Demonstration of composite material solutions to reduce fire and smoke in cabin environment

I. Roese-Koerner (DLR), J. Bachmann (DLR), F. Martaus (VZLU),
G. Mirra (LEONARDO), M. Liebisch (DLR), P. Lorsch (DLR)

Short abstract: Future Sky Safety is a Joint Research Programme (JRP) on Safety, initiated by EREA, the association of European Research Establishments in Aeronautics. The Programme contains two streams of activities: 1) coordination of the safety research programmes of the EREA institutes and 2) collaborative research projects on European safety priorities.

This deliverable is produced by Project P7 "Mitigating Risks of Fire, Smoke and Fumes" of Future Sky Safety, and is the technical report concerning an exploitation action performed within Work Package 7.2 "Improving material solutions to mitigate fire, smoke and fumes in cabin environment (plus toxicity)". The action consisted in designing, manufacturing and testing a technological demonstrator of an improved cabin aircraft part made of geo-polymer based composite materials.

Programme Manager	Michel Piers, NLR
Operations Manager	Lennaert Speijker, NLR
Project Manager (P7)	Eric Deletombe, ONERA
Grant Agreement No.	640597
Document Identification	D7.15
Status	Approved
Version	2.0
Classification	Public

This page is intentionally left blank

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

Contributing partners

Company	Name
DLR	P. Lorsch, I. Roese-Koerner, M. Liebisch, J. Bachmann,
LEONARDO	G. Mirra
VZLU	F. Martaus, J. Kuzel

Document Change Log

Version	Issue Date	Remarks
1.0	11-06-2019	First formal release
2.0	12-06-2019	Second formal release

Approval status

Prepared by: *(name)*	**Company**	**Role**	**Date**
I. Roese-Koerner	DLR	Author	01-06-2019
Checked by: *(name)*	**Company**	**Role**	**Date**
J. Bachmann	DLR	WP7.2 Lead	01-06-2019
Approved by: *(name)*	**Company**	**Role**	**Date**
E. Deletombe	ONERA	Project Manager (P7)	11-06-2019
L. Speijker	NLR	Operations Manager	12-06-2019

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

Acronyms

Acronym	Definition
AITM	Airbus Industries Test Method
ASTM	American Society for Testing and Materials
BVID	Barely Visible Impact Damage
CD	Cross Direction
CFRGC	Carbon Fiber Reinforced Geopolymer Composite
CFRP	Carbon fibre reinforced plastic
CIT4min	Conventional Toxicity Index In The 4th Minute (Dimensionless)
CIT8min	Conventional Toxicity Index In The 8th Minute (Dimensionless)
CO	Carbon Monoxide
CO2	Carbon Dioxide
CTE	Coefficient of thermal expansion
Dc	Specific Optical Density Of Smoke After The Measurement
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DMA	Dynamic mechanical analysis
Ds10	Specific Optical Density Of Smoke In The 10th Minute (Dimensionless)
Ds4	Specific Optical Density Of Smoke In The 4th Minute (Dimensionless)
DSC	Differential Scanning Calorimetry
Ds_{max}	Maximal Specific Optical Density Of Smoke (Dimensionless)
F	Flammability / Flame Propagation
FAA	Federal Aviation Administration
FED30min	Fractional Effective Dose (Total, Dimensionless)
FML	Fibre metal laminate
FRP	Fibre reinforced plastic
FST	Fire/Smoke/Toxicity
FST	Fire smoke toxicity
GF	Glass Fibre
GFRP	Glass fibre reinforced plastic
GP / GPL	Geopolymer
Gr	Gradient
HR	Heat release

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

Acronym	Definition
HRR	Heat release rate
L	Linum usitatissimum (Flax), Layer
MD	Machine Direction
OSU	Ohio State University
PF	Phenolic Resin (phenol formaldehyde)
rCF	Recycled Carbon Fibre
RTM	Resin transfer moulding
S	Smoke
SD	Smoke Density
T	Toxicity
TGA	Thermogravimetric analysis
TMA	Thermomechanical analysis
vCF	Virgin Carbon Fibre
VID	Visible Impact Damage
VOF4	Accumulated Value Of Specific Optical Density Of Smoke In The First 4 Minutes
VZLU	Czech Aerospace Research Centre

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

EXECUTIVE SUMMARY

Problem Area

Many studies on the current flights show that about 50% of the fatalities in case of aircraft accidents are linked to situations where fire is involved. Hundreds of fatalities could be saved per year if fire effects on the primary structure or in the cabin environment were mitigated. The development of larger, more electric and more lightweight aircraft (with an increase use of Carbon Fibre Reinforced Plastic (CFRP) composite parts) raises several safety questions with respect to unknown behaviours of the materials and structures when exposed to fire. But the scope of this problem is large, embracing a variety of problems and solutions: the use of fireproof and less toxic materials, the early detection of fire, the simulation of passengers' evacuation, etc. Future Sky Safety Project P7 "Mitigating the risks of fire, smoke and fumes" focuses on effects of fire on new materials with improved fire properties (production of heat, toxic fumes and smokes), and on the effect of fire on mechanical behaviour that can endanger the passengers' life. The scope of the works covers both primary structures materials (e.g. epoxy resin, carbon fibre reinforced polymers) and cabin materials (e.g. phenolic polymers, glass fibre reinforced plastics). The objective of WP7.2 is to develop and utilize novel and innovation material solutions with high potential for mitigating risks of fire, smoke and fumes in the cabin environment. To achieve this aim, proposed highly resistant materials have been tested according to prescribed test plan, which allowed addressing their mechanical properties with respect to fire exposure. The scope and magnitude of proposed test plan have respected industrial safety requirements and usage of state-of-the art simulation tools.

Description of Work

The present deliverable describes the exploitation actions performed within Work Package 7.2 of Future Sky Safety. This action consisted in designing, manufacturing and testing technological demonstrators compared to standard existing composite solutions.

On the one hand, it has been shown during previous FSS WP7.2 works that Fibre-Metal-Laminates (FML) are capable of improving the FST behaviour compared to their CFRP base material. A further improvement of the FML properties was then expected by tailored laminate design (e.g. thinner metal sheets and their positioning) that might be derived by using and enhancing the modelling methods developed in FSS. Furthermore, possible multifunctional aspects of FML compared to standard CFRP were also highlighted (e.g. electrical properties). To further demonstrate the benefits of FML under fire exposure, a comparative test has finally been proposed as part of the FSS WP7.2 exploitation action (demonstration). The competitor to the FML based solution is a plate produced from aviation certified aluminium that has a similar thickness as the FML and the identical width and height. The two panels were exposed to the identical fire conditions to show the differences in the behaviour of the materials.

On the other hand, a geopolymer-based panel was manufactured and tested in 2018. It was designed as a 406 x 610 mm flat panel to facilitate CS25 App. F, Part III flame penetration test. Lay-up of the panel represented hypothetical interior panel of CS23 or CS25 certified airliner. The emphasis was placed on the design of a lightweight, cost effective and good impact resistant structure. Basic information are available

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

also in technical reports D7.10 [3] and D7.13 [4]. Following this work, it was proposed and approved to further develop these works into the design and manufacturing of a structural demonstrator, as a part to the exploitation action for FSS P7. An actual interior panel of the CS 23 certified, Czech made regional turboprop was selected to be the FSS WP7.2 structural demonstrator, and more specifically the emergency exit door panel was identified as the optimal choice – it is a relatively complex part featuring window cut-out and dimple of the opening lever. Originally the part is made by autoclaving of qualified glass-phenolic prepreg. The demonstrator was not thought to be an exact copy of the original and certain level of design freedom was accepted. Several moldings of this demonstrator were manufactured for different purposes: in particular several composite materials solutions were used for the structural skins.

Results & conclusions

The demonstrators produced within the FSS P7 project were shown at the FSS Final Conference in Brussels. The presentation desk is shown within Figure 49 and Figure 50. Together with posters giving information about developed expertise within FSS the demonstrators were presented by their physical presence as well as a video showing the conducted fire tests (conf. Figure 50). The video compared FML and GP to their respective state of the art material and underlined the potential of the developed material systems. People were highly interested in spectating at the video and inspecting the physical demonstrators. The combination of the presented video and the physical demonstrators led to a lot of interesting talks and discussions. Additionally, a presentation was held at the conference presenting the material developments, CuFex test bench and test results.

The second VZLU demonstrator no.2 was presented during the Tandem Aerodays held in the Bucharest Palace of Parliament from 27-30 May 2019. About 800 participants and 100 journalists attended the Aerodays in Bucharest, including high level representatives of the aviation industry and research agencies. Interest in the demonstrators was high. Demonstrator No. 2 was designed as an actual interior panel of the CS 23 certified, Czech made regional turboprop. An emergency exit door panel was identified as the optimal choice with relatively complex design featuring window cutout and dimple of the opening lever. Originally the part is made by autoclaving of qualified glass-phenolic prepreg. One of the two demonstrators was fire tested to show improved fire properties of the material combination. Additionally, a video was shown on a screen nearby, featuring all demonstrator fire tests conducted in FSS.

Applicability

Realization of the second demonstrator has proved manufacturability of real aircraft interior part of inorganic, geopolymer based composite material. The tests show promising results with respect to fire resistance. For potential application in the aircraft structure, some specific problems that haven't been dealt nor studied yet, remain to solve. This requires further research and testing of composite material. Nevertheless, it is expected, that none of these problems should prevent utilization of Fiber Reinforced Geopolymer Composite (FRGC) material in the aircraft (or other vehicle) structures.

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

This page is intentionally left blank

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

TABLE OF CONTENTS

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

LIST OF FIGURES

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

LIST OF TABLES

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

1 INTRODUCTION

1.1. The Programme

FUTURE SKY SAFETY is an EU-funded transport research programme in the field of European aviation safety, with an estimated initial budget of about € 30 million, bringing together 32 European partners to develop new tools and approaches to aviation safety. The first phase of the Programme research focuses on four main topics:

- Building ultra-resilient vehicles and improving the cabin safety,
- Reducing risk of accidents,
- Improving processes and technologies to achieve near-total control over the safety risks,
- Improving safety performance under unexpected circumstances.

The Programme will also help to coordinate the research and innovation agendas of several countries and institutions, as well as create synergies with other EU initiatives in the field (e.g. SESAR,). Future Sky Safety is set up with an expected duration of seven years, divided into two phases of which the first one of 4 years has been formally approved. The Programme started on the 1st of January 2015.

FUTURE SKY SAFETY contributes to the EC Work Programme Topic MG.1.4-2014 Coordinated research and innovation actions targeting the highest levels of safety for European aviation, in Call/Area Mobility for Growth – Aviation of Horizon 2020 Societal Challenge Smart, Green and Integrated Transport. FUTURE SKY SAFETY addresses the Safety challenges of the ACARE Strategic Research and Innovation Agenda (SRIA).

