

FIRE PROTECTED CARBON FIBRE REINFORCED PLASTICS FOR STRUCTURAL AIRCRAFT COMPONENTS

I. Roesse-Koerner¹, B. Schuh², J. Bachmann¹ and P. Wierach¹

¹Institute of Composite Structures and Adaptive Systems, DLR German Aerospace Centre
Lilienthalplatz 7, 38108 Braunschweig, Germany
Email: imke.roese-koerner@dlr.de, web page: <http://www.dlr.de/FA>

²Institute of Propulsion Technology, DLR German Aerospace Centre
Eugen-Sänger-Straße 50, 29328 Faßberg, Germany
Email: benjamin.schuh@dlr.de, web page: <http://www.dlr.de/AT>

Keywords: fire protection, fire resistance, hybrid composites

ABSTRACT

The presented study deals with the optimization of fire properties of CFRP fuselage materials in a "pool-fire" scenario (a kerosene fire underneath an aircraft on ground) with the aim to increase the time until the structure fails. For this purpose hybrid material systems are being developed where the flame retardant is directly incorporated into the material. In this way, weight can be saved and the peeling effect, which is common for finishes, would be prevented. Due to the very high heat flux during a kerosene fire, powdered additives and layers are introduced into the composite, which form a thermal barrier or a barrier for gases in case of fire and protect the underlying structure from the effects of the flames. Of these materials, the fire behaviour with regard to smoke density and smoke toxicity is determined. The results show a significant reduction of smoke density for most of the tested materials and comply with the limits of toxic gases for cabin material systems. For a realistic re-leveling of the "pool-fire" scenario, a test facility with a propane torch was built, which creates a heat flux of 180kW/m². In this test, the specimens are exposed to flames for 4min and the temperature profile at their backside is recorded with a thermocouple. In order to investigate the mechanical damage of the materials through the fire, additional specimen were exposed to flame for 15s and the remaining compressive strength was determined. It was found that in particular a titanium foil under the top layer can contribute significantly to improvements in the mechanical properties as well as to slow down the temperature rise on the back of the material.

1 INTRODUCTION

For several years, the content of structural components based on composites has been rising steadily in aircraft constructions. Thus, the entire fuselage of new generation aircraft largely consists of carbon fibre reinforced plastics (CFRP). In contrast to conventionally used aluminium, CFRP has completely different fire behaviour with a high reliability against burn through as a result of the resistant carbon fibres. However, smoke is generated in large quantities and the heat release contributes to the propagation of fire. Even without burn through, the mechanical properties of CFRP decrease as a result of matrix decomposition, which in turn leads to loss of structural integrity and consequently to a hazard for the passengers. For this reason many efforts are undertaken to increase the mechanical performance of composite parts in case of fire. Current solutions are mostly flame retardants, which are introduced in the matrix material of the composite as filler [1]. These materials increase the time to ignition, reduce the development of toxic smoke and slow the heat release rate. Yet physical properties of the polymer are often badly affected by these additions. However, flame retardants are not suitable to adequately protect structural components in a fully developed fire with a high heat flux. In these cases, the use of heat-shields, which form a thermal barrier or a barrier for gases, is more effective.

This study investigates five different powdered additives and interlayers as solutions for the improvement of the fire properties, while protecting the underlying polymer composite. Therefore panels are manufactured and the smoke density and smoke toxicity are tested. For a realistic re-

levelling of the “pool-fire” scenario, a test facility with a propane torch is build, which creates a heat flux of 180kW/m². In this test the specimens are exposed to flames for 4min and the temperature profile at the backside is recorded with a thermocouple. The quality of the manufactured panels is verified using ultrasonic C-scanning.

2 MATERIALS AND EXPERIMENTAL METHODS

2.1 MATERIALS

For the production of the basic laminate, unidirectional prepreg (Ref) tape type Hexply® M21E with 34wt% resin content and IMA carbon fibres from Hexcel is used. The material has a width of 300mm and a thickness of 127µm. A number of additives, which form a thermal barrier or a barrier for gases, are procured. Expandable graphite (BG), an intumescent material, type Ex 9580 250 (220 _C) RZ is purchased from NGS Naturgraphit GmbH. 98.5-99% microcrystalline silicon (IV) oxide (SO) in form of quartz is supplied from Alfa Aesar and mixed with in the ratio of 3:1 with zinc borate (ZB) (Firebrake® ZB from Nordmann Rassmann GmbH). Two glass fibre meshes (GF) from P-D Interglas Technologies are used. Also used are type 04421 with a grammage of 81g/m² and a softening temperature of 850°C as well as type 02037 with a grammage of 49g/m². Titanium foil (Ti) with a thickness of 200µm is obtained as a barrier layer from ATI Wah Chang Allegheny Technologies. Two types of CFC-foil (CFC) are provided from SGL-Group. The grammages are determined with 286g/m² and 424g/m².

