Chapter 3

Toughening for impact damage

Timothy L. Norman
Cedarville University, Cedarville, Ohio USA

and

C. T. Sun
Purdue University, West Lafayette, IN, USA

Abstract

In-service use of laminated composite materials commonly includes impact loading events including handling, tool drops, and foreign object impacts such as runway debris. Low velocity impacts often result in internal damage that is undetectable by visual inspection. Internal laminate damage can grow with fluctuating load and may severely degrade residual strength and stability of a structure, especially under compression loading. This chapter addresses the issues related to foreign body impact damage of composites. The chapter begins with fundamental definitions on impact of composites and then explores impact testing and post-impact evaluation procedures. Failure modes and post-impact residual properties will also be examined. The chapter concludes with a look at modern approaches used to improve the impact response of composites.

3.1 Low velocity impact

Numerous studies have been used to characterize composites under impact loading. Experiments are conducted over a range of impact velocities and classified as low or high velocity impact. Generally speaking, low velocity impact is considered an impact event which can be treated as a quasi-static (long) event and having an upper limit on impact velocity that varies from one to tens m/s depending on the target and the impactor's stiffness (material properties, mass, and boundary conditions) [1–4]. In a low velocity impact event, the time duration of the event is of sufficient length

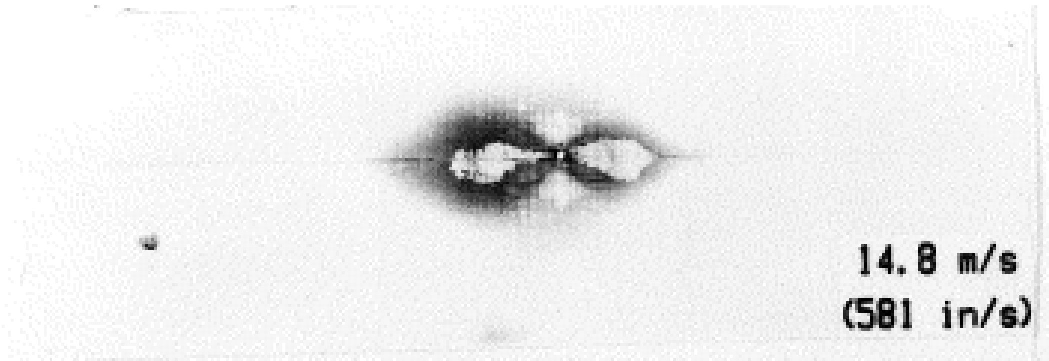

Figure 3.1: $[0_3/90_3/0_3/90_3/0_3]$ specimen after impact at 14.8 m/s velocity with a 2.22 cm (46 g) diameter ball and 5 J impact energy. The x-ray image shows significant delamination [7].

Impact event	Impact energy [J]
Falling tools	4
Runway debris	12–22
Refueling by gravity	20
Loading of pylons	16
Ramming of service platform	19
Hail impact	30–35
Aircraft/engine lifting and mounting equipment	5–57

Table 3.1: Typical impact threat for an aircraft structure (data from [12, Table 1]).

that the structural response plays a role in the total energy absorption of the target; furthermore, flexural waves and shear waves govern the plate's response [5]. Thus, for longer impact times, deflection and load have the same relation as in a static case [6].

Davies and Robinson [8,9] proposed a simple model that illustrates the transition to high velocity impact. The model defines low velocity impact when the through-thickness stress waves play no significant role in the stress state. The proposed model suggests a transition to stress wave dominated events at 10-20 m/s. An x-ray of a composite specimen impacted in this range (14.8 m/s and 5J) is shown in Figure 3.1. High velocity impact events are those for which the structural (quasi-static) response of the specimen has no time to develop before the event is completed; furthermore, the event is dominated by through thickness stress wave propagation [5]. In this case, damage can be localized and boundary conditions can be ignored. Others suggest that the classification of low vs high velocity impact can be made based on the damage found upon post-impact inspection [10, 11]; low velocity impact being characterized by delamination and matrix cracking and high velocity impact is characterized by fiber breakage, penetration, and in some cases perforation as discussed later in this chapter.

Impact events are often quantified in terms of impact energy. However, it has