1.2. Project context

Recent studies] have shown that, though "fires in flights" as a direct cause represented only 5% of fatalities, "fire/smoke resulting from impact" accounted for 36% of all fatal accidents. Often aircraft occupants have survived the impact only to be incapacitated by toxic fumes and/or heat, e.g. temperatures can rise above 600-700°C after only three minutes. Toxic fumes originate from components such as aviation fuel and combustible materials, producing various gases dependent on the composition of the material.

In recent years the development of more lightweight aircraft has seen an increased use of composite materials in primary structures, e.g. fuselages, as well as secondary and interior structures, such as furnishings. These materials have desirable properties such as corrosion resistance and high strength, however from a safety point of view the use of these materials may require specific controls concerning their behaviour when exposed to fire, or during normal conditions. The project seeks to address this safety aspect within three work packages:

- WP7.1 – The first work package aims to test and thus improve understanding of the effects of fire on these materials,
- WP7.2 – The second work package aims to develop and propose improved material solutions to mitigate fire, smoke and fume,
- WP7.3 – The third work package, for which this report is the final deliverable, aims to investigate the possible effects of new materials and technologies on the on-board air quality with the objective to further improve the air quality.

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

1.3. Work package content

The objective of WP7.2 is to develop and utilize novel and innovative material solutions with high potential for mitigating risks of fire, smoke and fumes in the cabin environment. To achieve this aim, proposed highly resistant materials are being tested according to prescribed test plan, which should allow to address their mechanical properties with respect to fire exposure. The scope and magnitude of proposed test plan respect industrial safety requirements and usage of state-of-the art simulation tools.

The objective of this investigation concerning fibre metal laminates is the development of FMLs with improved fire properties for the substitution of cabin and structural aircraft materials. This material combination offers the opportunity of a reduced smoke density production with a lower toxic gas content combined with improved mechanical properties during fire.

The objective of using natural fibres and (recycled) man-made fibres is to substitute classic cabin materials (glass fibre fabric) for reduced environmental impacts. The use of recycled carbon fibres will enhance the mechanical properties and also improve the fire properties to mitigate the risk of fire and fumes in the cabin environment.

The objective of utilization of geopolymers matrices reinforced by carbon fibres is to test innovative material systems providing limited smoke and toxic gas content with sufficient mechanical properties during fire exposure for passenger and cargo linings. Versatility of geopolymers matrices allows their exploitation both on laminate and sandwich structures, where e.g. foam could provide significant impact on mitigating the risk of fire and fumes in the cabin environment.

1.4. Research objectives

The overall objective of WP7.2 is to investigate the potential of materials that may contribute to reduce the impact of fire and smoke in the cabin environment. Specific avenues to be investigated include:

- Definition of tests to characterize material properties with respect to their fire and mechanical properties,
- Manufacturing of samples from composite materials with promising ,
- Developing and characterizing of new materials and their combinations for an improved fire behaviour of interior and structural materials,
- Model material degradation with respect to fire, fumes and smoke risks in the cabin environment.

The objective of this deliverable is to provide a summary of the results obtained by WP7.2.

1.5. Approach

Geopolymers

For 'non-flammable' shall be considered such substances that does not burn, smolder or carbonificate at normal pressure by the action of fire or high temperature. It is known that most inorganic substances meet these conditions. Thus application of inorganic based fibre composites is the possible way to meet the WP7.2 tasks. If appropriate lightweight, fire-resistant (e.g. carbon) fibres are applied in conjunction with inherently non-combustible inorganic matrix, there is an opportunity to get the material featuring new level of fire and FST safety. A promising candidate for such materials, are the geopolymer compounds. Geopolymers are a class of totally inorganic, alumino-silicate based ceramics. They are rigid gels, which are made under relatively ambient conditions of temperature and pressure into crystalline or glass-ceramic materials.

In WP7.2 Carbon Fibre Reinforced Geopolymer Composites (CFRGC) were subject of research in undermentioned spheres:

- Flame resistance,
- Fire smoke toxicity properties,
- Mechanical properties (including environmental expositions and impact tests).

Particular interest was paid to development of geopolymer based hard foam as a replacement of state of the art organic core materials.

FML

Compared to common CFRP materials, Fibre-Metal-Laminates (FML) propose improved behaviour under fire exposure. This behaviour is produced by steel layers that are integrated into the laminate and act as gas barrier. To investigate and underline this, subject of research were smoke toxicity and smoke density tests, as well as burn through tests with respect to varying layups. Furthermore, a new test facility was developed to investigate the mechanical performance of FML while it is exposed to fire. Within the test specimens that are exposed to axial compression are simultaneously loaded to fire. The test is intended to study the insulation effects, how material degradation proceeds and if the material can still be expected as load carrying in such a scenario. Since manufacturing and testing is a huge effort a simulation method is developed. The aim of the simulation is to decrease future testing effort and to detailed investigate mechanical degradation proceeding of FML within a fire scenario. To this, material properties are determined with respect to their temperature dependency. The material characterization does also lead to further knowledge about FML materials.

1.6. Structure of the document

The document is adopting the Future Sky Safety template and general structure. As a whole, this document is a synthesis report about the manufacturing of demonstrators by VZLU and DLR in WP7.2.

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

2 GEOPOLYMER BASED DEMONSTRATORS

2.1. Demonstrator No. 1

In year 2018, in frames of the Program task D7.2, geopolymer-based Demonstrator No.1 was manufactured and tested. Demonstrator No.1 was designed as 406 x 610 mm flat panel to facilitate CS25 App. F, Part III flame penetration test. Lay-up of the panel represented hypothetical interior panel of CS23 or CS25 certified airliner. In case of Demonstrator No.1 emphasis was placed on lightweight, cost effective and well impact resistant structure. Basic information on Demonstrator No.1 are stated on figures below[1]. More information about Demonstrator No. 1 are available also in technical reports [5]and [6].

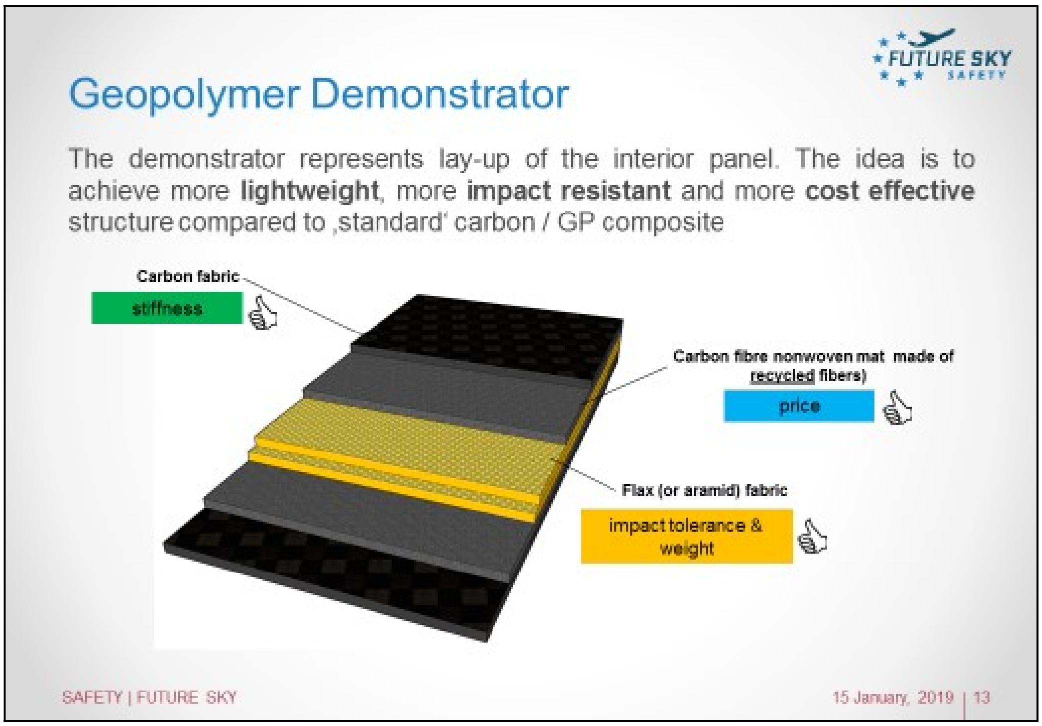


Figure 1: Demonstrator No.1 – the lay-up

[1] Figures 1-4 are taken from P7 Final Technical Meeting project task D7.2 presentation (May 2017, Embraer – Portugal)