2.2 SPECIMEN PREPARATION

Panels measuring 300x300mm² with a thickness of 2mm are manufactured for smoke toxicity testing and mechanical tests after fire exposure. The specimen and their lay-up are presented in Table 1. In addition, the grammage of modifications is separately specified and the increase of the total weight of the structure is presented.

Specimen name	Materials	Lay-up	Extra grammage [g/m ²]	Weight increase [%]
Reference (Ref)	Prepreg	[+/-/90/-/0/+90/0]s	-	-
BG-243	Prepreg, expandable graphite	[0/graphite+/-/90/-/0/+90/0/0/90/+0/-/90/-/+]	243	6,96
BG-263	Prepreg, expandable graphite	[0/graphite+/-/90/-/0/+90/0/0/90/+0/-/90/-/+]	263	7,49
BG-283	Prepreg, expandable graphite	[0/graphite+/-/90/-/0/+90/0/0/90/+0/-/90/-/+]	283	8,01
GFK-81	Prepreg, glas fibre mesh	glas[+/-/90/-/0/+90/0]s	81	2,43
GFK-284	Prepreg, glas fibre mesh	[0/glas+/-/90/-/0/+90/0/0/90/+0/-/90/-/+]	284	8,70
SOZB-60	Prepreg, silicone oxide, zinc borate	SOZB[+/-/90/-/0/+90/0]s	60	1,81
SOZB-80	Prepreg, silicone oxide, zinc borate	SOZB[+/-/90/-/0/+90/0]s	80	2,40
SOZB-100	Prepreg, silicone oxide,	SOZB[+/-/90/-/0/+90/0]s	100	2,97

Ti-1100	zinc borate Prepreg, titanium foil	[0/titanium/+/-/90/ /0/+90/0/0/90/+0/ /90/-/+]	1100	25,29
CFC-424	Prepreg, CFC- foil	CFC[+/-/90/ /0/+90/0]s	424	11,47

Table 1: Specimens and their lay-up and extra grammage for smoke toxicity testing and mechanical tests

Specimen with a thickness of 4mm and a different lay-up are manufactured to determine the temperature on the backside during fire exposure for selected materials. The panels also measured 300x300mm² and their lay-ups are shown in Table 2.

Specimen name	Materials	Lay-up	Extra grammage [g/m ²]	Weight increase [%]
Reference (Ref)	Prepreg	[+/-/90/-/0/+90/0]2s	-	-
BG-60	Prepreg, expandable graphite	[+/graphite/-/90/ /0/+90/0/0/90/+0/ /90/-/+] [+/-/90/ /0/+90/0]s	60	0,92
BG-263	Prepreg, expandable graphite	[0/graphite/+/-/90/ /0/+90/0/0/90/+0/ /90/-/+] [+/-/90/ /0/+90/0]s	263	3,90
GF-49	Prepreg, glas fibre mesh	[+/glas/-/90/ /0/+90/0/0/90/+0/ /90/-/+] [+/-/90/ /0/+90/0]s	49	0,75
GF-98	Prepreg, glas fibre mesh	[+/glas/-/90/ /0/+90/0]2s	98	1,49
SOZB-100	Prepreg, silicone oxide, zinc borate	SOZB[+/-/90/ /0/+90/0]2s	100	1,52
Ti-1794	Prepreg, titanium foil	[+/titanium/-/90/ /0/+90/0]2s	1794	21,64

Table 2: Specimens and their lay-up for 4min fire exposure

The cutting of the materials and the lay-up are carried out manually. Panels are manufactured using a Scholz GmbH autoclave with a vacuum build up. During the autoclave cure cycle the heat is increased to 180°C with a heating rate of ~ 1,1°C/min, then held for 130min before cooling down to 65°C at ~1°C/min under a pressure of 700kPa. The produced panels are tested by ultrasonic C-scanning to verify the quality of the laminates before they are cut into test samples of given dimensions with a diamond saw.

2.3 TEST SET-UP

Smoke density tests are performed in an N.B.S. Smoke Chamber according to CS/FAR Part 25 in flaming mode. The 73x73mm² specimens are wrapped in aluminium foil (sides and back only) before testing. In addition, the resulting smoke is used to measure the presence of toxic combustion components (HCl, HF, SO₂, NO_x, CO, HCN) according to ABD 0031.

