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The Group of Responsables "Structures and Materials (GoR SM)": An Overview of Activities and Success Stories

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Abstract

The Garteur Structures and Materials Group is active in initiating and organizing aeronautics oriented research on structures, structural dynamics and materials in general. Materials oriented research is related to material systems primarily for the airframe; it includes specific aspects of polymers, metals and various composite systems. Structural research is devoted to computational mechanics, loads and design methodology. Research on structural dynamics involves more especially response to shock and impact loading.

The group is active in theoretical and experimental fields of structures and materials to strengthen development and improvement of methods and procedures. Of great importance is the mutual simulation of the diverse scientific approaches. Experiments give new insights into the mechanisms of structural behavior that can be included in improved theoretical models. Finally, the theoretical results must be verified and validated by comparison with results from suitable experiments or trials.

Although the specific topics vary over the years, the scientific basis remains largely unchanged. The work is looked upon as an upstream research intended to discover valuable areas of future activity. Topics for research are explored in Exploratory Groups (EG's) and in case sufficient ground is found for the specific topic EG's are then being transferred to Action Groups (AG's). The present papers presents an overview/summary of recently closed AG's and recently started EG's.

Keywords: GARTEUR, Composites, Metals, Characterization and Modelling

1. Introduction

Structural and material research in aeronautics strives to reduce structural weight, improve safety and reliability, keep operation cost low, reduce environmental impact and improve passenger comfort. In many cases, the research tasks are strongly interconnected so that an optimum design can only be reached through balanced improvements in all fields. The GARTEUR Structures and Materials group is active in initiating and organizing aeronautics oriented research on structures, structural dynamics and materials in general. Materials oriented research is related to material systems primarily for the airframe but also for the landing gear and the engines; it includes specific aspects of polymers, metals and various composite systems. Especially the integration of new functionalities is the key to further enhance the performance of materials. Structural research is devoted to computational mechanics, loads and design methodology. Research on structural dynamics more especially involves response to shock and impact loading. The group is active in theoretical and experimental fields of structures and materials to strengthen development and improvement of methods and procedures. Of great importance is the mutual stimulation of the diverse scientific approaches. Experiments give new insights into the mechanisms of structural behaviour that can be included in improved theoretical models. Finally, the theoretical results must be verified and validated by comparison with results from suitable experiments or trials. Although the specific topics vary over the years, the scientific basis remains largely unchanged. The work is looked upon as an upstream research intended to discover valuable areas of future activity. Activities within the Exploratory and Action Groups cover several aspects of improved conventional and new technologies, new structural concepts and new design and verification criteria. Recent, current and upcoming work is devoted to:

• Fatigue and damage tolerance assessment of hybrid structures

• Damage repair with composites in composite and metallic structures

• Characterization and modelling of Composites with Ceramic Matrix submitted to severe thermo-mechanical loading

• Characterization of composites with polymer matrix at high temperatures

• Characterization and optimization of shock absorbers for civil aircraft fuselages

• Additive Layer Manufacturing

• Structural Health Monitoring for hydrogen aircraft tanks

The present papers gives an overview of the most recent three Action Groups (AG) and Exploratory Groups (EG) that were launched in 2021 and 2022.

2. Action Grous

2.1 SM/AG-34 Damage repair with composites

2.1.1 background

Composites are much more prone to being damaged in service than metals, for example, by mechanical impact. Repairability of such damage is an important consideration in the selection of composites for aircraft applications. In addition, metal structures can be repaired by using composite patches with great potential benefits such as cost reduction and time saving. These repair techniques can be considered applicable to a wide range of structures both metallic and composite (laminates or sandwich).

The repair scheme used for structural restoration should be the simplest and the least intrusive that can restore structural stiffness and strain capability to the required level and be implemented in the repair environment, without comprising other functions of the component or structure.

It is usually necessary to restore the capability of the structure to with stand a design’s ultimate load and to maintain the capability for the full (remaining) service life.

