaluate the most important variable of End-Notched Flexure (ENF) bonded composite joints in terms of the critical fracture energy values G_{IIc} by using the design of experiments. Finite element models are modelled using two-dimensional numerical analysis in Abaqus® software [4], where a quadrilateral four-node plane strain element (CPE4R) were employed for modeling the composite adherents and a quadrilateral two-dimensional cohesive element (COH2D4) for the adhesive layer. The Cohesive Zone Model (CZM) was used with a linear traction-separation degradation law. All numerical models were generated using Python™ scripts linked with Abaqus®. The data accuracy is validated by experimental results [5]. Figure 1 shows an ENF joint containing the dimensions of the specimen and its boundary conditions.

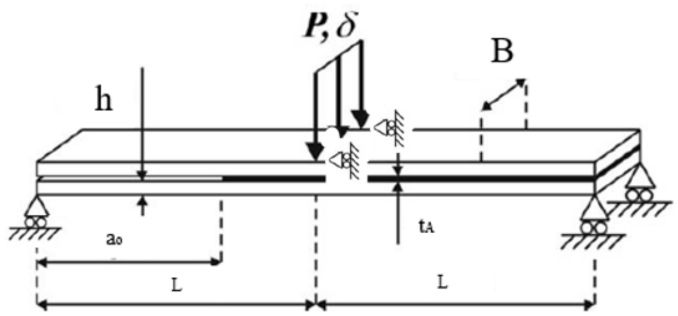

Figure 1 – ENF modeling containing its geometric dimensions: h – adherent thickness, a_0 – pre-crack length, 2L – adherent length, t_A – adhesive thickness, and B – adherent width. (Adapted from [6]).

A Design of Experiments (DoE) strategy is developed to reduce the number of experiments and to evaluate the effect of the design parameters. The space of design variables was defined in terms of the geometrical characteristics of the specimen and its material properties, totalizing 11 parameters. The placket-Burman method is used to define the number of numerical experiments [6], in which maximum (+) and minimum (-) levels correspond to a given mean value (μ) and standard deviation (σ). In other words, it is evaluated how much each variable influences the G_{IIC}. The force-displacement curves are obtained, and the Compliance-Based Beam Method (CBBM) is applied to determine the critical fracture energy in Mode II [7]. Thus, the Main Effect (ME) metric is used to analyze the influence of each parameter.

Finally, based on the Main Effect classification, the first five most influential variables in terms of the critical fracture energy values G_{IIc} and CBBM method are adherent thickness (h), adhesive thickness (t_A), critical strain release rate mode II (G_{IIC}), pre-crack length (a_0), and angular fiber variations on the laminate plane ($\delta\theta$). Also, it is noted that most of the variables presented epistemic uncertainty, represented by the geometric variables. Additionally, a force-displacement curve response envelope ($P \times \delta$) has been defined, where the respective numerical values for maximum and minimum limits are compared with experimental results from [4]. Therefore, it can be concluded that even with the computational model presenting limitations, it is still quite evident that the sensitivity analysis of the variables in an ENF test using the Plackett-Burman method was consistent. Finally, there is a good perspective for the application of this procedure to design composite joint structures.

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