For a realistic re-levelling of the “pool-fire” scenario, a special test set-up with a high heat flux is build. The test set-up is shown schematically in Figure 1. A propane torch with a burner head of 60mm

is used to create a heat flux of 180kW/m^2 , which is verified for each measurement with a heat flux transducer from Medtherm Corporation.

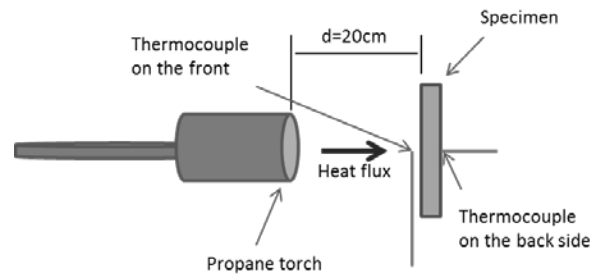


Figure 1: Schematic test set-up

The temperature in the flame near the specimen surface is measured to be $\sim 1100^\circ\text{C}$ via the thermocouple in the front of the specimen. The second thermocouple records the temperature profile at the backside of the specimen during the whole test time of 4min. The $(120 \times 120)\text{mm}^2$ specimen is clamped in a holder, so that the flame charged area is $(100 \times 100)\text{mm}^2$. Three static tests are performed on 4mm specimens per each laminate material combination.

The samples for the mechanical testing after fire exposure are flamed for 15s in the same test set-up. For this purpose, the $(190 \times 50)\text{mm}^2$ samples are clamped in a special frame which covers a part of the sample and leaves a $(50 \times 50)\text{mm}^2$ area in the middle of the sample open to the fire. After that, a Zwick 1476 with a hydraulic clamping tool is used for compression tests.

3 RESULTS AND DISCUSSION

3.1 FIRE TESTING

The results of the smoke density tests under a heat impact of 25kW/m^2 for 4min in flaming mode are presented in Figure 2. It is to be noted that the smoke density test does not create a characteristic material value due to the production of smoke, which is highly dependent on the conditions (oxygen content and heat impact) during the combustion. Smoke density tests cannot represent the real behavior of the material in case of fire, but they can identify general trends.

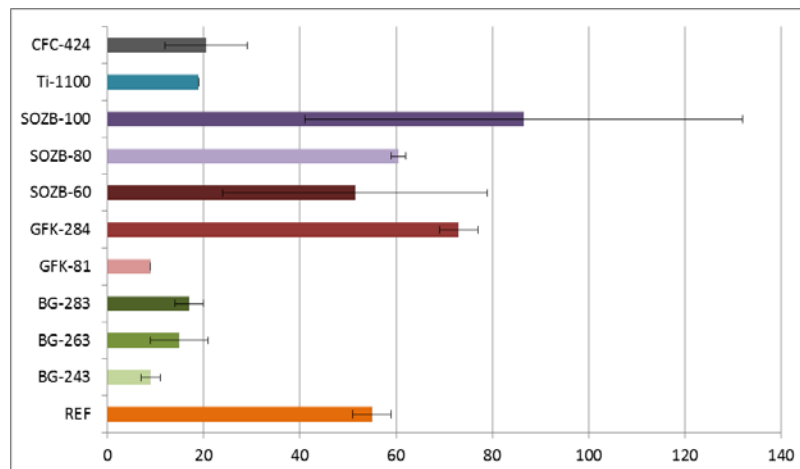


Figure 2: Results of the smoke density test

A significant smoke density reduction of more than 50% is shown for CFC, Ti, GFK-81 and all expandable graphite specimens, while the use of less expandable graphite under the surface layer leads to a higher smoke reduction. Conversely, using SOZB on the laminate surface does not exhibit a major effect, while the smoke density increases with increasing flame retardant content. Similarly, the

presence of glass fibre mesh under the surface layer (GFK-284) results in an increase of the smoke density in comparison to the reference material.

The effect of incorporation of additives and layers to toxicity of the smoke is presented in Figure 3. It is found that, for most specimens, the toxic gases are reduced by a decrease of smoke development.

