INFLUENCE OF THE NUMBER, WEIGHT AND STACKING SEQUENCE OF METAL LAYERS ON THE FIRE PROPERTIES OF HYBRID CFRP-METAL COMPOSITES

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Keywords: fibre metal laminate, CFRP-metal, fire properties, smoke density

Abstract
For several years, the content of aircraft components based on composites has been rising steadily. In contrast to commonly used materials, composites show different fire behaviour with a higher smoke production, generation of toxic gases and a temperature dependent decrease of the mechanical properties. This work focuses on the development of improved material solutions to mitigate fire, smoke and fumes in the event of a fire. A number of composite materials that could be used in a standard aircraft are inspected. These are composed of a CFRP material that is combined with a varying number of metal layers having different thicknesses. The staking sequence is also varied. The fire properties of these materials are tested using smoke density tests. Furthermore, to determine the level of protection of the underlying structure, the temperature profile at the back surface of specimens is recorded with a thermocouple while the front surface is exposed to the flame. It is found that the use of many thin metal layers in a CFRP can reduce the smoke density and protect the CFRP layers.

1. Introduction

For many years, the percentage of composite materials in commercial aircraft structures has been rising steadily. This trend and the related use of many different polymer and fibre materials lead to new challenges in the event of aircraft accidents involving fire (in-flight and post-crash fire). With respect to fire protection, the commonly used glass or carbon fibres show a good resistance against higher temperature and flame penetration, especially against burn through [1]. However the degradation of the matrix material can lead to a high smoke production and to the generation of toxic gases [2]. In addition, the heat released by the polymer combustion contributes to the propagation of fire. The heat, flame and toxic gases that are characteristically generated by these materials endanger the aircraft passengers and the associated smoke hinders the evacuation. Furthermore, the mechanical properties of composites subject to fire degrade depending on the temperature and on the matrix degradation [3]. This can lead to a loss of integrity of the whole aircraft structure as well as to falling cabin lining or hat rack debris that can endanger the passengers and complicate the evacuation. To investigate composite material characteristics and improvements that increase safety in the event of a fire, the Future Sky Safety project “Mitigate risks of fire, smoke and fumes”, funded by the European commission, has been started in 2015.

Excerpt from ISBN 978-3-00-053387-7

The presented study results from this project and focuses on the development of new material solutions using thin metal layers as a fire barrier in a commercially available composite material. It is reported in [4] that integrated titanium foils can act as a barrier against gases and source of delamination. This can lead to a reduction of smoke production, a reduction of toxic gases and higher mechanical properties after fire exposure. In this paper, the influence of the number, the weight and the stacking sequence of steel layers on the fire properties of hybrid CFRP-metal composites is investigated. To analyse the fire properties of the materials for an in-flight fire scenario, smoke density tests are performed. For a relevelling of a post-crash fire scenario, a DLR test facility with a high heat flux generation is used. In this test, the temperature at the back of the specimen is recorded as a value characterizing the fire protection offered by the metal layer.

2. Materials and experimental methods

2.1. Materials

For the production of the basic laminate, unidirectional prepreg tape with IMA carbon fibres from Hexcel is used. The material has a width of 300mm and a ply thickness of 0,127mm. As metal layers, a non-corrosive high-grade steel Type 1.4310 (X10CrNi18-8) from Deutsche Edelstahlwerke GmbH is used with a width of 300mm and 5 different thicknesses. The used thicknesses and the grammage of the steel foils are presented in Table 1.

Table 1. Thickness and grammage of used steel foils

Thickness (mm)	Grammage (g/m²)
0,03	237
0,08	632
0,125	987,50
0,25	1975
0,5	3950

For a good adhesion between the prepreg material and the steel, the coupling agent 3M™ Surface Pre-Treatment AC-130 from 3M Deutschland GmbH is applied on the metal surface.

2.2. Specimen preparation

A reference CFRP laminate and seven CFRP-steel composites with different lay-ups are manufactured via prepreg autoclave technology. The specimen and their different lay-ups are presented in Table 2. The number, weight and place of incorporation of the steel foils are varied and a symmetric 0°/90° lay-up is used. For comparison purposes, all panels have a thickness of approx. 2mm.
In a first step, the surface of the steel layers is sandblasted. After that, they are dipped in the coupling agent for 150s and dried for a minimum of 1hr at room temperature. Then the lay-up is build up and cured at 180°C in an autoclave. The panels are cut into test samples of given dimensions via water jet cutting.