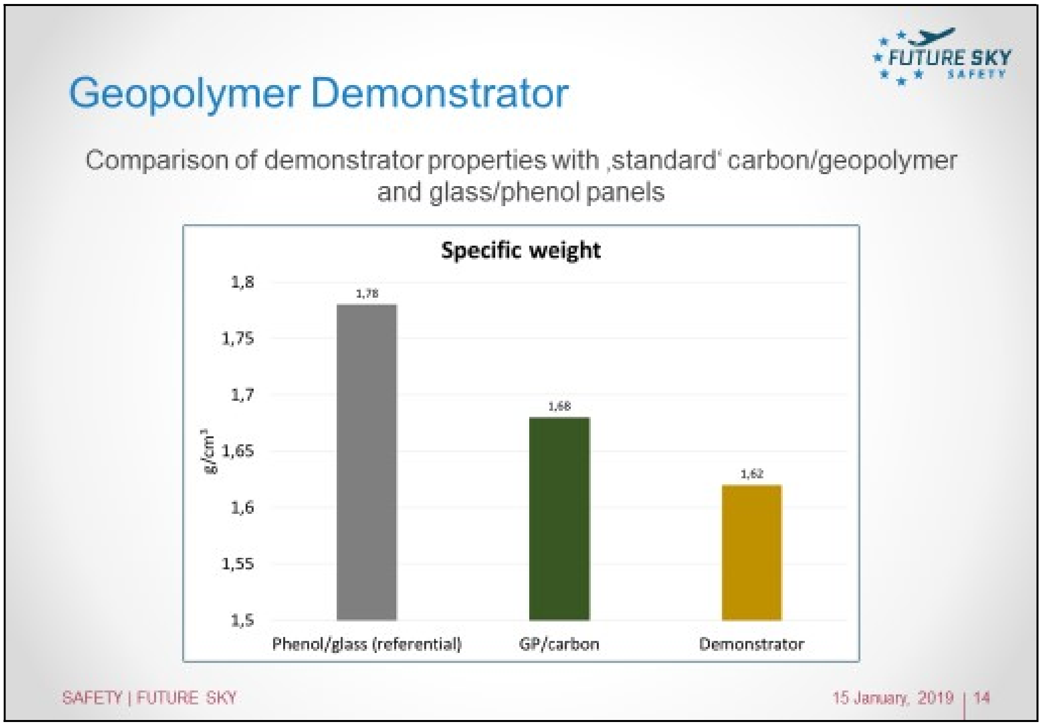


Figure 2: Demonstrator No.1 – specific weight

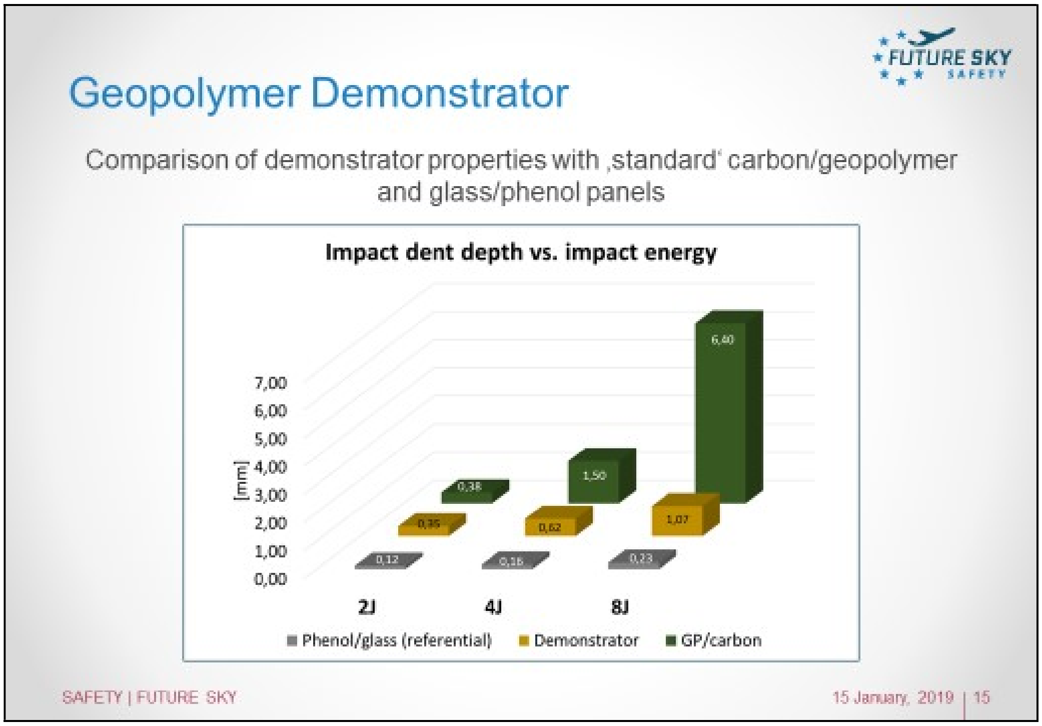


Figure 3: Demonstrator No.1 – impact properties

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

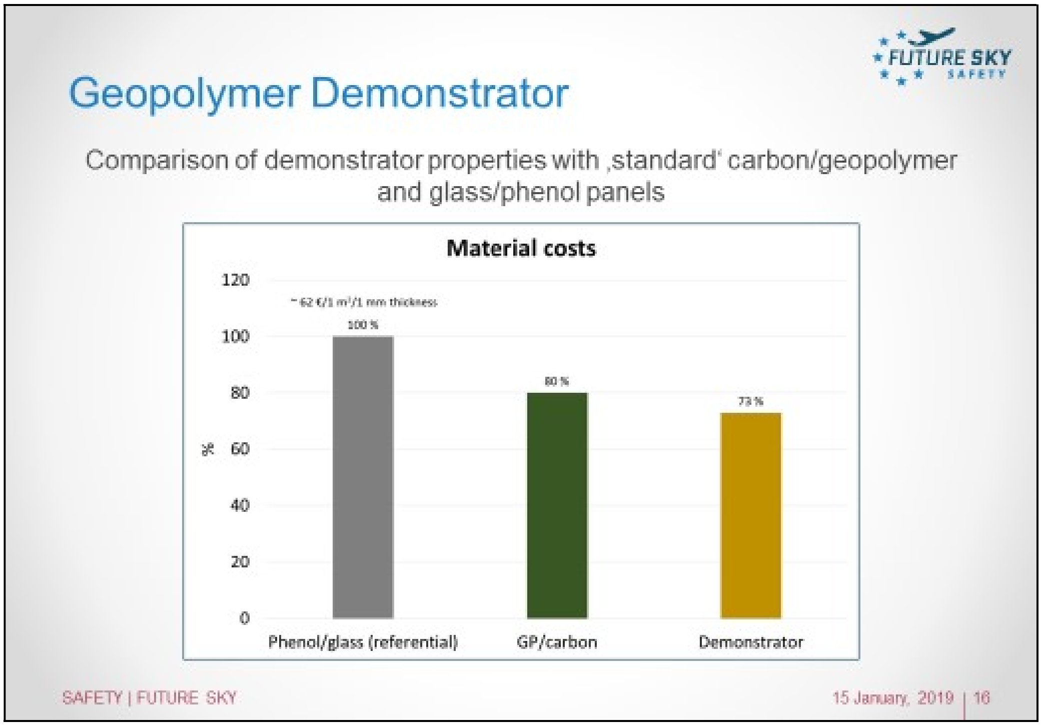


Figure 4: Demonstrator No.1 – material costs

Figure 5: Demonstrator No.1 (right) and referential glass/phenolic panel (left), both after the flame penetration test, as they were presented on FUTURE SKY SAFETY Final Conference (November 2018, Eurocontrol Headquarters, Brussels)

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

2.2. Demonstrator No. 2

2.2.1. The concept

The Demonstrator No. 2 was designed as a actual interior panel of the CS 23 certified, Czech made regional turboprop. Emergency exit door panel (Fig. 6) was identified as the optimal choice – it is relatively complex part featuring window cutout and dimple of the opening lever. Originally the part is made by autoclaving of qualified glass-phenolic prepreg. The Demonstrator No. 2 was not thought as an exact copy of the original and certain level of design freedom was accepted. Due to different type of applied fiber reinforcement the part thickness differs from the original. Unlike the original part, local sandwich reinforcement was added to demonstrate utilization of geopolymer based honeycomb. This should be taken into account when comparing the weight of both variants. The basic lay-up sequence of layers follows Demonstrator No. 1 (Par. 1) - except of carbon nonwoven mat that was found to be too thick material for intended application and was not used finally. Totally four moldings of the Demonstrator No. 2 were manufactured: molding A for exhibition purposes, molding B for the flame penetration test, molding C based on hybrid carbon-aramid fabric and referential molding D made of the glass-phenolic prepreg.

Figure 6: Emergency exit door [*www.aktualne.cz*]

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

Figure 7: Molding of the Demonstrator No. 2 – inner side

Figure 8: Molding of the Demonstrator No. 2 – outer side

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

2.2.2. Molding A - Drawing

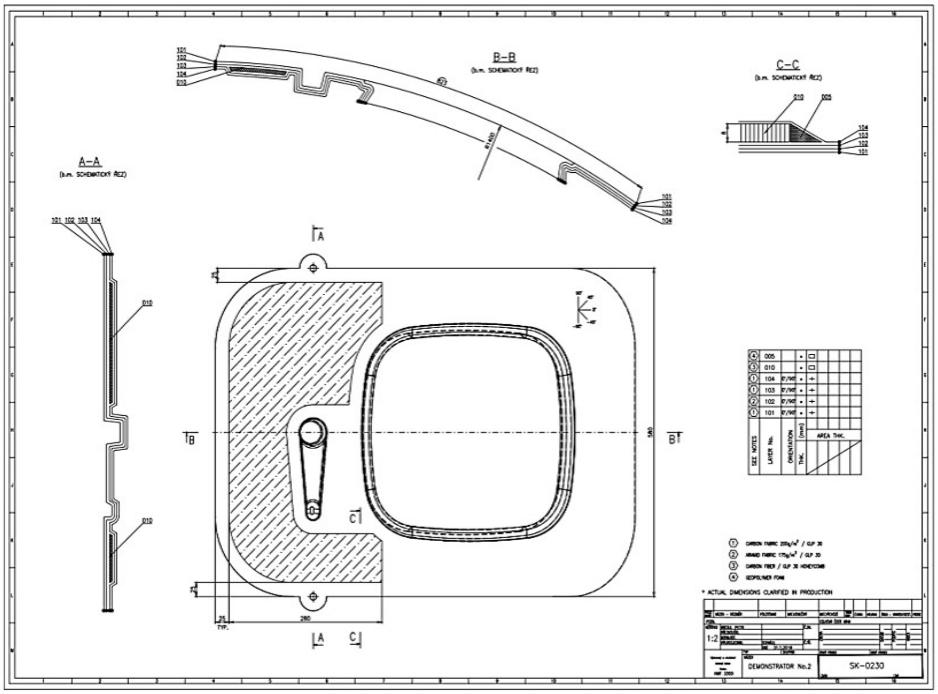


Figure 9: Drawing of the Demonstrator No. 2 (lay-up of molding A)

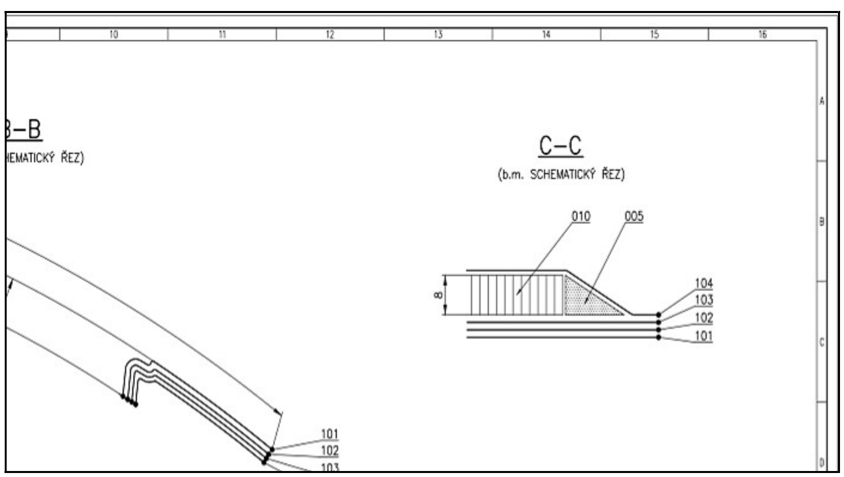


Figure 10: Drawing of the Demonstrator No. 2 (lay-up of molding A - detail)

