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FRACTURE TOUGHNESS AND SHEAR BEHAVIOR OF COMPOSITE BONDED JOINTS: THE EFFECT OF THERMAL TREATMENT, AGEING AND ADHESIVE THICKNESS

by

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Overview

- Introduction in composite bonded joints
- European project ABITAS
- Materials investigated and tests matrix
- Experimental results (Mode-I and II Fracture Toughness, static and fatigue strength)
- Conclusions

Composite Bonded Joints: State of the Art

Adhesive bonding in aerospace applications:

- Epoxy based *films* have been for years the 'state-of-the-art' adhesives for bonding of metallic or CFRP parts.

- Currently metal bonding is getting advanced by the development of innovative paste adhesives with extended tolerance window regarding processibility and bond-line geometry as well as long-term stability of joint properties

Composite Bonded Joints: State of the Art

Pre-treatment of surfaces to be bonded:

- Grinding is the typical pre-treatment for the bonding of composites. Although it is still done by hand it could be replaced by peel-ply removal in some film bonding cases, only.

- Recently, alternatives like Laser, Flame, Plasma and Grit Blasting have shown some potential, but none has been applied into series production yet, mainly due to a lack of methods for adequate assessment of surface quality.

European project:
'Advanced Bonding Technologies for Aircraft Structures'- [ABITAS]

Objectives of ABITAS European project:

- Development of new pre-treatment methods for polymer composites, which assure durable bonding and which are applicable for automated processing

- Establishment of on-line monitoring of the physico-chemical state of treated polymer composite surfaces for more effective quality control

- Investigation on 'adhesive chemistry', which enables more flexibility with processing and assembly via bonding on command and introduction of new material functionalities.

European project:
'Advanced Bonding Technologies for Aircraft Structures'- [ABITAS]

Main Research results of ABITAS :

- Optimization of the Atmospheric Pressure Plasma thermal treatment method and comparison with other conventional methods

- Development of a novel adhesive, namely the LMB adhesive, which is an advanced prototype paste adhesive showing improvements over Epibond 1590 A/B

Scope of the present work (in the frame of ABITAS)

- Perform an experimental investigation to compare the mechanical performance (fracture toughness and shear behavior) of the LMB adhesive with that of the well-established aerospace Epibond 1590 A/B adhesive.
- In the comparison, the effects of thermal treatment, wet-ageing and adhesive thickness (0.5 and 1.5 mm) are included.

Materials investigated and Test matrix

- Two adhesively bonded CFRP plates of AS4/8552 material stacked in the $[0_2/45/-45]_s$ sequence were bonded

G_{IC}

Epibond 1590			LMB		
	t=0.5 mm	*t*=1.5 mm		*t*=0.5 mm	*t*=1.5 mm
No treatment	5	5	No treatment	5	5
Thermal treatment	5	5	Thermal treatment	5	5
Wet ageing	5	5	Wet ageing	5	5

G_{IIC}

Epibond 1590			LMB		
	t=0.5 mm	*t*=1.5 mm		*t*=0.5 mm	*t*=1.5 mm
No treatment	5	5	No treatment	5	5
Thermal treatment	5	5	Thermal treatment	5	5

DLS-static

Epibond 1590			LMB		
	t=0.5 mm	*t*=1.5 mm		*t*=0.5 mm	*t*=1.5 mm
No treatment	5	5	No treatment	5	5
Thermal treatment	5	5	Thermal treatment	5	5
Wet ageing	5	5	Wet ageing	5	5

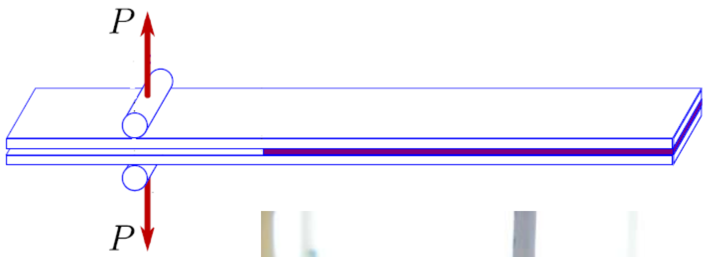
DLS-fatigue

Epibond 1590			LMB		
	t=0.5 mm	*t*=1.5 mm		*t*=0.5 mm	*t*=1.5 mm
No treatment	5	5	No treatment	5	5

Mode-I Fracture Toughness

Mode-I fracture toughness was characterized by means of the normal tension experiment using a DCB specimen.