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Table 2. Specimens and their lay-up and grammage of metal layers

Specimen Name	Lay-up	Total grammage metal layers (g/m²)	Thickness metal layers (mm)
0-0000-000	[0/90] [0/90] [0/90] [0/90]//[90/0] [90/0] [90/0] [90/0]	0	0
1-3950-500	[0/90] [0/90] [0/90] St [90/0] [90/0] [90/0]	3950	0,5
2-3950-250i	[0/90/0] St [90/0/90]//[90/0/90] St [0/90/0]	3950	0,25
2-3950-250a	[0] St [90/0] [90/0] [90]//[90] [0/90] St [0]	3850	0,25
2-7900-500	[0] St [90/0/90]//[90/0/90] St [0]	7900	0,5
4-3950-125	[0/90] St [0/90] St [0/90]//[90/0] St [90/0] St [90/0]	3950	0,125
7-4029-80/30	[0] St [90] [0] St [90] [0] St [90] St [90] St [0] [90] St [0] [90] St [0]	4029	0,08/0,03
2-1975-125	[0] St [0/90] [0/90] [0/90]//[90/0] [90/0] [90/0] St [0]	1975	0,125

2.3. Test methods

Smoke density tests are performed in an N.B.S. Smoke Chamber according to CS/FAR Part 25 in flaming mode. Before being tested, the 73x73mm² specimens are wrapped in aluminium foil (sides and back only). For the higher heat flux tests, the same test set-up and method as described in [4] is used. Here, the samples are flamed for 4min with a very high heat flux of 180kW/m² and the surface temperature at the back of the specimen is recorded with a thermocouple.

3. Results and Discussion

The results of the smoke density tests under a heat impact of 25kW/m² for 4min in flaming mode are presented in Figure 1. In all figures the results are compared to the reference CFRP laminate without metal layer (left side). The results are split in 3 test series: the smoke density values of the samples with a different number of metal layers (a), the same number of metal layers but with different weight (b) and several stacking sequences (c).

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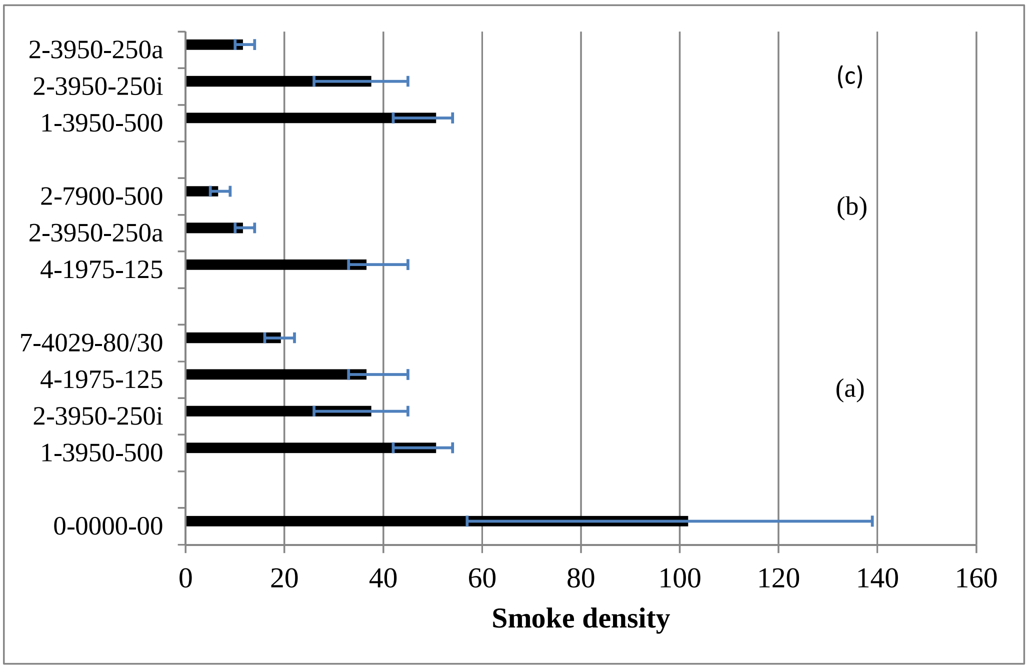

Figure 1. Smoke density test results based on (a) the number of metal layers, (b) the weight of the sample and (c) the stacking sequence

As seen in Fig. 1 (a), the use of a metal layer leads to a significant reduction of the smoke density of more than 50% compared to a pure CFRP material. Furthermore, the use of 2 and 4 layers lowers the smoke density value a little bit more. However, a significant increase compared to the one metal layer laminate can be achieved with 7 metal layers. One the one hand the reason for this low smoke density can be founded in the high number of metal layers, but on the other hand the metal layers in this sample are especially close to the specimen surface. This can cause more smoke is enclosed in the sample. In Fig. 1 (b), the influence of different weights on the smoke density is shown. It is found that a thicker metal layer leads to a higher smoke density reduction. This is due to the fact that a thicker layer is more impervious than a thinner layer and that this condition is maintained during the fire test. In Fig. 1 (c) a significant impact of the stacking sequence on the smoke density is shown. The incorporation of the metal layers under the first ply leads to a remarkable decrease of the smoke density of up to 90%. This is due to the gas impermeably of the steel foil, which traps the smoke in the sample.