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

2.2.3. Molding A - the lay-up scheme

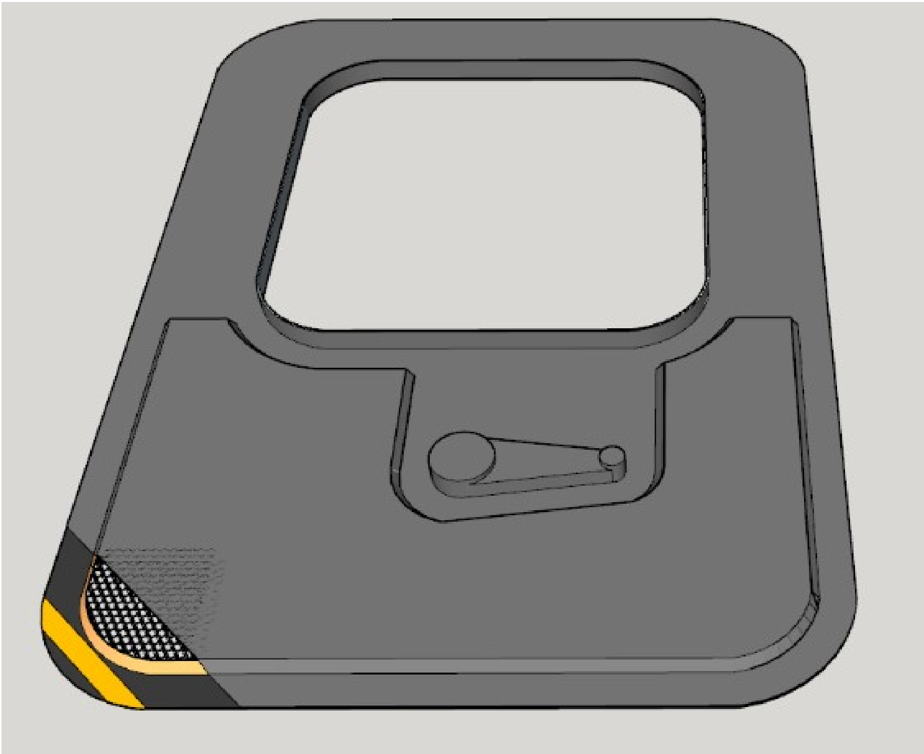


Figure 11: Lay-up scheme of the Demonstrator No. 2 (molding A)

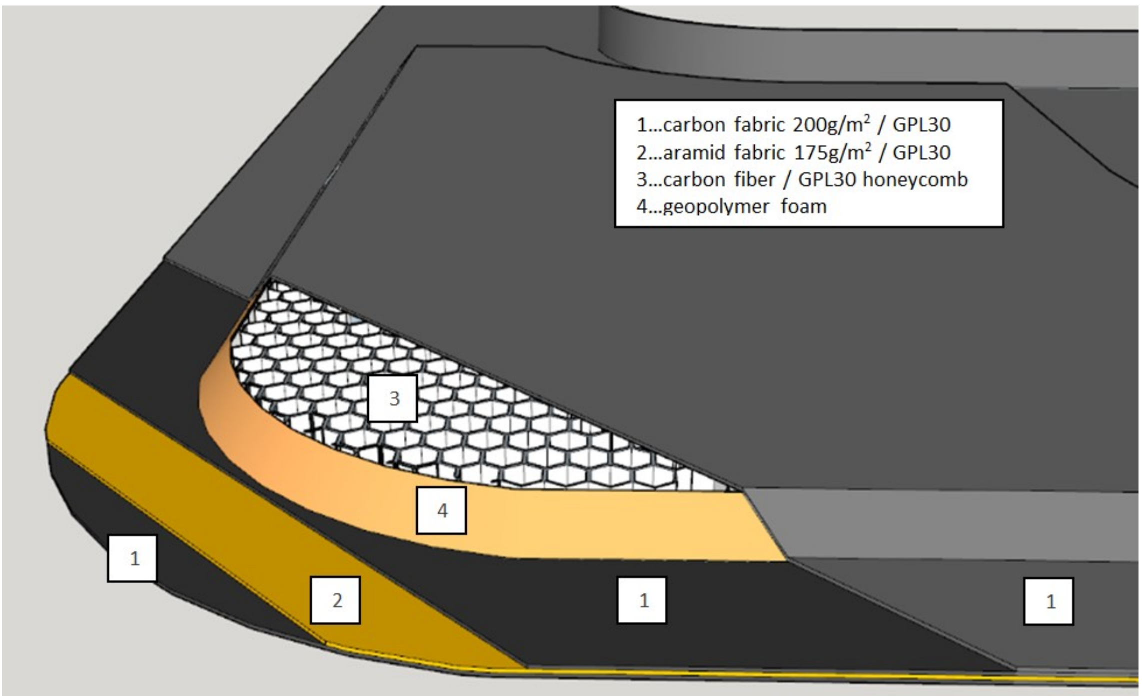


Figure 12: Lay-up scheme of the Demonstrator No. 2 (molding A) – Zoom of the sandwich design

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

2.3. Molding A - Manufacturing

2.3.1. The mold

For manufacturing the Demonstrator No. 2, ‚serial' mold was leased from the original part manufacturer (LA Composite, Prague). The mold is of standard design, negative, two piece, made of glass / epoxy temperature resistant composite (Airtech TMR 2001A / TMH 2001B resin system).

Figure 13: The mold

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

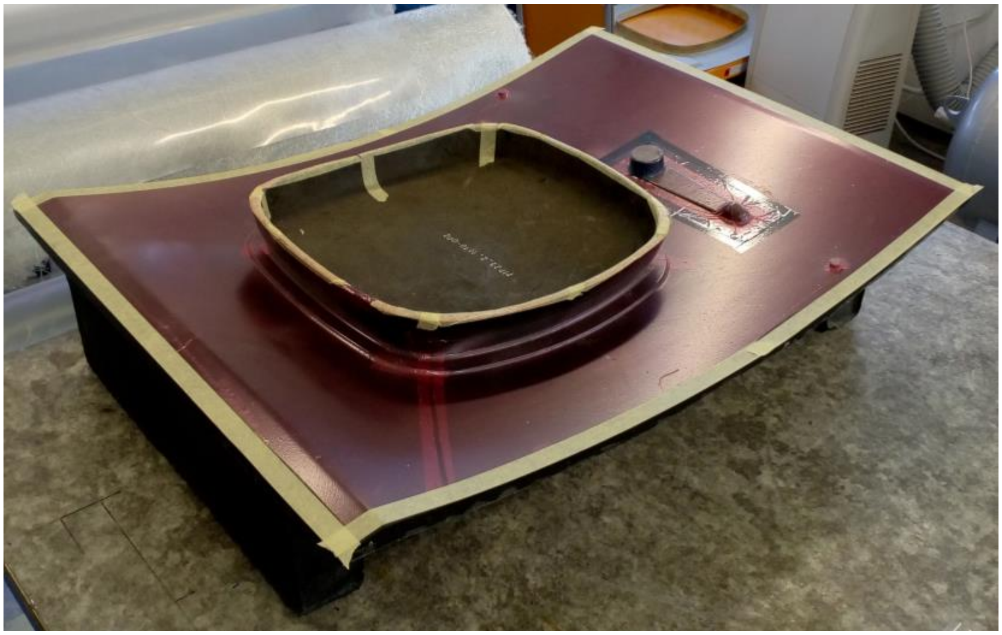


Figure 14: To protect the working surface, Diatex A5000 release film was applied on the mold

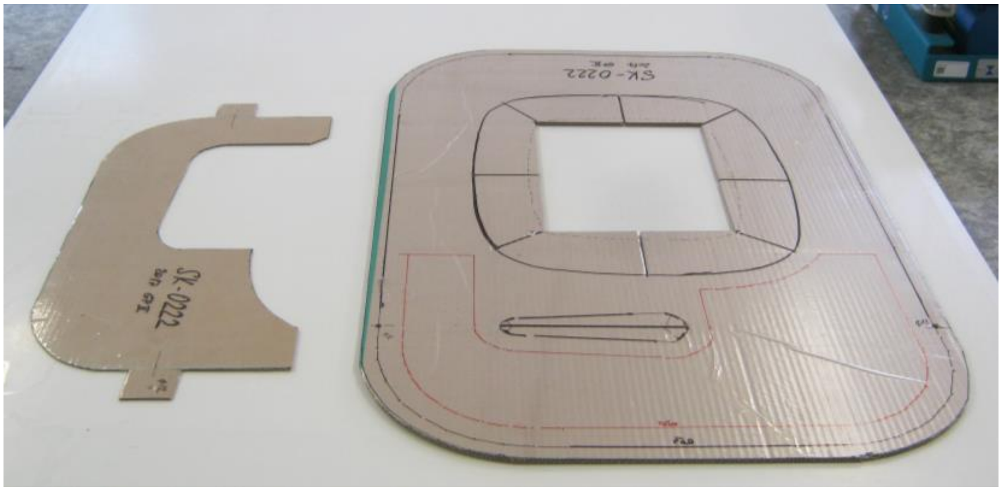


Figure 15: Simple cardboard cutting templates were used

2.3.2. Honeycomb core

The following figures present a scheme of „corrugate" manufacturing process of carbon fiber - geopolymer honeycomb[2]:

