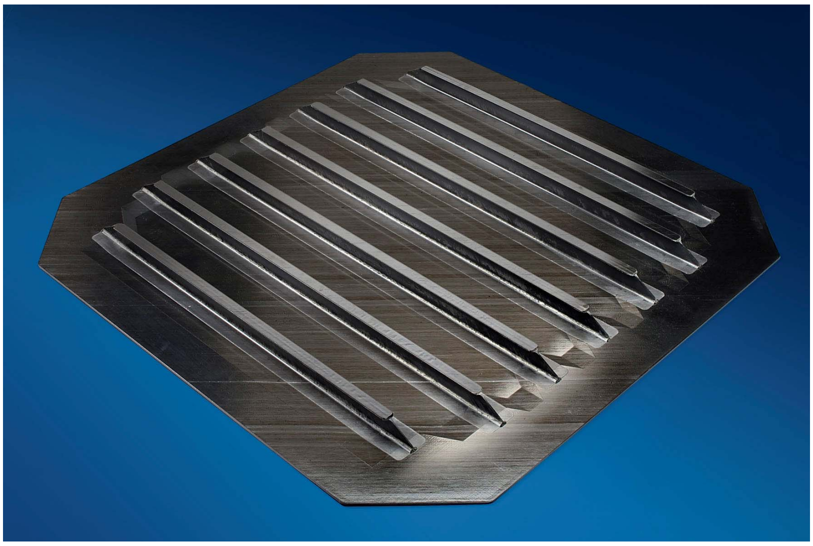
Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Executive summary

Innovative Stiffening concepts for thermoplastic panels



Problem area
Up to now most primary composite airframe components are made of thermoset materials. However, there is an increasing interest to use thermoplastic materials instead of thermoset materials. One of the main reasons is that thermoplastics have superior toughness properties compared to thermoset materials resulting in lightweight damage tolerant structural components.

Description of work
NLR started a research programme into co-consolidation techniques for innovative stiffened thermoplastic panels of carbon fibre reinforced PEKK. The objective of the programme was to demonstrate the feasibility of the innovative and very cost efficient ***ring*** and ***plate*** stiffener concept for beams, ribs and panels.

Results and conclusions
Test panels with ring and plate stiffeners were manufactured and tested statically in shear and compression. The test program also included damage tolerance aspects since a number of test panels were impacted during the tests.
The tests showed the feasibility of the ring and plate stiffener concepts since all panels failed beyond their expected failure load.

Applicability
The ring and plate stiffener concept can be applied in primary aircraft structures like frames, beams and panels for aircraft and helicopters.

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This report is based on a presentation held at the SAMPE Europe SETEC 03/-08 Technical Conference, Augsburg, Germany, September 18th -19th 2008.

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Summary

Up to now most primary composite airframe components are made of thermoset materials. However, there is an increasing interest to use thermoplastic materials instead of thermoset materials. One of the main reasons is that thermoplastics have superior toughness properties compared to thermoset materials resulting in lightweight damage tolerant structural components.

Within this scope NLR started a research programme into co-consolidation techniques for innovative stiffened thermoplastic panels of carbon fibre reinforced PEKK. The objective of the programme was to demonstrate the feasibility of innovative stiffening concepts for beams, ribs and panels.

The paper will present the new innovative concept for stiffening beams and panels and will highlight results of the manufacturing trials followed by the results of several test campaigns.

Contents

1 Introduction

The use of composite materials in aerospace industry is increasing exponentially. The prime reasons for this increase are the targets that are set by the aircraft manufacturers to reduce both weight and cost drastically [1]. Until now most of the primary composite components are made of thermoset materials. However, from a weight efficiency point of view thermoplastic materials offer more potential due to the superior damage tolerance character (caused by the high allowable strain levels) in comparison to thermoset materials. Other advantages of thermoplastic materials in comparison to thermoset are [2]:

- Improved chemical resistance
- Improved fire, smoke and toxicity
- Not a hazardous substance
- Possibility of welding
- Room temperature storage
- Unlimited shelf live.

Disadvantages are:

- Higher processing temperatures
- Higher costs/kg
- Availability.

The objective of the programme described in this paper was to develop innovative stiffening concepts for beams and panels by fully exploiting the advantages of thermoplastic materials.

2 Ring Stiffener Concept

Thermoset beams and ribs often are stiffened by integral stiffening elements like beads. These double curved components often are manufactured using fabrics as fibre reinforcement in order to allow draping of the fibre in the area of the beads. Also the manufacturing tools and the vacuum bag can become rather complex in order to avoid fibre bridging of the fabric in the concave double curved areas of the beads. Cost reductions can be realised by composing the beams and or ribs from flat or single curved elements.

Figure 1: Fibre placement machine used to manufacture the thermoplastic tubular element.