Excerpt from ISBN 978-3-00-053387-7

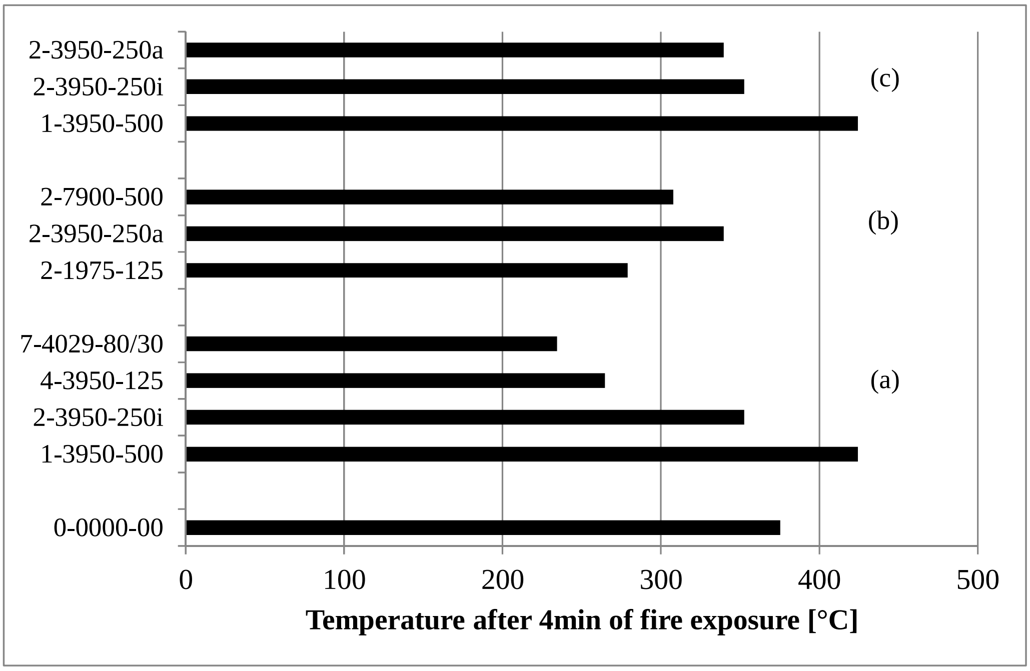

Figure 2. Temperatures at the back of the specimen based on (a) the number of metal layers, (b) the weight of the sample and (c) the stacking sequence

Figure 2 shows the temperature at the back of the specimen surface after 4min of fire exposure. In Fig. 2 (a), the back surface temperature as a function of the number of metal layers are shown. It is found that the introduction of more metal layers leads to a decrease of the surface temperature at the back of the specimen. This effect can be explained by the number of delamination, which are contained by the metal layers. Each delamination leads to an insulating air film, so that more delamination lead to a greater insulation. Fig. 2 (b) shows the influence of the weight of the metal layer to the temperature on the back of the sample. It is found that the thickness of the metal layer has only a slight impact and that a thick layer can't reduce the temperature at the back of the sample compared to a thin layer. This can be caused by the insulating influence of the air film, whereas the metal layer with its good thermal conductivity shows no insulation effect. The influence of the stacking sequence on the temperature at the back is shown in Fig. 2 (c). It is found that the incorporation of the metal layer under the first ply leads to the best properties, whereat the incorporation of a metal in the middle of the sample shows a negative impact on the temperature at the back.

4. Conclusion

The presented results show that the introduction of metal layers in a CFRP material reduces the smoke density value and leads to lower temperatures at the back surface of the sample under fire exposure. The smoke density value can be affected positively by a high number of metal layers that are thick and incorporated as close as possible to the surface of the laminate. A higher number of incorporated metal layers which lead to a higher number of delamination shows the biggest insulation effect which leads to a low temperature on the back surface of the specimen under fire exposure. The weight of the used metal layers show no impact on the insulation, whereat the incorporation of the metal layer near to the surface of the material leads to an improved insulation of the fiber metal laminate.

Excerpt from ISBN 978-3-00-053387-7

Acknowledgments

The author would like to thank Benjamin Schuh and Torsten Rinneberg for their assistance. This work was carried out in the frame of the project Future Sky Safety "Mitigating the risk of fire, smoke & fumes" with funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 640597.

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Excerpt from ISBN 978-3-00-053387-7