The functions that must be restored can include: aerodynamic shape, balance, clearance of moving parts and resistance to lighting strike. The requirement in military to restore the stealth properties of the component may also have to be considered and may influence the type of repair chosen.

The wide spreading use of composite structures but also the need to reduce costs have lead to an increasing interest in repair and especially in repair with composites and in its potential applications.

However, uncertainties remain in the behaviour of repaired structures that generally lead aircraft manufacturer to use repair only for secondary structures, to prefer bolted repair over bonded repair and to limit the use of bonding only to limited-size damage.

The partners in this action group were: CIRA, RISE Sicomp, FOI, Imperial College London, NLR, Consiglio Nationale delle Richerche,INTA, Norwegian University of Science and Technology, Lulea University of technology and SAAB.

2.1.2 Objective

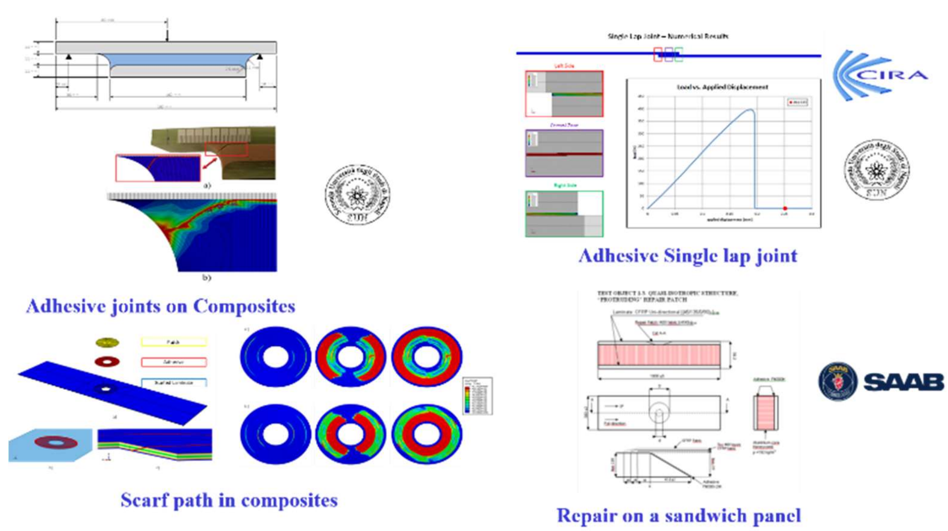
The main objective of this action group was to define effective repair techniques for aircraft structures through the development of numerical/experimental methodologies. The following topics were addressed: repair criteria, design of patches and repair strategies, analysis of the repair, manufacturing and test, repair strategies and technology end effective repair methods.

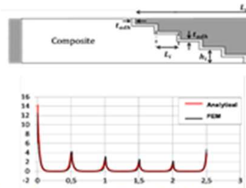
2.1.3 Results

The effective outcomes of this action group can be summarized in: minimized down-time of the aircraft for repair operations, minimize costs for repair, promote the repair of components instead of substitution and reduce certification costs and of the time for certification for repaired structures.
The main challenges that were addressed consisted in (Figure 1):

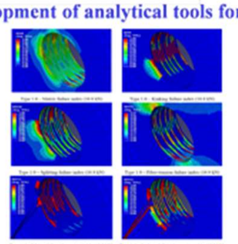
Failure mechanisms:
When dealing with bonded repair (composite patches) problems are related to the complex behavior of composite material itself as well as to the many potential failure mechanisms associated with its design and use. It is worth noticing that, in this kind of failure mechanisms, both the adhesive behavior but also manufacturing issues such as surface treatment play an important role. Indeed, any contamination – be it dust or fluid – between the adhesive and the bonding surface can cause an adhesive failure. The development of failure mechanisms has been extensively simulated in the frame of the project.

Repair design procedures:
The design of effective repairs on the structures have been considered. The choice of proper geometry for the repair patch and the correct dimensions for the repaired area have been proven to provide advantage in repair operations.