- Tests have been conducted according to the AITM-1.0053 Airbus specification



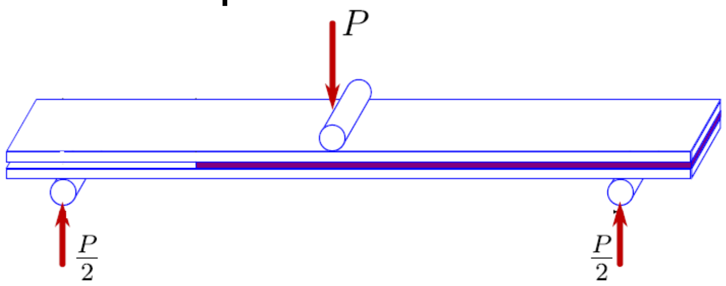
- Fracture toughness has been evaluated in terms of the mode-I critical energy release rate given by

$$G_{IC} = \frac{A}{a \cdot W} \times 10^6 \,(J/mm^2)$$

where *A* is the energy required to achieve the total crack length, *a* is the total crack length (final minus initial crack length) and *W* is the specimen's width.

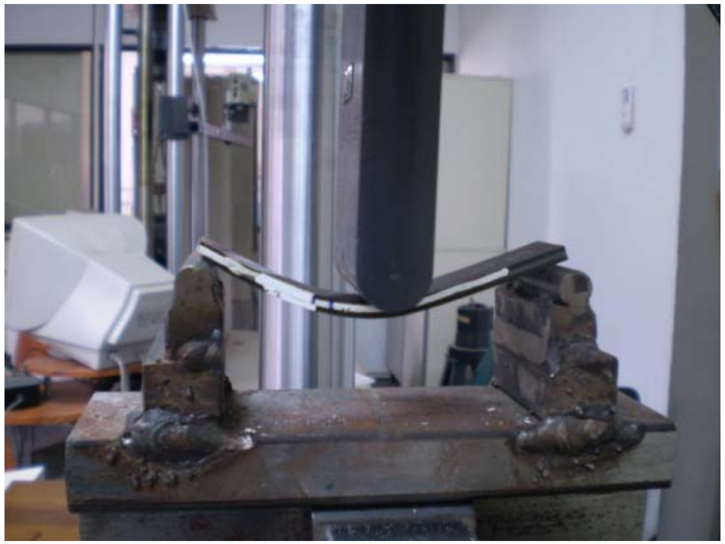
Mode-II Fracture Toughness

Mode-I fracture toughness was characterized by means of the 3-point bending experiment in the DCB specimen.



- Tests have been conducted according to the AITM-1.0006 Airbus specification
- Fracture toughness has been evaluated in terms of mode-II critical energy release rate by:

$$G_{IIC} = \frac{9Pa^2 d \times 1000}{2W(1/4L^3 + 3a^3)} (J/mm^2)$$

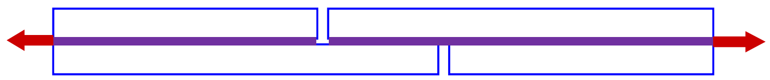


where *d* is the crosshead displacement at crack propagation onset, *P* is the critical load to start the crack, *a* is the initial crack length, *W* is the width of the specimen and *L* is the span length.

DLS static and fatigue

The shear behavior of the bonded joints has been characterized by means of static and fatigue double-lap shear (DLS) tests.

