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A Repair Criterion for Impacted Composite Structures Based on the Prediction of the Residual Compressive Strength

R. Borrelli[a*], S. Franchitti[a], F. Di Caprio[a], U. Mercurio[a,b], A. Zallo[c]

[a]CIRA S.C.p.A. – Centro Italiano Ricerche Aerospaziali, 81043 Capua (CE), Italy
[b]IMAST S.c.a.r.l. – Technological District on Engineering of Polymeric and Composite Materials and Structures, 80055 Portici (NA), Italy
[c]AVIO S.p.A. 00034 Colleferro (RM), Italy

Abstract

The residual strength in particular the compression strength after damages due to low velocity impact is one of the most critical issue for composite laminates. If the impact event induces relevant damages on composite components, a repair of the degraded parts is necessary. The aim of this work is to develop a repair criterion to be applied on the composite structures of the European launch vehicle VEGA. The criterion is based on a numerical procedure which was validated in a previous research work and which allows to predict the impact damage and the post impact residual strength as function of the impact energy, making possible to determine the energy threshold beyond which it is necessary to repair the component.

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1. Introduction

Fiber-reinforced polymer composites, especially CFRP, are very susceptible to reductions in strength due to accidental impact damage. For compression loaded structures, such reduction in strength can be important and it is typically accounted for in design through the use of conservative material design allowable. Composite structures impacted and damaged during maintenance or handling operations become production rejects resulting in huge economic losses. For these reasons, the definition and the validation of a repair methodology is a task of primary interest for composite manufacturers.

The aim of this work is to develop a repair criterion to be applied on the composite structures of the European launch vehicle VEGA. VEGA is a four stages vehicle; the first three stages (P80, Zefiro23 and Zefiro9) are powered

* Corresponding author. Tel.: +39-0823-62-3544; fax: +39-0823-62-3515.
E-mail address: r.borrelli@cira.it

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by one Solid Rocket Motor (SRM) which is typically a filament winding cylindrical composite case with closed dome. Each case is supplied with a forward and aft ward skirt which assures stages connection (Fig. 1).

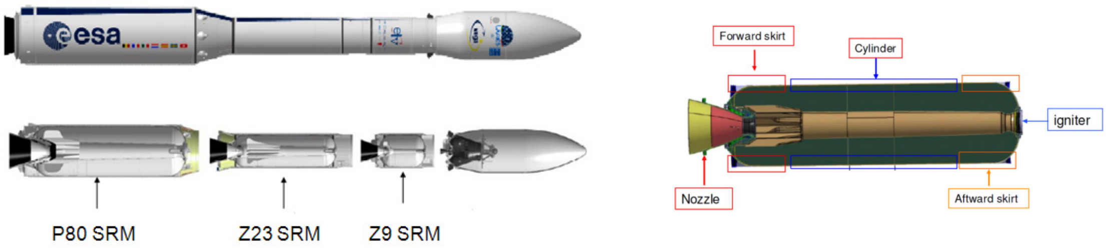

Fig. 1: Typical lay-out of VEGA SRM

The impact risk analysis starting from the manufacturing activity (composite case production) up to the final assembly revealed that, from an impact threat point of view, the most critical parts of the launch vehicle are the skirts. The skirts, which have the purpose of supporting the flight loads transmitted from the engine to the rest of the launcher, are mainly subject to compressive loads. Given such state of stress and given the large radii of curvature of the skirts it is reasonable to investigate the impact and post-impact behavior of these parts assimilating them to standardized Compression After Impact (CAI) 100 x 150 mm flat specimens.

The repair criterion proposed in this work has been applied on CAI specimens representative of the skirt parts of the three stages that constitute the launch vehicle. The criterion is based on the numerical procedure which allows to predict the impact damage and the post impact residual strength. Such research activity was developed within the context of the project PRADE, funded by the Italian Ministry of University and Research (MIUR).

2. Literature

In the past, a lot of effort has been spent on the prediction of the impact damage and residual strength of impacted composite structures. Abrate gives a good overview of impact studies on composite materials in his book [1] and his survey papers [2], [3]. Considerable experimental studies [4] - [9] have been devoted to the problem with the aim of improving impact tolerance and investigating sensibility to stacking sequences, thickness, impact location, resin and fiber properties. The use of composites in the manufacture of cryogenic fuel tanks for future reusable launch space vehicles was the motivation for the study performed in [10] on the CAI performance at low temperature of composite laminates subjected to low-velocity impact.

At each step of the certification process of composite structural components, a combination of testing and analysis techniques is typically performed [11] since only the testing can be prohibitively expensive due to the large number of specimens needed to verify every geometry, loading, environment and failure mode. Therefore developments of reliable analysis tools for the prediction of both the impact response and the residual strength are very important in order to assess and improve structures.

In literature the prediction of residual strength of composite structures is approached in different ways.

The difficulties in facing this kind of problem, from a numerical point of view, stay in the fact that the prediction of the impact response and the prediction of its evolution under the service loads belong to two different disciplines. Such disciplines are usually indicated with the terms “damage resistance” and “damage tolerance” and have historically travelled independently to each other: the impact event is a dynamic one and it is better simulated by using FE code based on explicit time integration scheme. On the other hands, service loads are usually applied in a quasi-static way making the use of implicit code more appropriate. For these reasons, many authors proposed to predict the residual strength of impacted composite laminates by replacing the real and complex impact damage with a simpler “artificial” equivalent damage like delamination [12] - [14] or open hole [15], [16]. Thus, the damage tolerance of the structure is investigated by including these equivalent defects in a simulation approach for determining the residual strength.