Impact coating for high-stressed composite structures in aerospace applications

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***Abstract*— This publication deals with impact coatings for aerospace applications. Impact-absorbing and impact-indicating coatings for the application of tension-/ compression rods in the aviation industry are investigated. Impact-absorbing coatings do not lead to the desired results, whereas the impact-indicating coating DW330 shows very good visualization of impact damage at low energies.**

***Keywords*— Impact, BVID, AirStrut®, Tie rod, tension-/ compression strut, coating, fibre composite, DW330**

I. Introduction

An impact load on fibre reinforced plastic laminates (FRP) often leads to significant damage within the laminate. They are barely visible on the laminate surface. In the aviation industry such impact damage is called "barely visible impact damage" (BVID). The damage is usually visible on the opposite laminate surface in case of appropriate impact energy. If impact loads cause fibre fractures, matrix cracking and delamination, the stiffness and strength of the composite is reduced. The residual compressive strength is determined, for example by CAI (compression after impact) tests [1].

Impact damage leads to reduced buckling stiffness, especially for FRP tension/compression rods (strut, tie rod, AirStrut®). The tie-rods are dimensioned with sufficient safety to withstand the ultimate load with an existing pre-damage of the laminate. Due to this requirement the laminates are thick-walled and increase the component's weight.

In order to increase the light-weight quality of AirStruts® new coatings are being investigated. In principle impact-absorbing or impact-indicating coatings can be used.

II. State of the Art

According to the current state of the art FRP struts are coated with a light textured lacquer. In order to provide additional FST (Fire Smoke Toxicity) properties, this lacquer is used for a better visualization of impact damage. The light colour creates a contrast in the area of the impact. Nevertheless the damage is difficult to detect and requires trained personnel. Fig. 1 shows an example of a light-coloured CFRP surface which has been pre-damaged with 8.5J.

Fig. 1: FRP with painted surface and impact damage (8.5J)

A lot of work has been done on the subject of impact damage on FRP structures, e. g. [2], [3] and [4]. For example coatings are known to change colour as a result of impact loads.

III. Types of Coatings

In the development phase impact-absorbing and impact-indicating types of coating were investigated. The reference is a painted "state-of-the-art" tie rod (see Fig. 2).

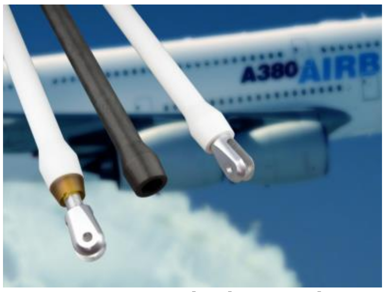

Fig. 2: State-of-the-art AirStruts® painted and unpainted

1. *Types of impact-absorbing coatings:*
    a. Aramid winding with top coat
    b. Elastomer coating with top coat
    c. Polyester winding with top coat

The impact is damped by an absorbing coating whereby as much energy as possible is converted by the coating (cross-section see Fig. 3). This can lead to a higher residual compressive strength.

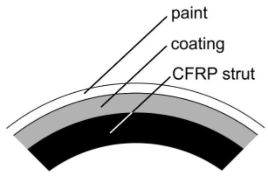

Fig. 3: Schematic image of a CFRP tubular body with partial cross-section with coating and top paint

2. *Types of impact-indicating coatings :*
   a. Two-component rigid foam
   b. DW330

An indicating-coating should visualize an impact as early and clearly as possible. For example this can be achieved by plastic deformation of the coating. Similar to the absorbing-coating a small portion of the energy is absorbed. This allows a BVID to be triggered at low energy impact levels without causing significant damage on to the laminate. Struts with such a coating therefore have the same residual compressive strength as a state-of-the-art AirStrut® with a lower component mass.

IV. Samples

In the tests state-of-the-art tie-rods are used for various coating tests, impact tests and tensile and compression tests. In addition tube specimens (d_i 27,5mm; d_o 36mm; L 300mm) are used for impact tests, ultrasonic tests and microscopic examinations.

V. Tests

1. *Impact tests*

The impact tests are carried out by means of a drop tower. A spherical impactor with a diameter of 16mm is used (see Fig. 4).