- Static and fatigue DLS tests have been conducted according to the AITM-1.0019 Airbus specification

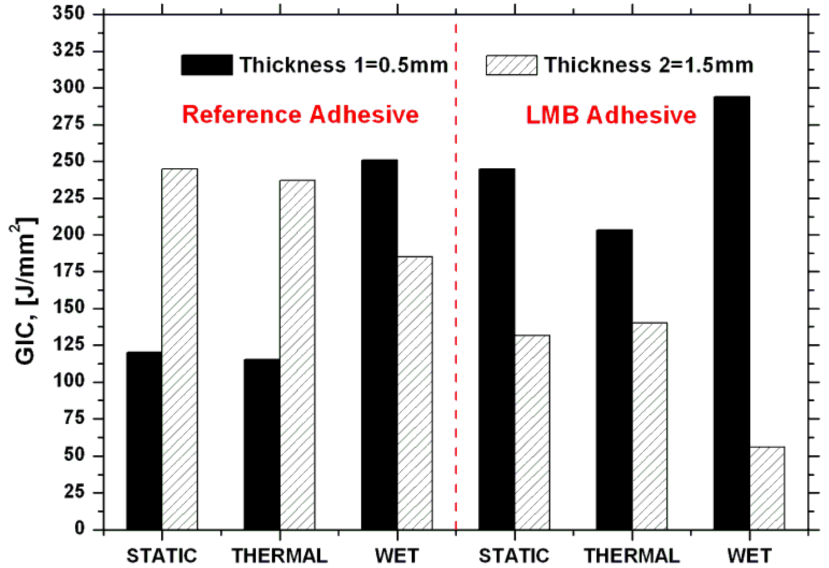


- Static shear behavior of the bonded joints has been evaluated by means of DLS shear strength taken as

$$\tau = \frac{P_{\max}}{2LW}$$

where P_{max} is the maximum sustained load, L is the overlap length and W is the overlap width.

Experimental Results: **Mode I fracture toughness**

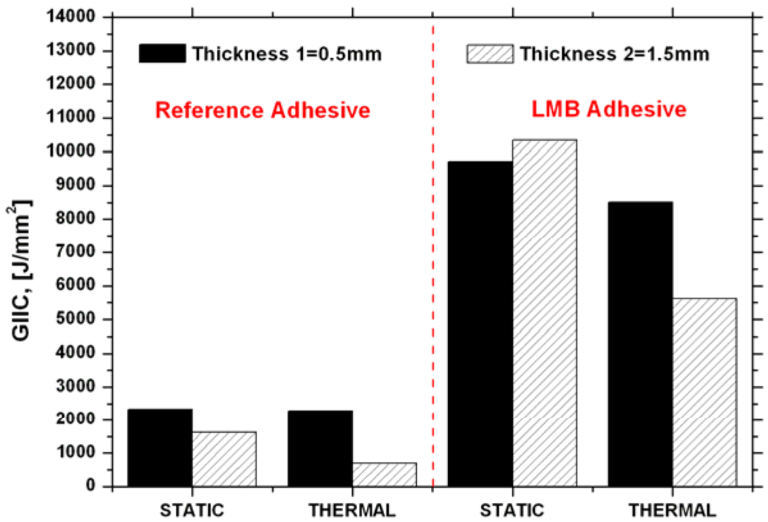


• Adhesive thickness has a contradictory effect on the fracture toughness of the two adhesives: increase in the Epibond 1590 A/B and decrease in the LMB adhesive, attributed to the different interaction mechanisms between yielding and adhesive thickness of the two cases

• On the other hand, thermal treatment leads to a decrease in the toughness of the bonded joints, which is significant in the case of the LMB adhesive.

• Wet-ageing increases the toughness of the bonded joints, attributed to plasticization within the adhesive as a consequence of water uptake