Development of analytical tools for Repair Design

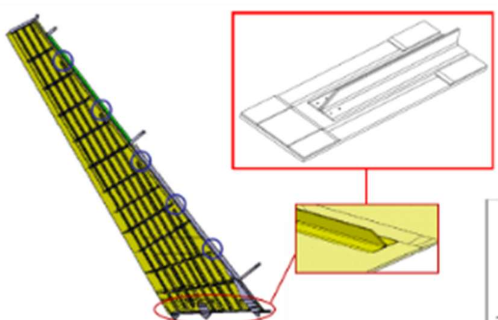


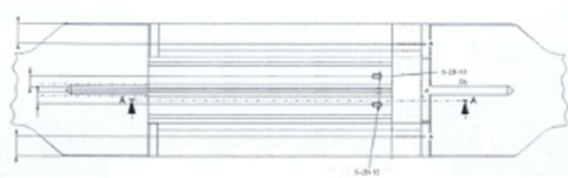
Numerical analysis progressive damage in composite joint

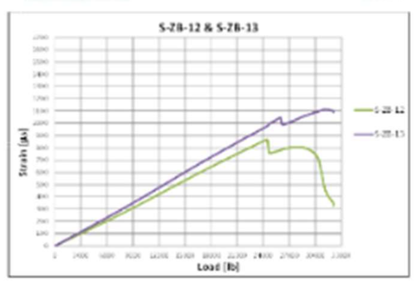
Repair on UAV wing

- VERTICAL STABILIZER – MAIN BOX

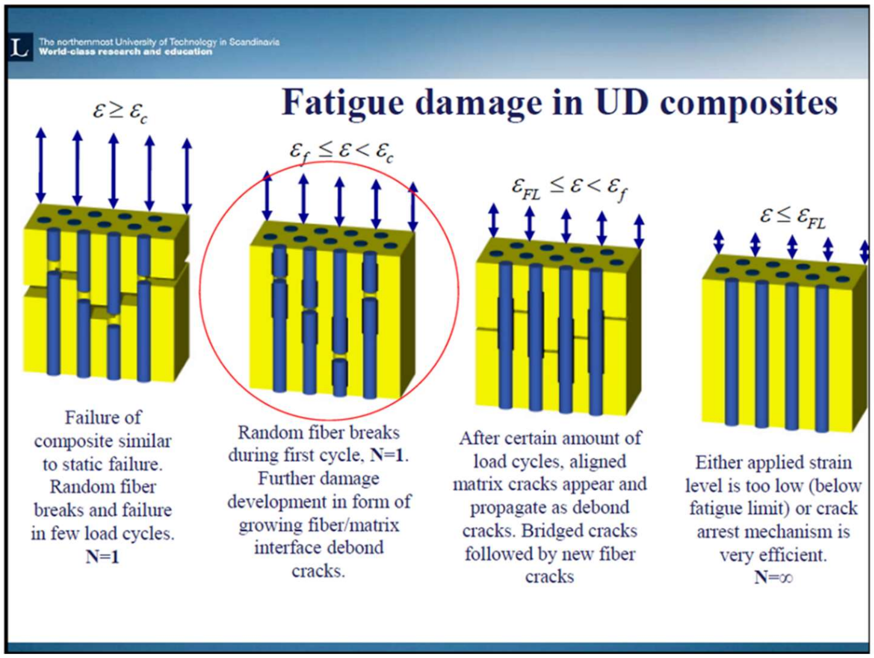
Stringer Termination in built-up co-bonded structures identifies areas characterized by high interlaminar stresses leading to disbonding at the skin-stringer bondline. Identification of analysis models and methodologies to predict the stringer termination behaviour. Suggested bonded bolted repair to prevent the debonding

