Impact Characterization Diagram for Damage Resistance/Tolerance in Composite Structures

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Summary. This paper presents preliminary work on the utility of a characterization diagram in impact damage tolerance studies for composite structures. By placing the impact response on the diagram useful information on the type of response and damage could be deducted prior to running experiments. It is expected that this methodology could be a very powerful tool to designers and experimentalists who work in the area of commissioning composite structures for damage resistance and tolerance.

1 INTRODUCTION

Through simple lumped-parameter models and numerical simulations of various structures subject to low-velocity impact by spherical objects, we produced a characterization diagram, which is set of characteristic curves showing the functional relationship of normalized maximum impact force and three non-dimensional impact parameters, the "relative mobility, z," the "relative stiffness, l," of the structure, and the "effective mass ratio, m" [1]. The characterization diagram is shown in Figure 1. Using the characterization diagram, three response regions can be identified and classified: The local and infinite structure regions, where the normalized impact force depends on z alone, the transition region, where the normalized impact force depends on z, l and m, and the fully global or quasi-static region, where the normalized impact force depends on l alone. Definitions and methods (analytical, computational and experimental) to obtain the non-dimensional parameters are given in Reference [2].

2 IMPACT RESPONSE AND DAMAGE

In order to characterize the impact event (i.e. place the response in the appropriate region, get the type of response and maximum force), all that is required is the knowledge of the relative stiffness and the relative mobility of the structure. Furthermore, the characterization diagram can be used for damage resistance and tolerance studies. It is well known that the type of impact event has a significant effect on the response and consequently on damage. One use of the characterization diagram is to place the response, i.e. we can say before we run any simulation (experimentally or numerically) what type of a response we expect. Our conjecture is that we will also be able to say something about the expected damage. Preliminary work using ABAQUS simulations look promising. In Figure 1 the normalized maximum impact force for a number of simulations for a variety of aluminum structures are shown and compared to the characterization diagram predictions [2]. As it can be seen the agreement is excellent for the entire dynamic spectrum. In those simulations only local plastic deformation was accounted for and there was no structural damage. Figure 1 also shows simulations for a

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composite plate having relative stiffness of $\lambda = 0.078$ for three different type of responses, from the quasi-static to the infinite structure range. As it can be seen the maximum impact forces are lower than the predictions of the diagram, which is to be expected since the simulations include structural damage, such as delamination, matrix cracking and fiber failure. For the quasi-static case and for an undamaged plate, the characterization diagram would predict a normalized maximum impact force of 0.27 (9860 N), whereas the ABAQUS simulation with damage would predict 0.18 (6570 N). On an average sense all three simulations have a 32% reduction in the impact force due to damage. From the diagram it is deduced that the composite plate has a damaged effective $\lambda = 0.05$, which means that the plate has lost 37% of its original stiffness because of damage. Figure 2 shows the impact response for the composite simulations, demonstrating the different type of responses from the quasi-static to the infinite structure range, and the effect of damage on the response.

To the best of our knowledge, the main problem with available experimental data is that they are mainly quasi-static and/or small mass types, and thus they don't cover the complete dynamic spectrum of impact events. We expect that the most critical impacts are in the transition zone. Therefore, by using our characterization diagram we can design a 'smart' test matrix that covers the complete dynamic spectrum. Furthermore, we can do scaling studies where simpler structures are tested. We expect that this tool will benefit standards that aircraft manufactures use for impact commissioning structural elements. The CAI tests that are used for damage tolerance can be preceded with a more thorough impact testing matrix.

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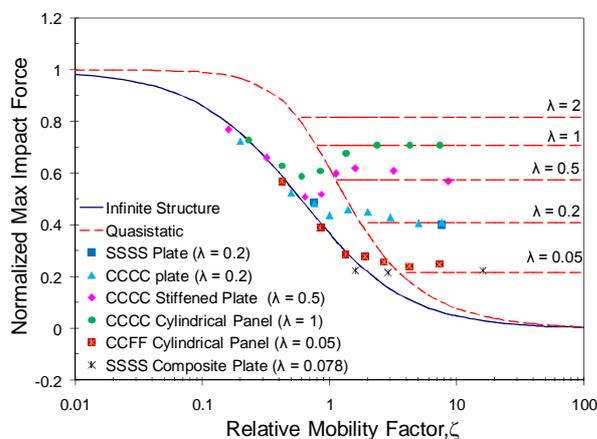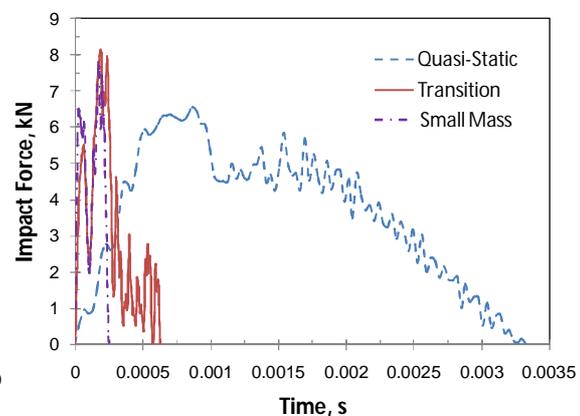
Fig. 1: Characterization Diagram

Fig. 2: Impact Response of Composite Plate