Experimental Results: **Mode II fracture toughness**

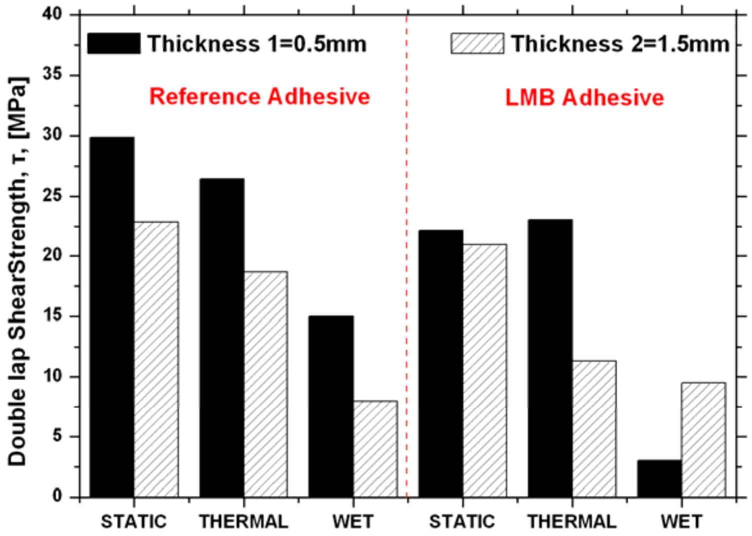


• Mode II crack propagations take place at much higher loads for the LMB adhesive than the Epibond 1590 A/B, which is a clear indication of a higher mode-II resistance, indicating a superiority of the LMB adhesive over the Epibond regarding the mode-II fracture resistance.

• As in the case of the mode-I load-case, thermal treatment has caused a decrease in the values of critical fracture toughnes .

• Increase of adhesive thickness leads to a reduction in the values of critical fracture toughnes *in most cases*

Experimental Results: **Static DLS**



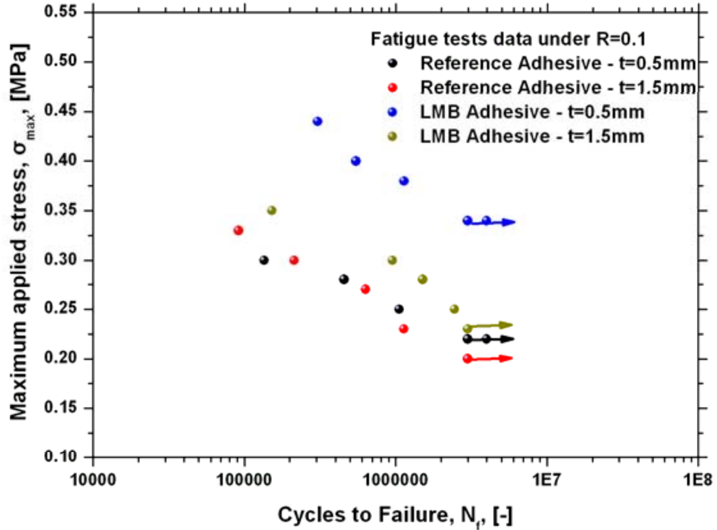
Failure due to debonding

• Contrary to the fracture toughnes results, the reference adhesive (EPIBOND) gives larger values of shear strength, compared to the LMB adhesive indicating a better shear behavior under static loading.

• The effects of thermal treatment and adhesive thickness remains the same as in the mode-I fracture toughness (strength reduction in most cases).

• Wet-ageing leads to a significant degradation of the static shear behavior of the bonded joints (in contrary to its effect in fracture toughness).

Experimental Results: **Fatigue DLS**



- Constant amplitude tension-tension (R=0.1) fatigue tests have been conducted for the un-treated samples
- Maximum applied stress (as a percentage of the double lap shear strength of each category) versus cycles to failure are plotted
- The fatigue limit has been considered at 3x106 cycles
- By far, the best performance under constant amplitude DLS fatigue loading is observed for the bonded joints with the thin LMB adhesive (in the order of 35% of the static DLS shear strength)
- The fatigue behavior of the other three categories is quite similar. (in the range of 20% to 25% of the static DLS strength).

Conclusions

An experimental programme has been conducted to compare the performances of two epoxy structural adhesives, namely the newly developed LMB adhesive and the Epibond 1590 A/B adhesive. Comparison has been performed on the basis of the effects of thermal treatment, wet ageing and adhesive thickness on the fracture toughness and shear behavior of bonded joints between CFRP laminates.

- ❑ The LMB adhesive showed a better fracture resistance and shear behavior compared to the Epibond 1590 A/B adhesive in all cases except from the static DLS tests
- ❑ The thin adhesive films (0.5 mm) lead to a better performance of the bonded joints except from the case of the mode-II fracture toughness without treatment
- ❑ Thermal treatment degraded the performance of the joints in most cases
- ❑ Wet-ageing enhanced the fracture toughness of the bonded joints, while degraded their shear response

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Thank you !