[2] Note: VZLU geopolymer honeycomb is the subject of patent pending process

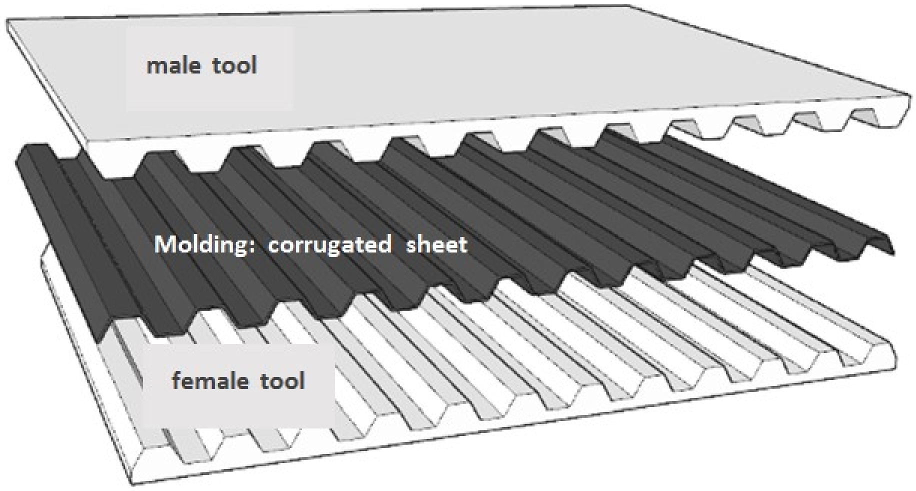


Figure 16: Step 1. Manufacturing of 'trapezial¨ sheets

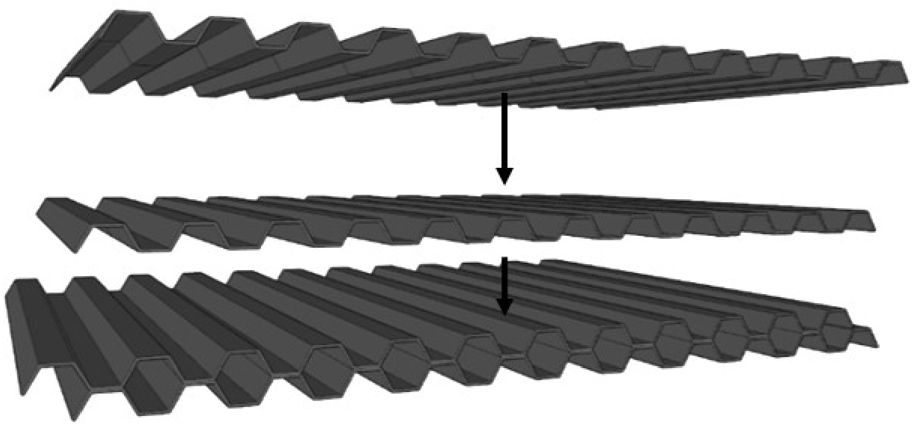


Figure 17: Step 2. Bonding sheets together using inorganic adhesive

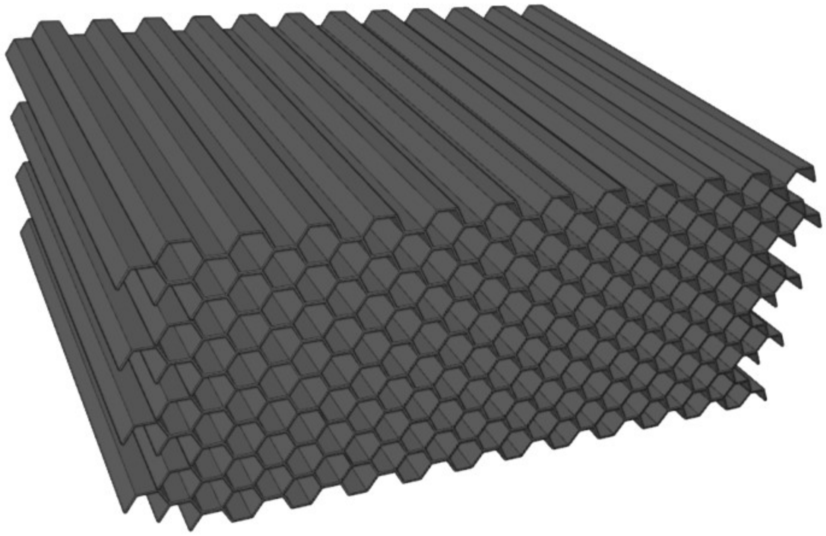


Figure 18: Step 3. Honeycomb block

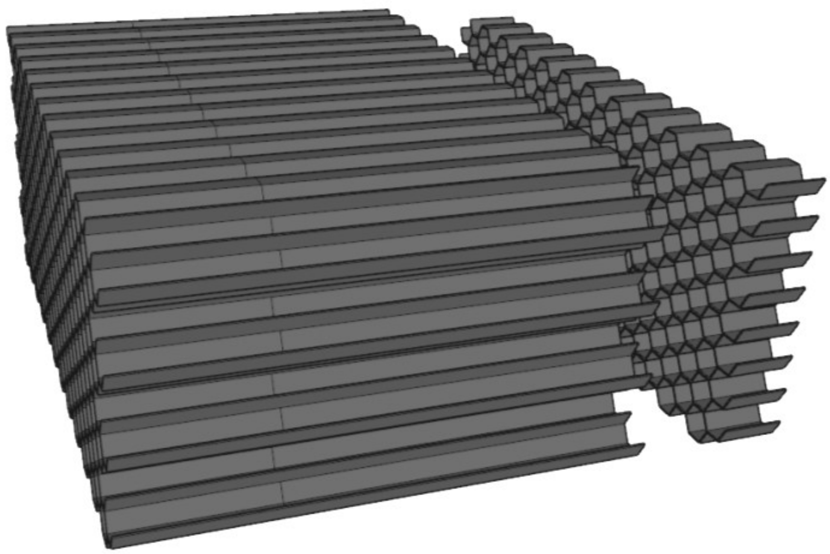


Figure 19: Step 4. Cutting the block to plates of desired thickness

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

2.3.3. Geometry & material of the core

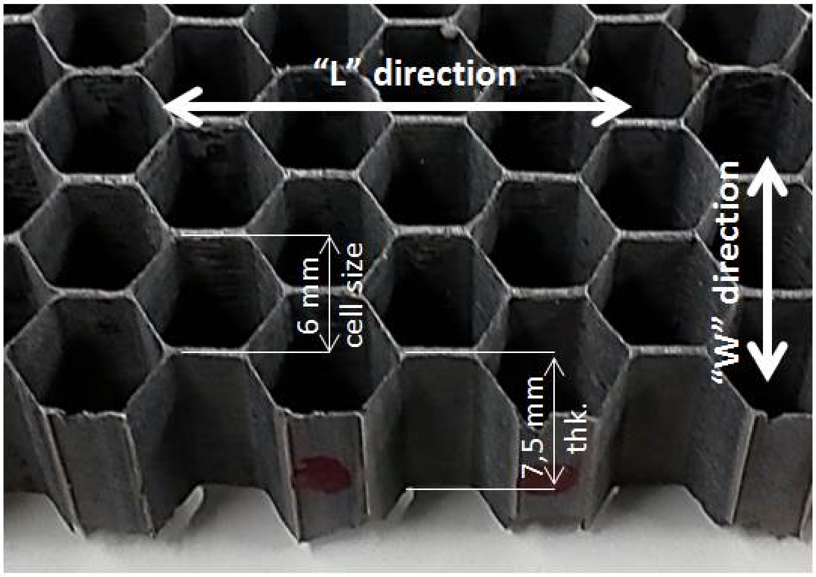


Figure 20: The core geometry

Material: 1 layer of 20 g/m^2 carbon nonwoven + 1 layer of 60 g/m^2 carbon plain fabric / GPL30 geopolymer resin

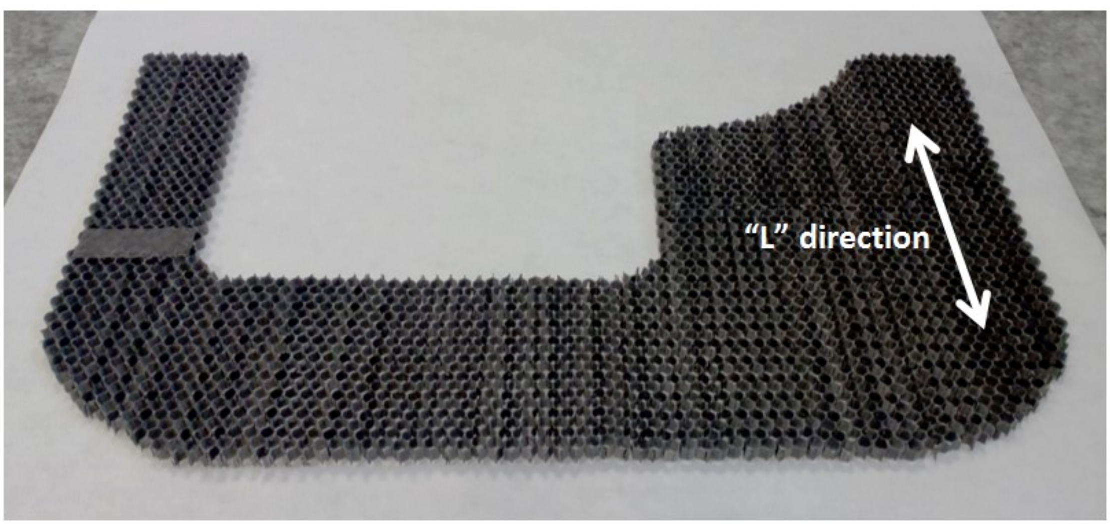


Figure 21: The sandwich core. Specific weight of the honeycomb is approx. 234 kg/m^3

The core edge

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

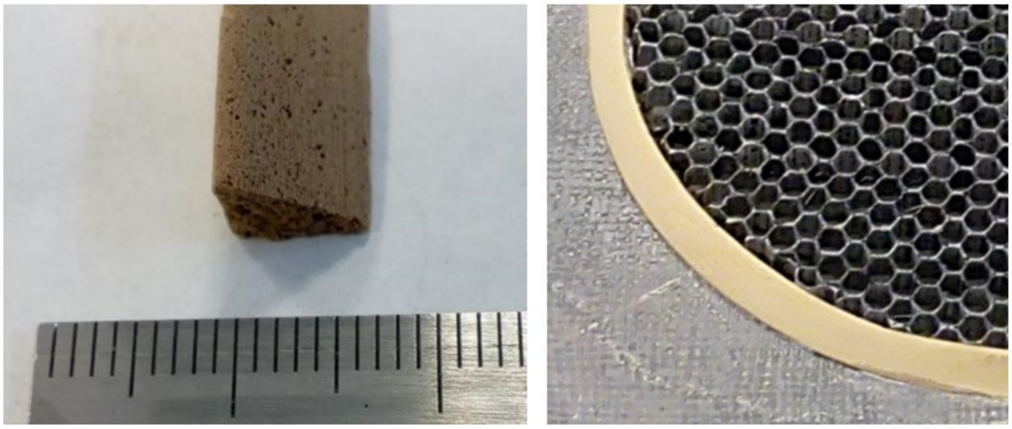


Figure 22: Chamfered edge of the sandwich field made of the geopolymer foam[3]. Specific weight of the foam is approx. 230 kg/m^3

2.3.4. Laying-up the molding A

Figure 23: All plies of the Demonstrator were proceeded by wet-laminating method. Standard vacuum bagging process (-95 kPa, R.T., overnight curing) was typically applied

[3] Note: VZLU geopolymer foam is the subject of a patent pending process

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

Figure 24: Honeycomb core (dwg. positions 010, 005) assembled and bonded on cured outer skin

Figure 25: Inner ply No. 104 laid and vacuum cured (-95 kPa, R.T., overnight). Molding A was post-cured[4] 110°C / 6 hrs prior to demolding

[4] Drying process where residual free and chemically bonded water is removed

Figure 26: "Bag side" and "tool side" of the molding A prior to painting. Weight of trimmed molding A (without surface finish) was 770 g

Figure 27: Outer side of the molding A (surface filled and painted)

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

Figure 28: Inner side of the molding A (painted only)

Figure 29: Detail of the sandwich core (molding A)

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

2.4. Molding B

Molding B was meant for the flame penetration test. The lay-up and manufacturing process was identical with the molding A (except of layer No. 102 which was made of 200 g/m^2 carbon plain fabric). No filling or painting was carried out on this part. Weight of trimmed molding B (without surface finish) was 793 g.