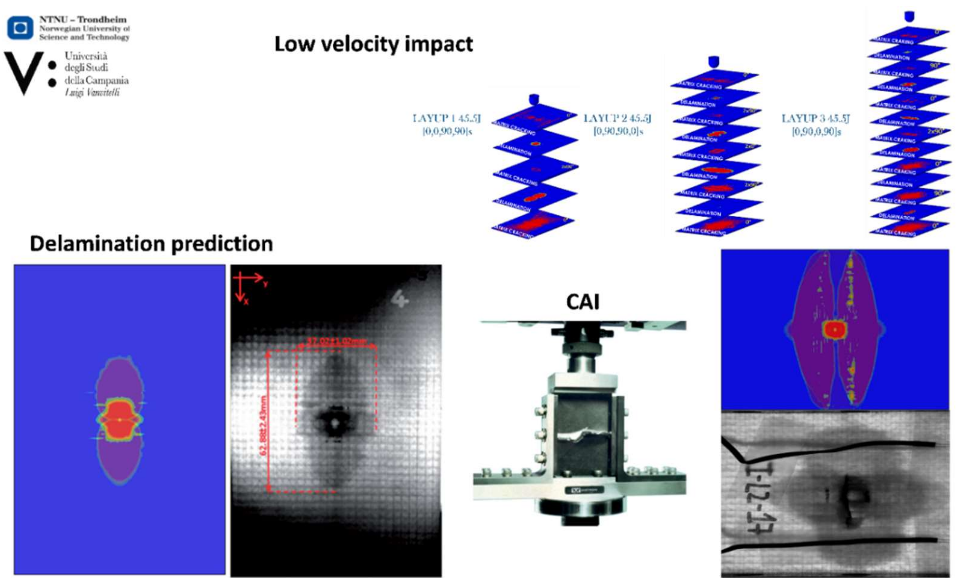






- Fatigue Damage in UD composites





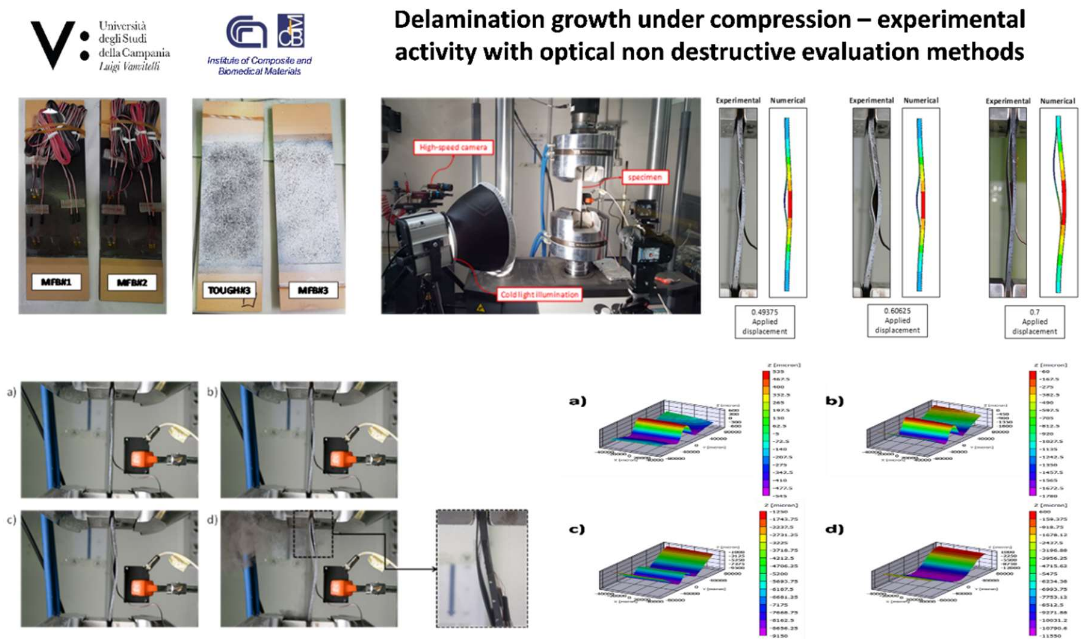


Fig. 1: Summary of the main results concerning the development of new numerical tools, new repair design tools and repair procedures for composites.

The final report of this action group was finalized in November 2021 and accepted by the Garteur Council on November 17, 2021. The Action Group is closed.