This concept was evaluated by developing a ring stiffener as stiffening element for the webs of these structural elements. The concept can be described as follows. First a flat plate is made from thermoplastic unidirectional tape. Then a tubular element is manufactured using Advanced Fibre Placement (see Fig. 1). This tubular element then is cut into slices. These slices are co-consolidated to the flat plate in order to provide the required stiffening element. The advantage of this concept is that:

- Unidirectional tape can be used instead of fabric which has a positive effect on the weight and cost of the component
- The autoclave tooling and vacuum bags are very simple and easy to use because of the lack of double curved surfaces.

Four different specimens were made (see Fig. 2) to demonstrate the feasibility of the concept: two without a central hole and two with a central hole. The specimens were tested in shear by using a picture frame test set-up (see Fig. 3). The failure mode of the specimens with the ring stiffeners showed that failure initiated from the base plate and not from the interface between the ring stiffener and the base plate. The results of the tests are presented in table 1. The table shows that the ring stiffener concept is a very promising concept for stiffening the webs of beams and ribs.

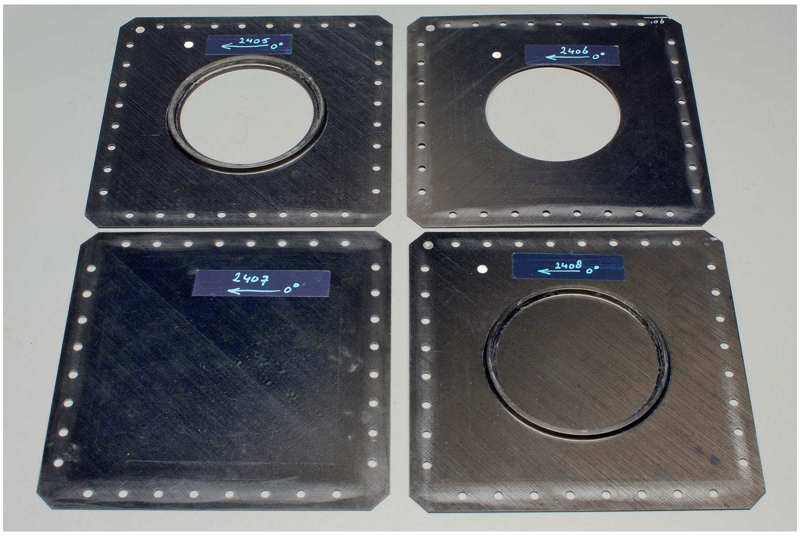

Figure 2: Four specimen configurations used to evaluate the feasibility of the ring stiffener concept.

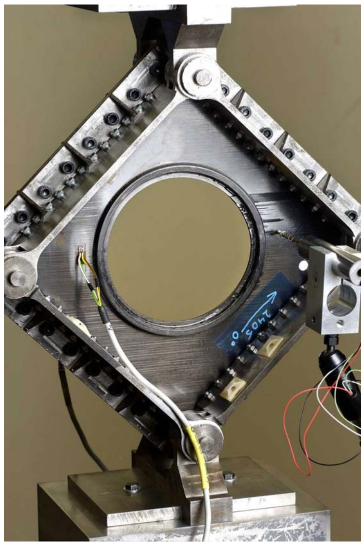

Figure 3: Picture frame test set-up showing the failure mode originating from the base plate and not from the interface between the ring stiffener and the base plate.

Table 1: Test results of the ring stiffened panels loaded in shear.

ID	Configuration		Failure load (kN)	Thickness
	Hole	Ring	Test	(mm)
2407	No	No	20.6	1.93
2406	Yes	No	12.7	1.98
2408	No	Yes	49.9	1.90
2405	Yes	Yes	27.9	1.91

3 Plate stiffener concept

After the successful demonstration of the ring stiffener concept, the plate stiffener concept was evaluated as an attractive concept for stiffening panels for movables and or stabilizers. The concept of the plate stiffener is the same as for the ring stiffener. This means that flat thermoplastic plates are cut into strips which are co-consolidated to a thermoplastic base plate. In order to test the feasibility of the concepts, small stiffener-skin specimens were manufactured (see Fig. 4). FEM analyses and static stiffener pull-off tests were carried out. The static strength of the plate stiffener concept outperformed the results of stiffener pull-off tests on traditional blade stiffener specimens [3].
The next step in the development of the plate stiffener concept was to develop a manufacturing method for plate stiffened panels.

Figure 4: Plate stiffener specimen

After several trails a feasible tooling and manufacturing concept was realised and several panels were manufactured by consolidating strips (strips for the web of the stiffener and strips for the top flange of the stiffener (see Fig. 5) to a base plate (see Fig. 6).

One shear panel and two compression panels were manufactured. The panels were designed for:
- Local buckling at Limit Shear Load.
- Local buckling at Limit Compression Load.
- Local strain criterion at Ultimate Shear Load.
- Local strain criterion at Ultimate Compression Load.

Ultimate Load was defines as 1.5 times Limit Load.