Figure 30: "Bag side" and "tool side" of the molding B

Figure 31: Molding B prior to the flame penetration test. Window cutout was covered by 0,5 mm stainless steel

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

Figure 32: Flame penetration test: two thermocouples (in yellow circle) located 100 mm above the back surface

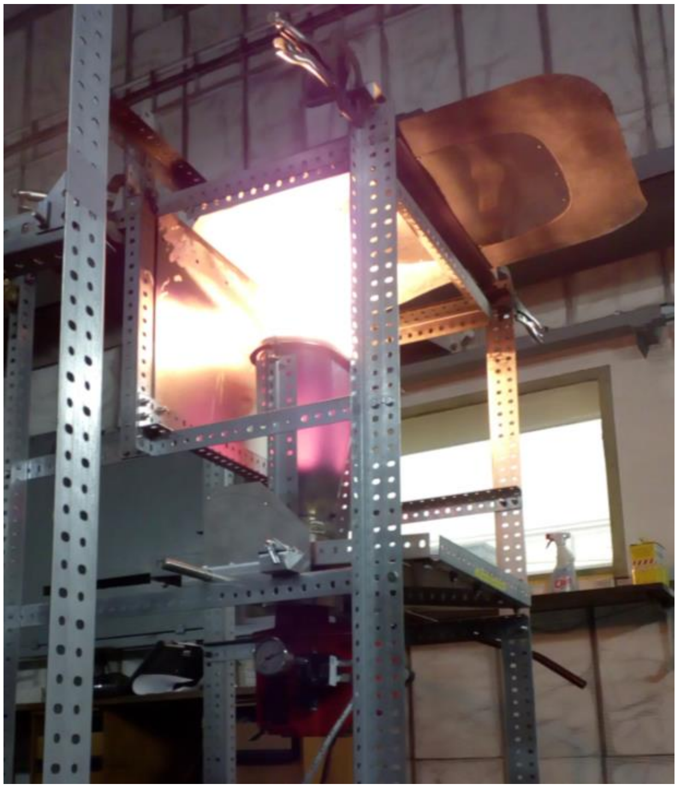


Figure 33: Flame penetration test arranged per CS 25, App. F, Part III. Test time was prolonged to 10 minutes instead of standard 5

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

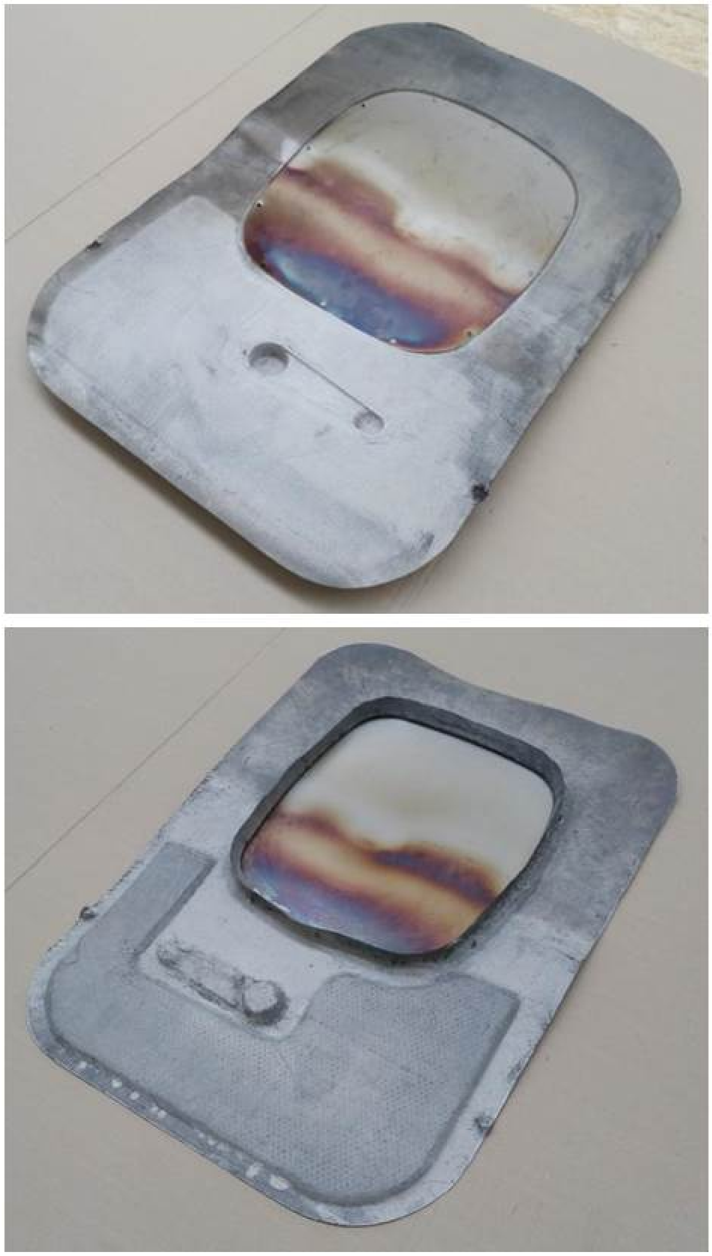


Figure 34: Molding B after 10 minutes of the flame penetration test. Exposed side (above) and back side (below). After the test, no visible changes have been registered on the molding, except of colour change and warpage of the edges. Due to application of geopolymer honeycomb, no sandwich "pillow effect" was registered. The molding has maintained integrity and very good stiffness

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

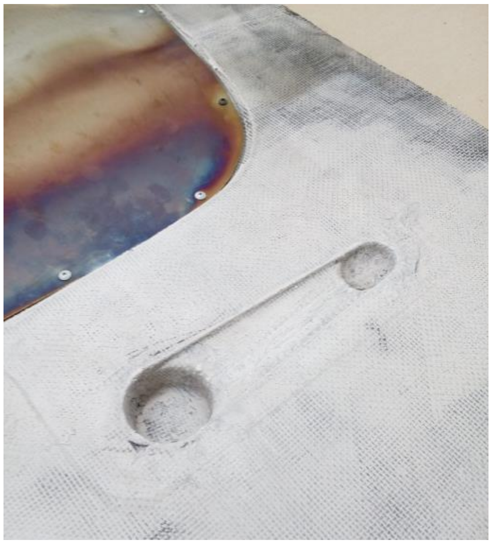


Figure 35: The emergency opening lever dimple has retained without the change

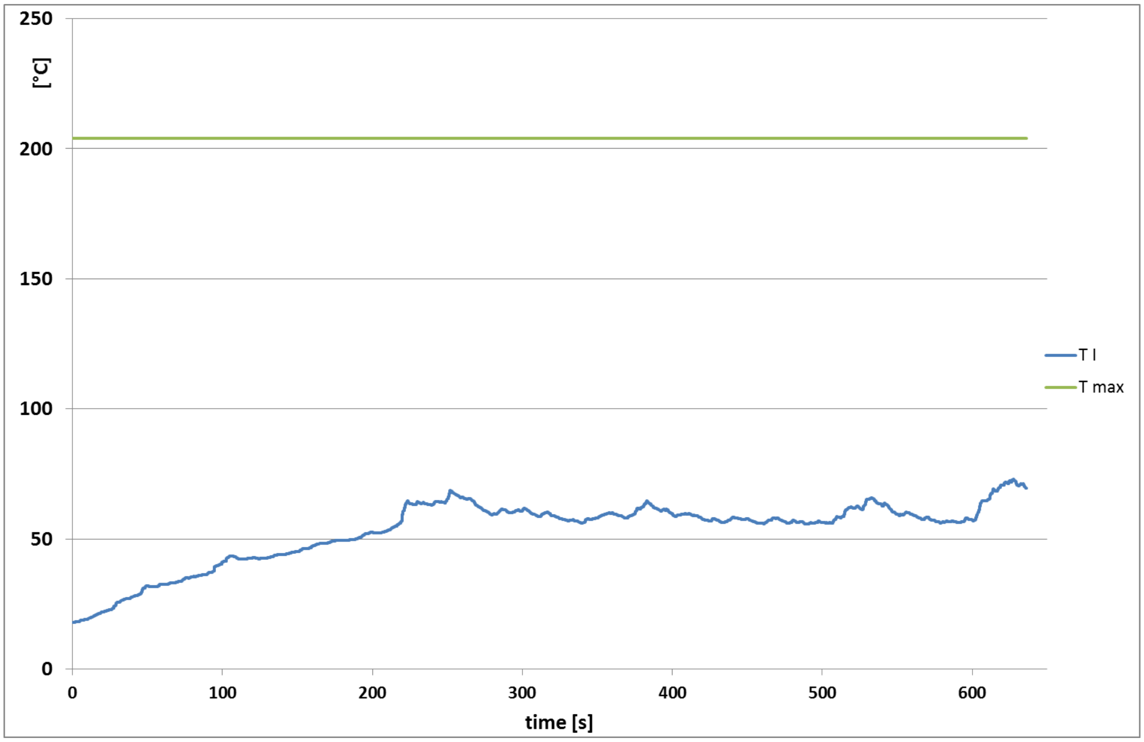


Figure 36: Temperature above the back surface:T I (blue line): temperature 101 mm (4 inches) above the back surface of the part. T max (green line): max. allowable temperature per CS25, APP. F, Part III (204oC / 400 °F). Temperature of the flame: 969,9oC on the average. Compare with graph on Fig. 37 where data from monolithic panel are presented

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

2.5. Molding C

As base fiber reinforcement of the molding B carbon-aramid hybrid fabric KORDCARBON CA 164 P - 120 (164g/m^2) was used[5]. This solution is an alternative to the molding A design where aramid is located as a separate layer between the carbon layers. The lay-up of the part was identical with molding A (Figs. 10, 11) except of the reinforcement material (layers 101, 102, 103, 104 are made of the hybrid). Fabric KORDCARBON in the industrial-grade quality was applied to reduce material costs. Manufacturing process of the part was identical with the molding A. More detail information is available in the report [6].

Weight of trimmed molding B (without surface finish) was 623 g.

Figure 37: Molding C (primer paint applied on the left half)

2.6. FST tests of carbon-aramid-geopolymer hybrid composite

Designing the part there were some doubts about FST properties of the hybrid reinforcement as aramid fibers come up to the surface (are not hidden between carbon layers as in the molding A). Considering yet unknown FST behaviour of the hybrid material, set of FST tests involving flame penetration test (CS25, App. F, part III), vertical test (CS25, App. F, part I) as well as smoke density and toxicants analyze have been carried out. The results of the FST tests have confirmed that the presence of aramid fibres does not impair significantly FST properties of the composite. All the test results have passed standards requirements and highly surpassed referential glass-phenol. More detail information is available in the reports [6] and [7].