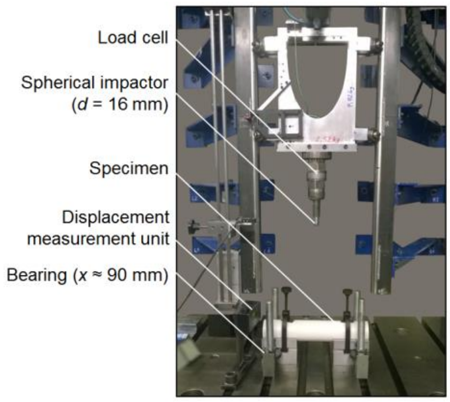

Fig. 4: Impact drop tower

2. *Tension- and compression tests*

The tensile and compression tests are carried out with a servo-hydraulic 250kN machine. The following test method is used:

a. Apply a preload of 1kN with 8mm/min
b. Hold the preload for 3s
c. Unload to 200N
d. Apply the load with 2mm/min (displacement controlled)

3. *Ultrasonic tests*

In order to evaluate the laminate damage after impact tests the specimens are subjected to ultrasonic testing using the pulse-echo method in a dip tank with water as the coupling medium.

4. *Microscopic examinations*

To measure the indentation depth of the damaged surface, microscopic examinations are carried out on the samples.

VI. Results

The impact tests on state-of-the-art struts with topcoat show that even at high energies only a small indentation depth (< 0.1mm) is generated. The BVID level depends on several factors: Local stiffness, wall thickness, fibre orientation, surface quality, etc.. Preliminary impact tests show that the BVID level can vary between approx. 7J and 32J depending on these factors.

No significant influence of the impact on the residual strength under tensile load could be determined whereas an impact has got a significant influence on the residual compression strength. Fig. 5 shows the force-displacement diagram of an undamaged strut and a strut which has been pre-damaged with 10J (impact position in the middle).

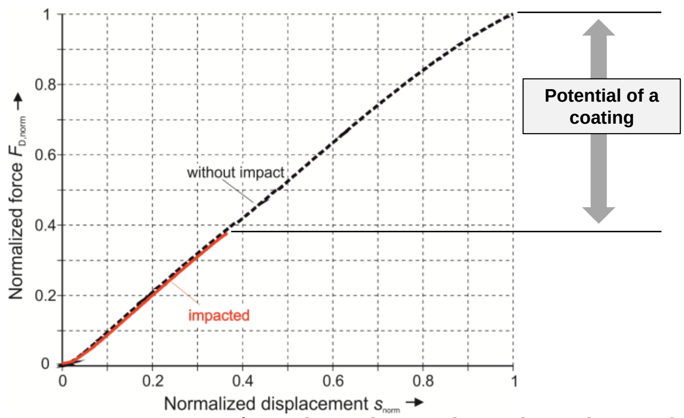

Fig. 5: Compression test of an undamaged strut and a pre-damaged strut with 10J

There is a force difference of approx. 60% between the tested struts. This means that an enormous weight saving is possible due to a suitable coating.

AirStruts® with impact-absorbing coatings are loaded with defined BVID energies (see Table 1).

TABLE I. IMPACT ABSORBING-COATING - BVID ENERGY AND WEIGHT

Coating (top layer, painted)	**BVID energy** [J]	**Weight per length** (relative)
Reference	8,5	100%
Aramid layer	8	+ 12%
Elastomer layer	10	+ 19%
Polyester layer	8	+ 19%

Fig. 6 shows the force-displacement diagrams for struts with an absorbing coating and a pre-damage according to Table 1.

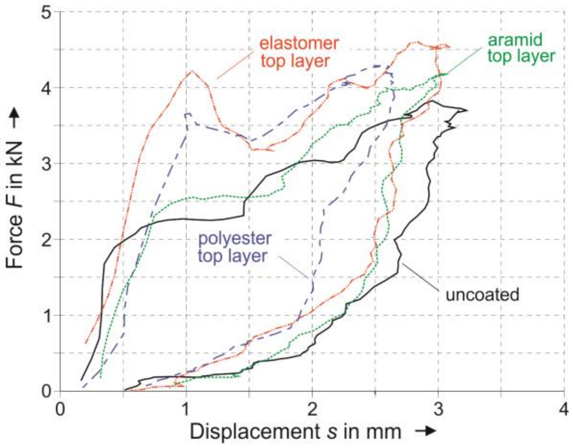

Fig. 6: Force-displacement diagram of struts with impact-absorbing coating

The results show that only a slight increase in force could be achieved even with an impact-absorbing coating. As the additional coating mass or the total component mass is a key factor, the tested impact-absorbent coatings are not suitable for the application.

In the tests of impact-indicating coatings, preliminary tests are carried out on plates with a wall thickness of 10mm made of the corresponding materials. Both plates are subjected to the same impact energy (see Fig. 7).