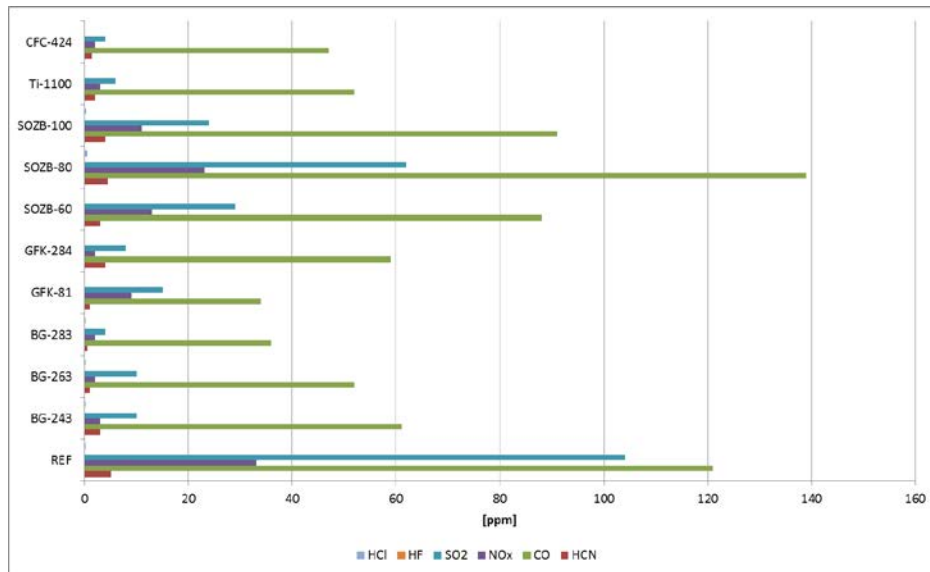


Figure 3: Results of the toxicity test

A different behavior is found when GF is present under the surface (GFK-284). This specimen has a higher smoke density than the reference material, but also a lower content of the tested toxic gases. This could be justified by a changed combustion process based on a delamination in the laminate during the test.

The results of the “pool-fire” scenario tests for the first 130s are shown in Figure 4. It is found that SOZB has the same temperature profile then the reference material and thus no influence on the temperature of the specimen backside.

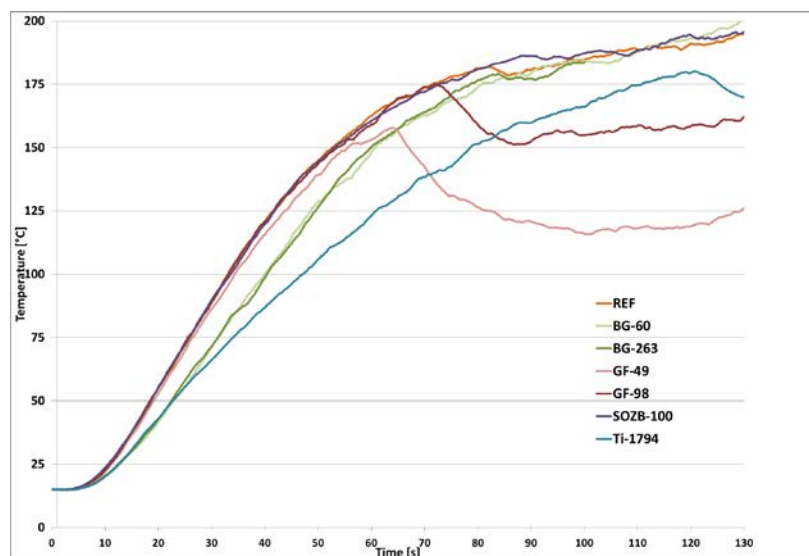


Figure 4: Temperature profile at specimen backside for 130s

Increasing temperature has no effect on the surface of the GF in the beginning of the measurement. After ~65s (GF-49) and ~75s (GF-98) the temperature on the backside drops by ~25°C. This can be explained by a delamination of the glass fibre mesh. The fibre glass layer comes off and forms a

protective layer closer to the flame. This protective layer is detached from the underlying structure, so that the heat transfer in the structure is constricted, until the fibre layer and the formed space between protective layer and structure are completely heated. It is observed, that after that point the temperature on the specimen backside increases with the same gradient as the temperature on the backside of the reference material.

Samples with BG below the surface show a slower rise in temperature on the specimen backside. However, the temperature after 100s is almost the same as the temperature of the reference material and there is no difference between different BG contents found.

In spite of its good thermal conductivity, the titanium layer (Ti) leads to the lowest temperature rise on the backside. Moreover, a delamination is found after 120s. This leads to a reduction of the backside temperature by $\sim 25^{\circ}\text{C}$, which is similar to the delamination of the GF surface layer.

3.2 MECHANICAL TESTING AFTER FIRE

The results of the mechanical testing are shown in Figure 5 and Figure 6. All materials are tested undamaged and after a fire exposure of 15s. Figure 5 gives an overview of the rupture force of the undamaged specimens so as to show the impact of the modifications on the mechanical properties of the laminate in comparison to the unmodified reference material.