[5] http://www.kordcarbon.cz/products

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

2.6.1. Flame penetration test

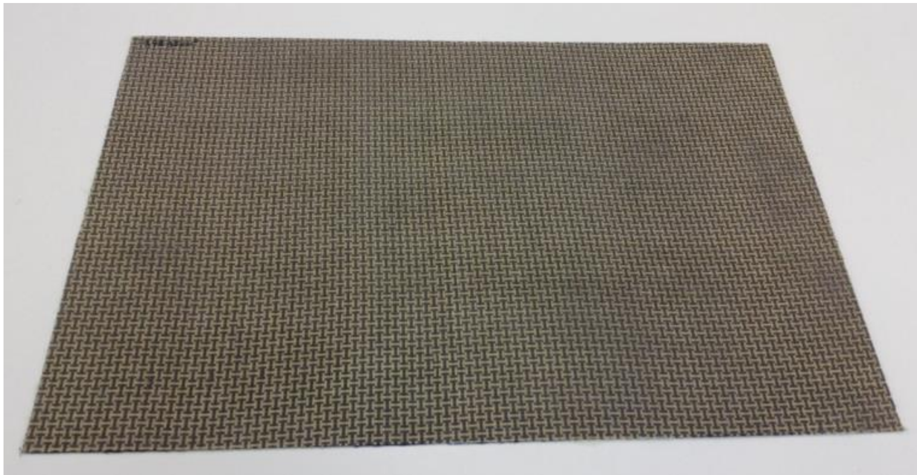


Figure 38: Test panel for the flame penetration test made of carbon-aramid-geopolymer hybrid composite (407 x 612,5 mm , mean thickness 1,05 mm, specific weight 1,45 g/cm^3)

Figure 39: Exposed side after the test

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

Figure 40: Back side after the test

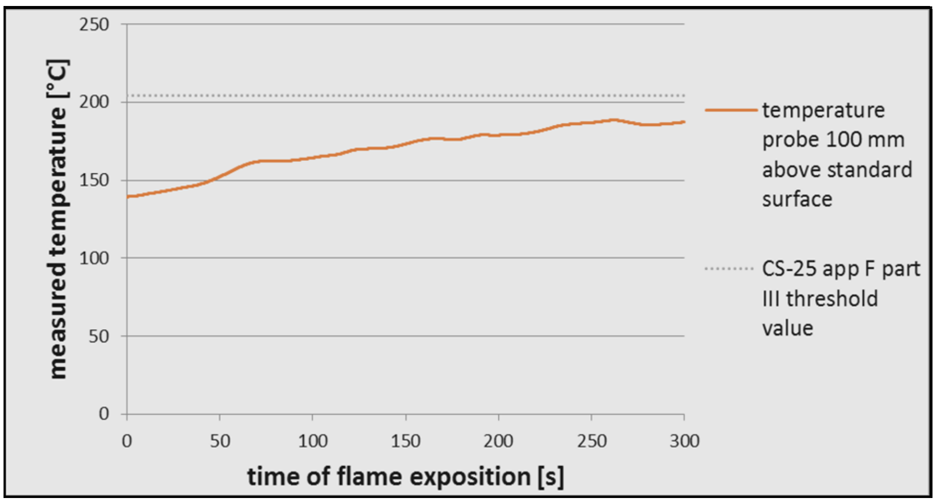


Figure 41: Temperature 100 mm above the back side of the panel

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

2.6.2. Vertical test

Figure 42: Test specimen for the vertical test made of carbon-aramid-geopolymer hybrid composite (50 x 305 mm , mean thickness 1,05 mm, specific weight 1,45 g/cm^3)

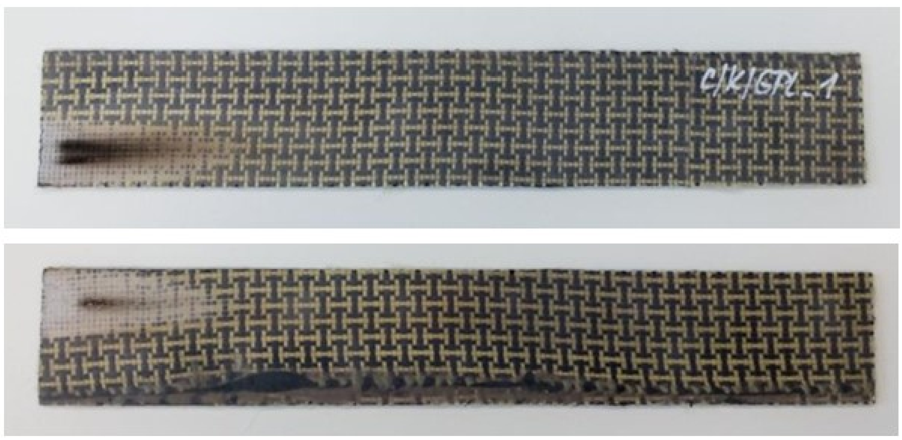


Figure 43: The specimen after the test

2.7. Molding D

Molding D was meant as referential made of GURIT PHG 600-68-37 T2 glass-phenolic prepreg and AIREX R82.60 foam. The lay-up of the molding is described on Figure 44. The part was manufactured by vacuum / oven curing. No filling or painting was carried out on this part. More detail information available in the report [8]. Weight of trimmed molding D was 776 g.

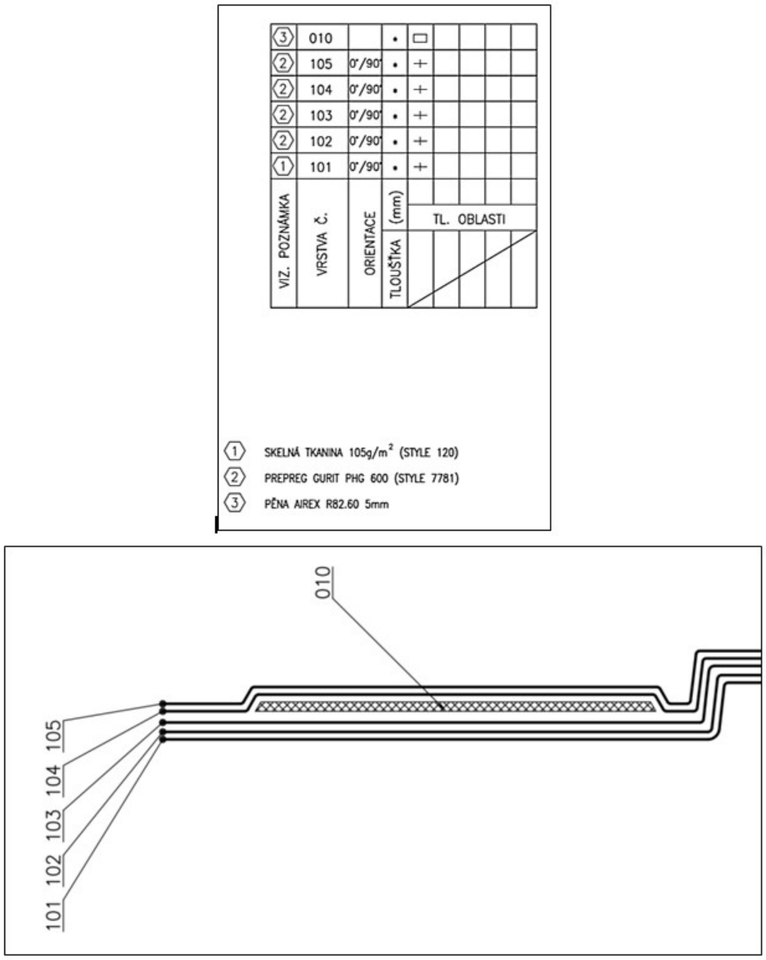
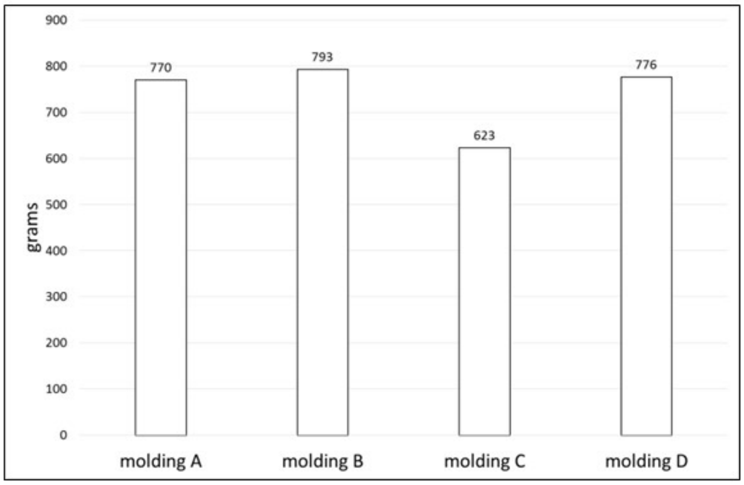


Figure 44: Lay-up of molding D

Figure 45: “Tool side” and “bag side” of the molding D

Future Sky Safety has received funding from the EU’s Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.



Note - specific weight of sandwich cores should be taken into account when evaluating weight of the moldings:

molding A – 234 kg/m³ gp honeycomb sandwich core
molding B – 234 kg/m³ gp honeycomb sandwich core
molding C – 60 kg/m³ Airex R82.60 sandwich core
molding D – 60 kg/m³ Airex R82.60 sandwich core

Figure 46 Weight comparison of moldings

Table 1 Informative comparison of molding C vs. molding D material costs

Molding variant	Main structural material	Structural material price incl. VAT (100 g)	
C (carbon / aramid / geopolymer)	carbon - aramid hybrid fabric KORDCARBON CA 164 P 164 g/m²	7,44 € [6]	7,84 €
	GPL 30 resin	0,4 €	
D (glass / phenol prepreg)	GURIT PHG 600-68-37 T2 prepreg	8,24 € [7]	8,24 €

2.8. Conclusion and outlook

Realization of the Demonstrator No. 2 has proved manufacturability of real aircraft interior part of inorganic, geopolymer based composite material. Standard serial molds as well as common vacuum bag manufacturing procedure have been applied with no complications. Molding A was intended for exhibition purposes only. Its surface was extensively filled and painted (and its weight exceeded expected value, but was not a priority criterion here). The molding B underwent prolonged flame penetration test (10 minutes instead of prescribed 5 minutes). Design and material of the molding B showed (as expected) exceptional fire resistance and negligible smoke emission during the test. The geopolymer honeycomb

[6] Seller: Havel Composites 2018

[7] Seller: Skolil Kompozit 2018

core didn't cause "pillow effect" as was observed at the previous tests at organic sandwiches cores ([9]) and the part has retained very good structural integrity after the test. The temperature 101 mm above the back surface ranged from approx. 60 to 70oC that is deeply under CS25 limit. In the molding C, newly hybrid carbon/aramid fabric was applied and relevant FST tests were made. These have shown improvements compared with the 'carbon only' composite ([6]). Implementation of aramid fibres has enhanced the impact resistance and reduced the specific gravity of the geopolymer composite ([5]), so molding C was characterized by the lowest weight among the other moldings.

Outlook:

For potential application in the aircraft structure, some specific problems that haven't been dealt nor studied yet, remain to solve. To ensure the uniform quality of the composite material it is necessary to introduce mechanized manufacturing of the semi-product, so-called 'wetpreg'. Accurate machine dosing and distribution of geopolymer resin in the fiber reinforcement is the important factor to achieve low specific weight and uniform mechanical properties, which are critical parameters of the FRGC material. In the VZLU recently special impregnating device was designed and manufactured, but is still in the trial operation and was not used for the Demonstrator manufacturing. The methods of suitable surface treatment of geopolymer moldings should be also studied. Still unknown, specific issues relating to durability of standard coating systems on geopolymer surface may arise. In the ideal case, to get response from practical operation, one or more parts will be deployed in the real service whilst monitoring its operational characteristics during long-term exploitation. If the FRGC structure is applied in the serial airplane production, a range of administrative and regulation questions should also arise concerning a certification process, since FRGC is unknown material in the aerospace practice as yet. Nevertheless, none of these issues, on principle, should prevent utilization of FRGC in the aircraft (or other vehicle) structures.

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

3 FIBER METAL LAMINATE DEMONSTRATOR

3.1. Background

Fibre metal laminates (FML) were investigated to improve the present CFRP material behavior within a fire scenario. To this, it was shown, that the metal layers acting as gas barrier significantly reduce the generation of smoke and toxic gasses. Moreover, the burn through resistance is improved allowing increased duration of mechanical performance of the structure. To further investigate this, a compression under fire exposure test was developed.