Figure 7 presents an overview of the plate stiffened panel tested in shear. Figure 8 presents the panel tested in compression. In both pictures the local buckling pattern clearly can be identified. Test results in terms of failure load show that the strain criteria used are rather conservative if applied to the current thermoplastic material based stiffening concept. One compression panel was impacted from the skin side in the middle of the central stiffener with 35 Joule in order to demonstrate the damage tolerance properties of the panel concept. The panel reached 1.1 X

Ultimate Load without failure. The panel then was impacted at the same location with 50 Joule and was loaded to failure. It failed at 1.67 x Ultimate Load. The results of the static tests are presented in tables 2 and 3.

Figure 5: Strips to form the individual elements of the plate stiffeners

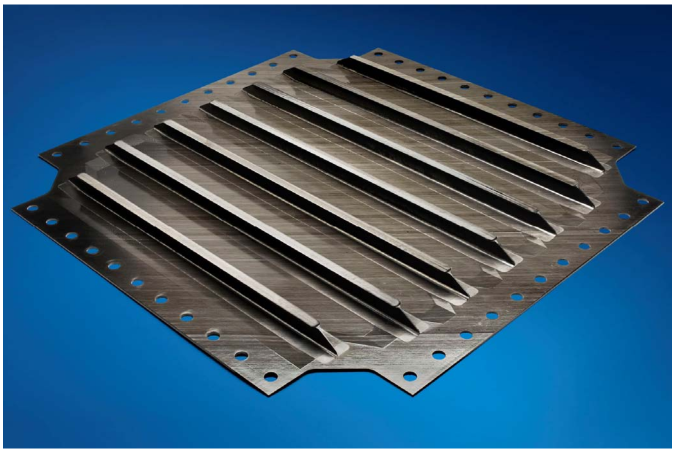

Figure 6: Plate stiffened panel

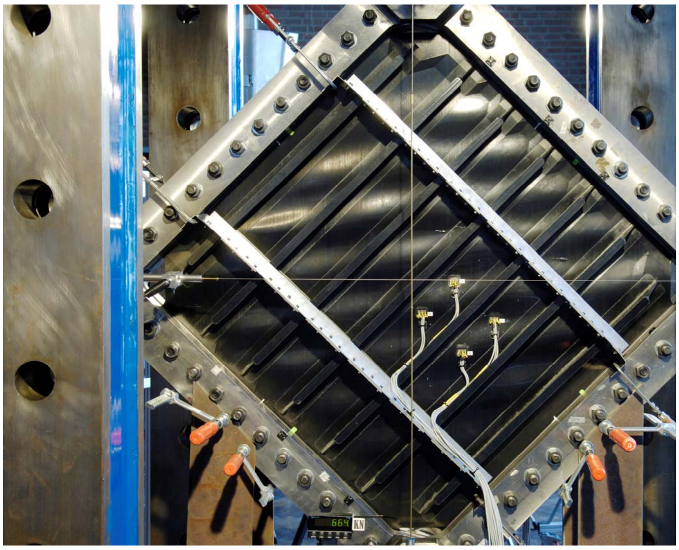

Figure 7: Shear test

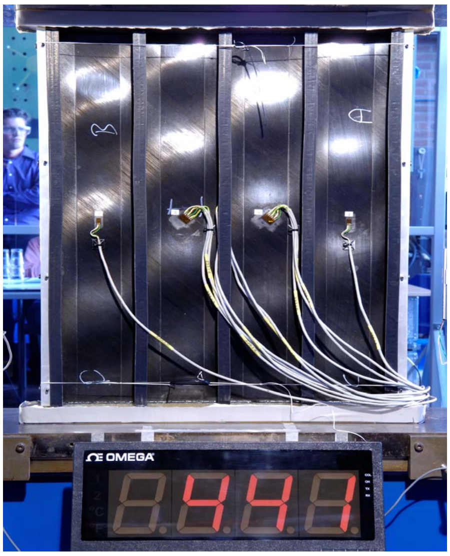

Figure 8: Compression test

Table 2: Test results of the static shear and compression tests.

Test	Four design paths using FEM analyses		Test results	
	Local Buckling Load (kN)	Ultimate Load (kN)	Local Buckling Load (kN)	Failure Load (kN)
Shear	262	393	265	667
Compression	154	220	155	450

Table 3: Test results of the damage tolerance tests on the compression panel.

Specimen A:	Ultimate Load (kN)	Damage Tolerance test results		
		Local Buckling load (kN)	Maximum test load (kN)	Failure load (kN)
Compression test with impact of 35 Joule	220	154	241 (1.1x U.L.)	----
Compression test with additional impact of 50 Joule	220	154	---	368 (1.67xU.L.)

4 Conclusions

In order to realise the ambitious targets from the aerospace industry it is necessary to develop novel structural concepts. One of these novel concepts for stiffening beams and panels are the thermoplastic ring and plate stiffeners.

Manufacturing tests were carried out in order to optimise the interface between the ring and the plate stiffeners to the base laminates.

Several static tests including damage tolerance tests (impact tests) were carried out successfully.

The programme discussed in the present paper clearly shows the high potential of this concept.

5 Acknowledgement

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