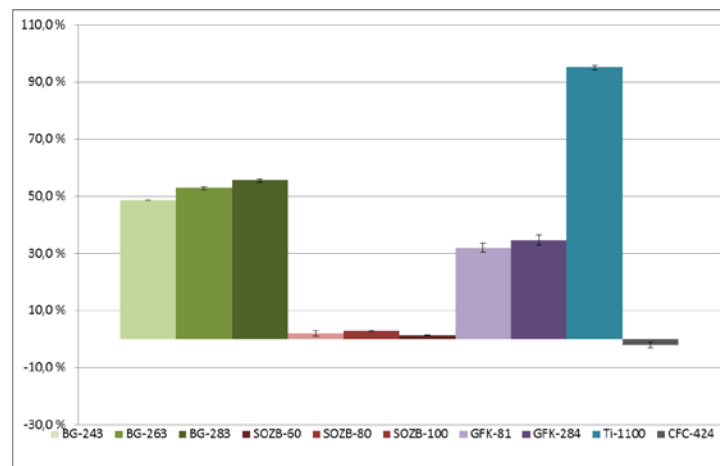


Figure 5: Rupture force relative to the reference (undamaged)

It is found that GF raises the rupture force by $\sim 30\%$ and BG by $\sim 50\%$ due to the extra CFRP layer. Titanium, which is already used as reinforcement material for CFRP [2], increases the rupture force by about $\sim 90\%$. Conversely, SOZB and CFC only shows a slight influence on the mechanical properties.

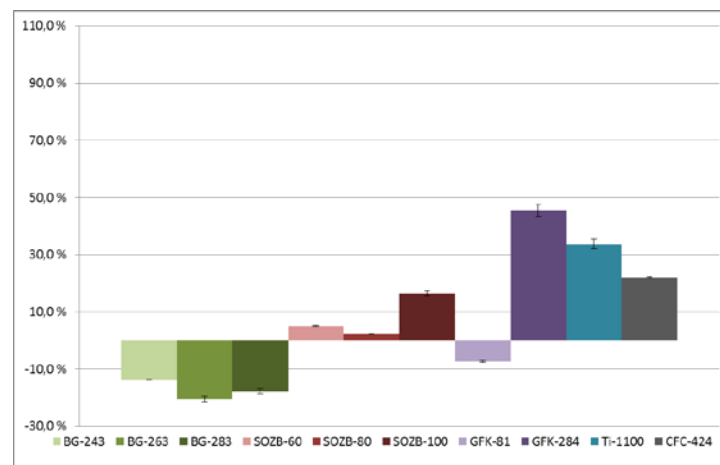


Figure 6: Rupture force relative to the reference (damaged)

The rupture forces after fire exposure relative to the reference material are given in Figure 6. Unexpectedly, the sample with GF under the surface layer exhibits the highest rupture force. This result cannot be explained at present and needs to be investigated further. Titanium, CFC and SOZB lead to an increase of the braking force after fire exposure, where titanium has the greatest influence. Specimens with BG under the surface all shows lower rupture forces in comparison to the reference material. This can be explained by a deformation of the specimens, which occurs during the flame exposure. Figure 7 shows this deformation on the upper sample, while the lower sample doesn't contain BG. The BG specimen is deformed by the incorporated intumescent material, which leads to lower rupture forces and consequently lower mechanical properties in fire.



Figure 7: Specimen after fire exposure (side view)

4. CONCLUSION

The presented results show that the introduction of powdered additives and layers, which form a thermal barrier or a barrier for gases, reduce the smoke density and the content of toxic gases. In addition, it is found that the use of smaller amounts of flame retardants can be quite useful to reduce the smoke density, while the development of toxic gases can be different. The introduction of layers (Ti, GF) affects a delamination in case of fire and forms a good thermal barrier. These materials also exhibit acceptable mechanical properties. The use of BG results in a delay of the increase of the backside temperature. However, BG leads to a deformation in the event of fire and thus to lower mechanical properties.

Future work will consist of deeper investigation into the burning behavior and more mechanical testing especially of the interface between flame retardant and laminate.

ACKNOWLEDGEMENTS

This work was carried out in the frame of the project Corinna (project number LUFOIV4-249-115) with funding from the German Federal Ministry of Economic Affairs and Energy. Responsibility for the content of this publication is assumed by the author.

REFERENCES

- [1] E. D. Weil, S. Levchik, A Review of Current Flame Retardant Systems for Epoxy Resins, *Journal of Fire Sciences*, **22**, 2004,
- [2] A. Fink, Lokale Metall-Hybridisierung zur Effizienzsteigerung von Hochlastfügestellen in Faserverbundstrukturen, *DLR Forschungsbericht*, Dissertation 2010