It has been shown that Fibre-Metal-Laminates (FML) are capable of improving the FST behaviour compared to their CFRP base material. This could be used not only for aviation load-bearing structures but also for other means of transport with stringent fire requirements (e.g. railway, marine). A further improvement of the FML properties is expected by tailored laminate design (e.g. thinner metal sheets and their positioning) that might be derived by using and enhancing the modelling methods developed in FSS. Furthermore, possible multifunctional aspects of FML compared to standard CFRP should be investigated (e.g. electrical properties). A new test stand for axial compression loading under fire exposure (CUFEX) has been developed and build-up at DLR. First tests on FML show promising results. The CUFEX test stand can be used for future research activities and further understanding of scale effects. This could include stiffened specimens to facilitate the step from coupon level to a more realistic structure level.

This chapter describes the manufacturing of a demonstrator FML and benchmark panel made of classic Aluminium, including fire testing.

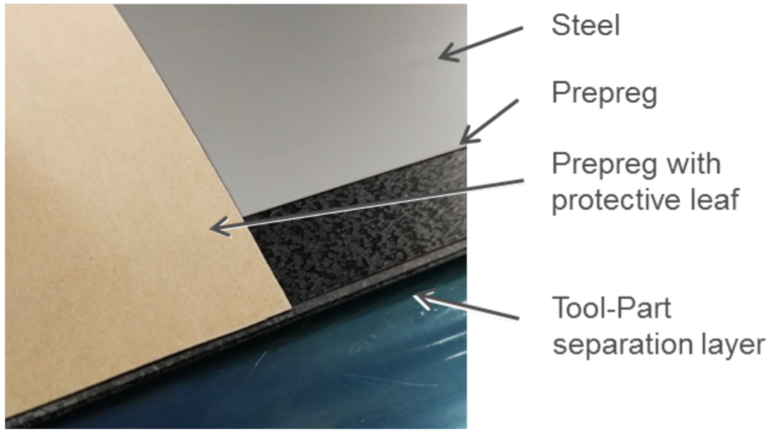
3.2. Materials

Two laminates, a basic laminate and a fibre metal laminate, were manufactured to demonstrate the different behaviour under fire exposure. For the production of the basic laminate, unidirectional prepreg tape with IMA carbon fibres from Hexcel was 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 a ply thickness of 0.125mm.

3.3. Manufacturing

The basic CFRP laminate and the CFRP-steel composites (FML) were manufactured via prepreg autoclave technology. For comparison purposes, the laminate and the aluminium panel have a thickness of approx. 2.0 mm. The basic laminate is based on 12 plies with 0/90° orientation and in the FML 4 plies are replaced by pre-treated metal layers. In a first step, the surface of the steel layers was sandblasted. After that, they were dipped in the coupling agent for 150s and dried for a minimum of 1hr at room temperature. Then the lay-up was build up and cured in an autoclave. During the autoclave cure cycle the heat was 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 panels were cut into samples of 500 x 500 mm via water jet cutting.

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.



-

Figure 47: Layup example for FML with description of the layers [DLR]

3.4. Testing

To demonstrate the benefits of FML under fire exposure, a comparative test was chosen. The competitor is a plate produced from aviation certified aluminium that has a similar thickness as the FML and the identical width and height.

The two panels were exposed to the identical fire conditions to show the differences in the behaviour of the materials. Similar to the CuFEx-test, a gas burner was used to simulate a pool fire. The gas burner has a temperature of approx. 1200°C and thus transfers approx. 200kW/m² of energy to the panels. The panels were clamped all-around to simulate the surrounding structure that hinders excessive warpage and overall deformation. The flamed area was defined by an aperture with a size of 250x250mm². However, the hot-spot of the flamed area is smaller due to the diameter of the gas burner. The burner was brought close to the panel with an identical distance for both panels. The measured time for the test was measured from the moment the burner was in the near position. Both panels showed an immediate reaction to the flame and warped away from the gas burner. From that point onwards the behaviour differed dramatically. The aluminium panel started to show a softening of the material after approx. 25s of fire exposure. This led to the formation of a bulge that ripped apart after further 30s of flame exposure. The burn-through occurred after 57s of flame exposure and left a circular hole in the otherwise barely damaged panel. The moment of the burn-through is shown in the lower picture below Figure 48).

The FML panel showed first formation of additional flames after just 9s of fire exposure. This is supposedly caused by decomposition of the matrix material. The additional flames extinguished after further 30s as the matrix material was fully decomposed in the layers that faced towards the burner. In the meantime the backside of the panel formed a "pillow" in the size of the aperture. This is caused by decomposition gases that form between the steel layers and the CFRP layers. As these gases are trapped, the blow up the "pillow". The flame exposure was continued up to a total exposure time of 120s. The FML panel suffered no burn-through. The FML was still intact from a structural point of view and prevented flames from penetrating through the panel. This can be seen well in the upper part of Figure 49.

Figure 48: Comparison of the fire response of a FML test panel and an aluminium certified tast panel submitted to a flame penetration test

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

4 CONCLUSIONS

The demonstrators produced within the FSS P7 project were shown at the FSS Final Conference in Brussels. The presentation desk is shown within Figure 49 and Figure 50. Together with posters giving information about developed expertise within FSS the demonstrators were presented by their physical presence as well as a video showing the conducted fire tests (conf. Figure 50). The video compared FML and GP to their respective state of the art material and underlined the potential of the developed material systems. People were highly interested in spectating at the video and inspecting the physical demonstrators. The combination of the presented video and the physical demonstrators led to a lot of interesting talks and discussions. Additionally, a presentation was held at the conference presenting the material developments, CuFex test bench and test results.

The second VZLU demonstrator no.2 was presented during the Tandem Aerodays held in the Bucharest Palace of Parliament from 27-30 May 2019 (see Figure 51 and Figure 52). About 800 participants and 100 journalists attended the Aerodays in Bucharest, including high level representatives of the aviation industry and research agencies. Interest in the demonstrators was high. The Demonstrator No. 2 was designed as an actual interior panel of the CS 23 certified, Czech made regional turboprop. An emergency exit door panel was identified as the optimal choice with relatively complex design featuring window cutout and dimple of the opening lever. Originally the part is made by autoclaving of qualified glass-phenolic prepreg. One of the two demonstrators was fire tested to show the improved fire properties of the material combination. Additionally, a video was shown on a screen nearby, featuring all demonstrator fire tests conducted in WP7.2. Information about the Aerodays and more images available under: **http://www.tandemaerodays19-20.eu/media/**

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

Figure 49: Demonstrator presentation desk at FSS Final Conference in Brussels (Eurocontrol, 2018/11/06-07)

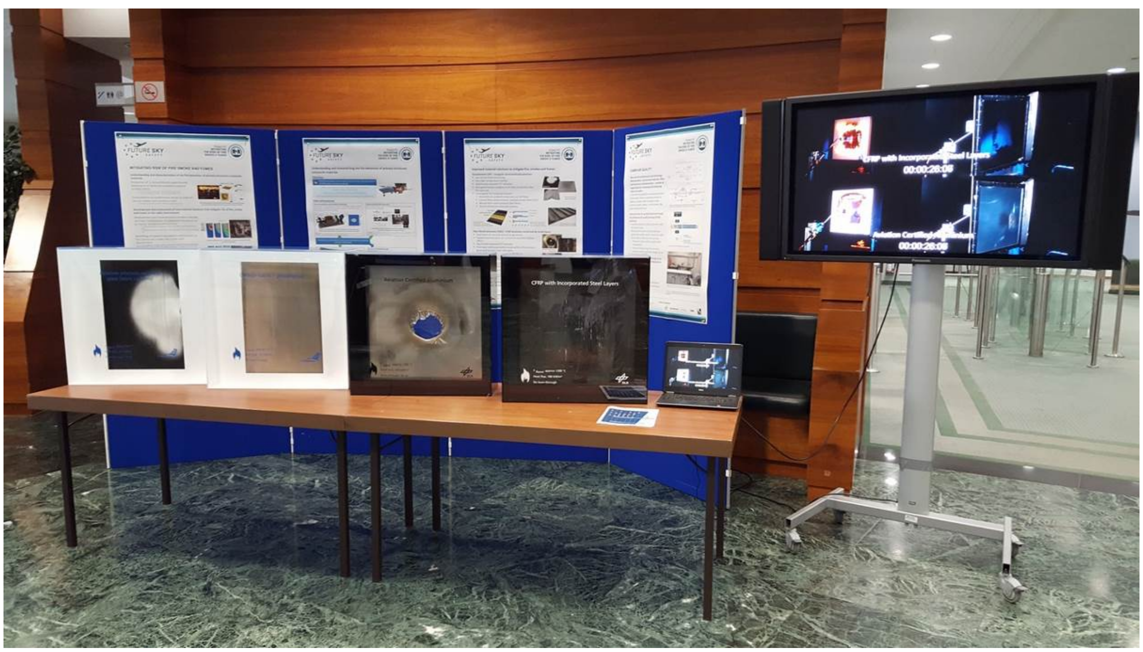


Figure 50: Demonstrator presentation desk and video screen at FSS Final Conference in Brussels (Eurocontrol, 2018/11/06-07)

Figure 51: Demonstrator and video presentation at TandemAerodays 2019 in Bucharest, Romania (27-30 May 2019)

Figure 52: Presentation area at TandemAerodays 2019 in Bucharest

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

5 REFERENCES

[1] D7.5 New materials for fire protection in cabin environment – Test results first batch

[2] D7.8 New materials for fire protection in cabin environment – Test results second batch

[3] D7.10 Materials for cabin environment protection - Models for material degradation

[4] D7.13 Improving material solutions to mitigate fire, smoke and fumes in cabin environment – final report

[5] I. Roese-Koerner, J. Bachmann, F. Martaus, G. Mirra, J. M. Liebisch, P. Lorsch (2018) [online]. Improving material solutions to mitigate fire, smoke and fumes in cabin environment – final report. Report FSS_P7_DLR_D7.13. Pages 33-34. European Research Establishments in Aeronautics, 2018 [03-28-2019]. Available from: https://www.futuresky-safety.eu/download/

[6] MARTAUS, F. Fire Effluents and Smoke Optical Density of Fiber Reinforced Geopolymer Composites. Research report R-6897/2018. Praha: Czech Aerospace Research Centre (VZLU), 2018.33 p.

[7] MARTAUS, F. Flame Penetration and Vertical Tests of Geopolymer Composites Containing Ductile Fibers. Research report R-6886/2018. Praha: Czech Aerospace Research Centre (VZLU), 2018.18 p.

[8] MARTAUS, F. Demonstrátor letadlového dílu zhotovený z kompozitu na bázi geopolymerní matrice. Research report R-6726/2018. Praha: Czech Aerospace Research Centre (VZLU), 2018.24 p.

[9] MARTAUS, F. Composite Sandwich Panels for Flame Penetration Tests. Research report R-6723/2017. Praha: Czech Aerospace Research Centre (VZLU), 2017.27

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.