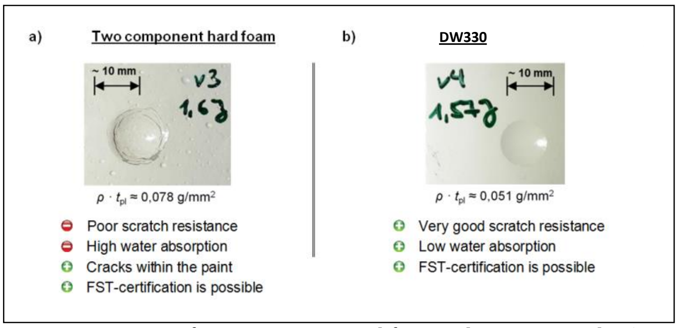

Fig. 7: Comparison of two component rigid foam and DW330 samples (Epot ≈ const.; t_{pl} plastic indentation depth)

Both types of coating already display significant plastic deformations at low energy impacts (< 2J). The DW330 coating proves to be beneficial. All further tests are carried out on CFRP tube samples. Different wall thicknesses and formulations of the coating are tested. Ultrasonic inspections show that all specimens with an energy load of approx. 8.5J will cause extensive damage to the laminate. If the wall thickness falls below 0.7mm, even impacts with an energy of ≤ 1J cause slight damage to the laminate. For this reason a minimum wall thickness of 0.7mm is targeted for the impact-indication coating. Fig. 8 shows an example of a C-scan of a tube specimen with impact and coated with DW330.

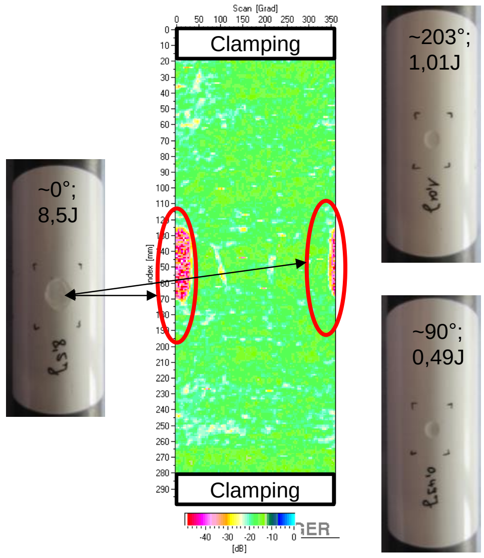

Fig. 8: Ultrasonic C-Scan of a CFRP tube sample incl. DW330 coating with different impact energies

The indentation depths for different impact energies (see Table 2) are measured on the basis of the microscopic investigation of the impact (see Fig. 9).

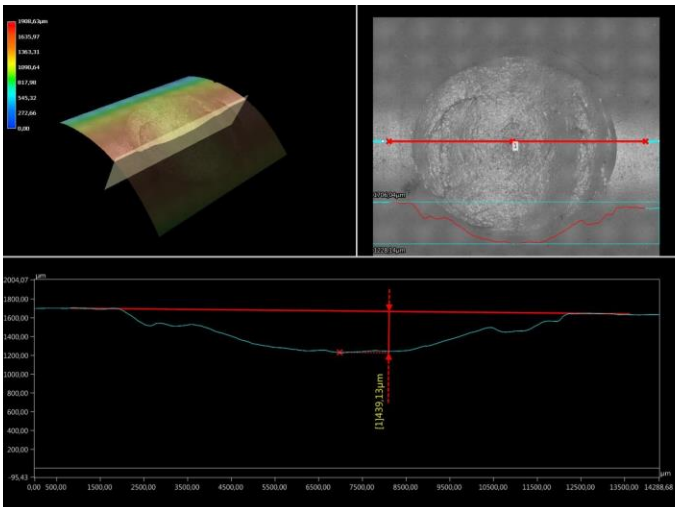

Fig. 9: Microscopic image of the DW330 coating (wall thickness 0.7mm) and an impact of 8.5J

TABLE II. INDENTATION DEPTHS OF DW330-COATING (WALL THICKNESS 0,7MM) FOR DIFFEREND IMPACT ENERGIES

Impact energy [J]	**Indentation depth [µm]**
8,5	439
1,01	328
0,49	323

The DW330 coating visualizes impact loads even at low energies (< 1J). As a result struts with such a coating could be dimensioned much lighter.

With the developed DW330 coating, there is a weight saving potential of approx. 40% compared to state-of-the-art struts with conventional topcoat at the same ultimate load. The coating could be adapted to increase the BVID limit energy.

VII. CONCLUSION

As part of the development of an impact coating, impact tests were carried out with subsequent tensile and compression tests on impact-absorbing coatings. It was determined that the absorbing properties of the coatings do not provide any additional benefits for AirStruts® compared to the additional coating compound.

Impact tests on impact-indicating coatings show an early visualization of the impact at low energies. A coating consisting of DW330 has proven to be particularly suitable. Struts can thus be dimensioned more weight-optimized and offer a weight-saving potential of approx. 40% compared to conventional AirStruts®.

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