2.2 SM/AG-35 Fatigue and damage tolerance assessment of hybrid structure

2.2.1 Background

Hybrid structures i.e. structures consisting of a metallic and CFRP component, are becoming more prevalent in aircraft structures. Structural components made out of metal require a different approach with respect to fatigue analysis and fatigue testing than components made out of fibre reinforced plastics (composites). A major challenge in the fatigue analysis and subsequent fatigue testing of hybrid structures originates from differences in deriving fatigue spectra for metal and composites and incorporation of required environmental load factors for composites. Also the joining of metallic components with carbon fibre reinforced polymers will require additional care and attention in terms of design and assembly requirements. In particular the influence of the environment is of important for hybrid structures. Due to the differences in thermal expansion coefficient between metal and composites thermal stresses may arise and have to be dealt with in static and fatigue strength substantiation. Another concern is the long-term stability and degradation of bonded joints and fibre-metal laminates (FML) due to environmental influences: the aging of joints in humid environments.

The partners in this action group were: FOI, Fokker Aerostructures, NLR, DLR, Technische Universität Kaiserslautern and SAAB.

2.2.2 Objective

The main objectives of the AG are listed below and should load to a joint "best practice" approach for testing of hybrid airframe structural components.

Task 1: Loading aspects of full scale fatigue and damage tolerance tests.
A major challenge in the fatigue analyses and subsequent fatigue testing of hybrid structures originates from the differences in deriving fatigue spectra for metal and composites and the incorporation of required environmental load factors for composites. Therefore in this tasks the following aspects were addressed:

- Composite structures are sensitive to environmental conditions, metal parts usually are not. Relevant aspects of the environment are in this case the temperature and the in-service moisture content, both as environmental history effect during the lifetime of the structure as well as conditions during proof of residual strength. If it is decided not to perform fatigue- or residual strength tests under these conditions, which aspects should be taken into account via environmental factors on the applied loads?
- Material scatter for composites is much higher than for metals. However, to avoid non-linear behaviour of the test set-up and to avoid high stress levels in the metal parts a maximum overall load increase should be respected.
- In general, damage growth in composite materials is most sensitive to compression-compression cycles, where metal fatigue initiation and crack growth are more sensitive to tension-compression and tension-tension cycles. A generic process for a load spectrum reduction technique covering both aspects should be discussed.
- Fatigue spectrum truncation levels are different for metals and composites. Where composites experience high damage from high peak loads, metals will experience crack retardation after application of a severe load condition.

Task 2: Determination of the optimum way to account for thermal loads in a non-thermal test-set-up of hybrid airframe structural components
One of the most important effects of the environment on a hybrid structure are thermally induced interface loads due to the differences in coefficient of elongation between metals and composites (e.g. attachment areas between a “warm” fuselage and a “cold” wing) come in addition to the mechanical loads. In non-thermal fatigue testing it is a challenge to apply these loads mechanically. As thermal loads will generally build up in all directions throughout an aircraft structure, the combination with mechanical loading can result in either a uni-axial or a bi-axial stress state (Fig. 2). It is to be discussed when the thermal loads are significant enough to be considered for the fatigue and damage tolerance justification.

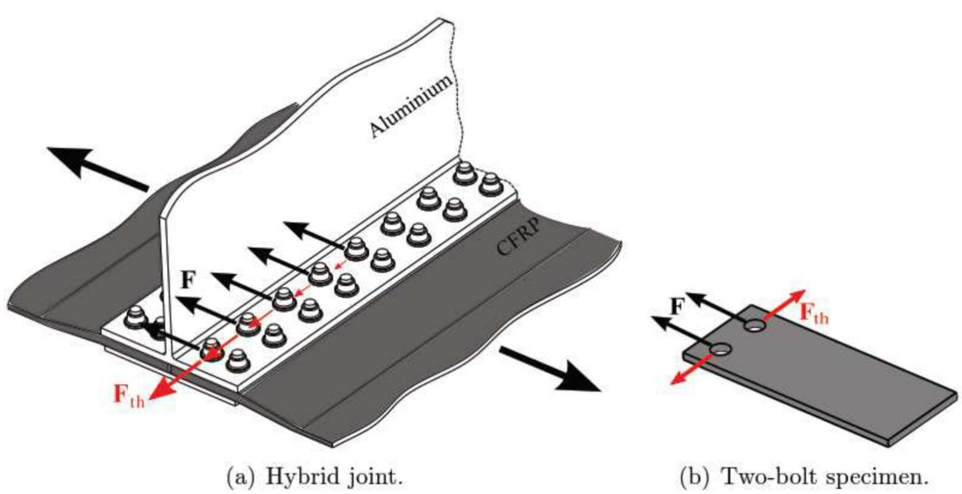


Fig. 2: Mechanically and thermally induced bolt loads in a composite plate in a hybrid bolted joint and a simple two-bolt specimen.

Task 3: Environmental influences

One particular focus of this research in on the long-term stability and degradation of bonded joints and fibre-metal-laminates due to environmental influences was the aging ff joints in humid environments. Very often the major challenge in adhesive bonding is not the load carrying performance of the joints, which can typically be realized even with simple pre-treatment technologies like grid blasting, but in ensuring that the joints will not fail after a short period due to e.g. the effect of water ingression.

2.2.3 Results

A joint "best practice" approach for full scale fatigue testing of airframe structural components was established for the different tasks (Fig. 3).

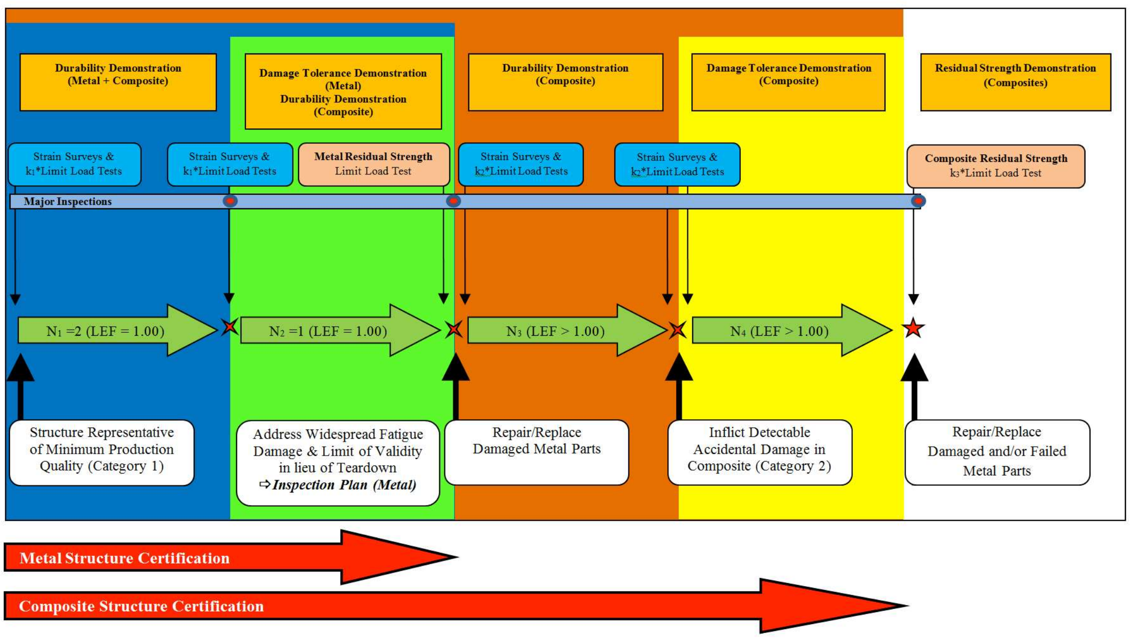


Fig 3: Example of full-scale test sequence.

Task 1: The experimental program for this task was designed to show any differences between a traditional – and widely accepted – approach for the derivation of the test spectrum for a hybrid structure and two new approaches. The Load-Life-Shift (LLS) and the Multi Load Enhancement Factor (Multi-LEF) approach respectively.

Task 2: Experimental and numerical studies of static and fatigue bearing failure were conducted in uniaxial and bi-axial loading of composite joints at elevated temperature (Fig. 2). The experiments were designed to isolate the local phenomena and to represent, in a simplified way, the effect of thermally induced loads on hybrid composite-aluminium assemblages.

Task 3: The bonding and the resistance against degradation by water has been studied for different aerospace relevant titanium alloys joint with thermoplastic PEEK. Morphological details of pre-treated metal surfaces, wetting and infiltration by the polymer melt, mechanical and aging behaviour have been characterised in order to further understand the aging and bonding mechanisms and to derive specific surface pre-treatments for reliable high performance adhesive joints.

The final report of this action group was finalized in December 2021 and accepted by the Garteur Council February, 2022. The Action Group is closed.

2.3 SM/AG-36 Additive layer manufacturing

2.3.1 Background

Additive Manufacturing (AM) with metals is an emerging technology that finds more and more applications in different markets such as orthopedic implants, dentistry and high-end industry. There is also a lot of interest coming from the Aerospace industry. Metal AM technology can provide great advantages with respect to conventional metal working techniques, such as significantly lower waste of materials, a larger freedom of design, high potential for weight reduction and the possibility to integrate additional functionality (e.g. integrated cooling capability). Specific design guidelines must be taken into account and currently available CAD design tools are considered inadequate for designing for AM. Currently it still difficult for AM technologies to compete with traditional machining and forming techniques on reliability and reproducibility because the quality of final products depends very strongly on material and process parameters. Metal AM material qualification and process certification methods are not available yet. Qualification and certification procedures are therefore essential for getting metal AM technology accepted for high demanding applications like aerospace.

Aluminium and its alloys are widely used in the aerospace sector due to their excellent mechanical performance in combination with their light weight. Their strength and low density are the main advantages of these materials. Fabricating components with complex geometries from high strength aluminium alloys by conventional processing techniques is challenging due to their low formability. In contrast, metal additive manufacturing techniques allow the production of near-net-shape and complex parts, adding value to the use of aluminium alloys in the aerospace sector. Even so, not all aluminium alloys are easy to process by AM. Currently, there are several novel aluminium alloys being investigated for application in AM. Great advancements are being achieved on laser powder bed fusion (L-PBF) and also on directed energy deposition (DED). One of the focus points is to broaden the materials palette towards higher performance aluminium alloys. On one hand, the high-strength 7000 series are being investigated aiming at avoiding solidification cracking during the AM process. Several works have focused on modifying the composition by additions of Zr, Sc or Si in order to avoid cracking and improve the mechanical properties. On the other hand, casting aluminium alloys have been widely investigated with addition of nano- /micron-sized particles such as TiB2 or TiC aiming at increased fatigue performance. Examples of these modifications have resulted in commercially available aluminium alloys such as A20XTM developed by Aeromet with Cu and TiB2, or Scalmalloy® developed by Airbus & commercialized by APWorks. Besides the advancements on alloy development for AM, there is still a big gap with regard to commercialisation of these novel alloys. Therefore, great efforts should be done to fully characterise these compositions in order to get a full overview of their mechanical performance in various conditions. In addition, aluminium processing is still a big challenge due to the laser related high reflectivity & unstable melting behaviour of the alloy.

The activities of this group are organised in the following work packages:

- WP 1 Literature study
- WP 2 Process optimisation Liquid Powder Bed Fusion (LPBF)
- WP 3 Property characterization LPBF
- WP 4 Exploration of AL-Alloy Directed Energy Deposition (DED).

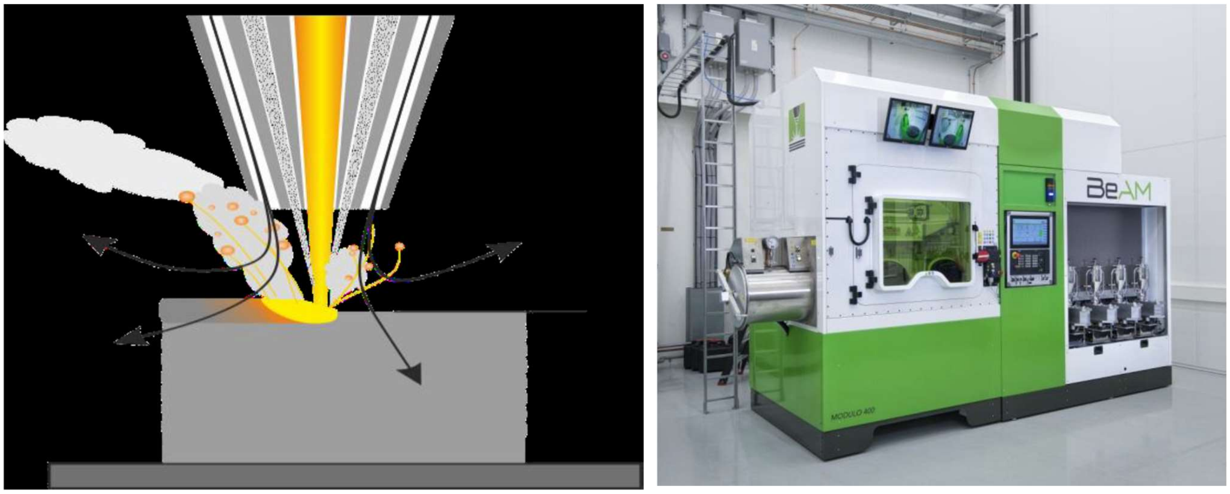


Fig 4: DED process and DED machine

2.3.2 Objective:

Based on these considerations Action Group SM/AG-36 was launched in January 2022 and focusses on “Additive Manufacturing of novel high strength aluminium alloys”. The goal of Action Group is to build up knowledge and skills in the field of metal AM processes and materials in order to support the manufacturing industry and increase its competitiveness.

The expected impact of the AG is to develop AM processes for high performance aluminium alloys (AL-Alloys) and to achieve static and/or dynamic performances that are equal but preferably higher than the current AL-Alloys.

Partners in the SM/AG-36 are NLR, ONERA, University Campania, INTA and Airbus.

3. Exploratory Groups:

3.1 SM/EG-44 Characterization of composites with polymer matrix at high temperature

This topic has first been proposed by ONERA and DLR. Both partners participate to the SuCoHS H2020 project (Sustainable & Cost efficient High-performance composite Structures) which emphasizes the industrial needs of experimental characterization methods for composite properties at high temperature (< 400°C). The exploratory group will use the results of the SuCoHCS project as starting point for further research. More detailed the proposed objectives of this exploratory group are:

- The definition of experimental methods for mechanical properties for the ply and the interface;
- How take into account the thermal degradation in the characterization process;
- Experimental methods and analysis of DMA results;
- Characterization of the thermal expansion coefficient;
- Analysis of the thermomechanical results by taking into account the thermal strain evolution;
- Improvements of test stands for testing classical coupons (Fig. 5).

Fig. 5: High temperature set-up for testing composites

This EG will be further explored after completion of the SuCoHS project (mid 2022).

3.2 SM/EG-45 Characterization and modelling of CMC submitted to severe thermomechanical loading.

This topic has been proposed by ONERA and DLR. The objective consists in the characterization of the mechanical properties and modelling of Composites with Ceramic Matrix (CMC) submitted to high mechanical loadings and extreme thermal conditions.
More detailed objectives consist in the:

- Comprehension of the damage and failure mechanisms under static and fatigue loading at very high temperatures;
- Definition of standard tests for the measurement of mechanical properties (behaviour, damage, failure) at very high temperatures;
- Proposition of damage and failure models to predict behaviour, damage, failure and fatigue lifetime of composite materials;
- Testing and simulation of CMC composite structures (Fig. 6) under static or fatigue loading (evaluation of predictive capabilities of models).

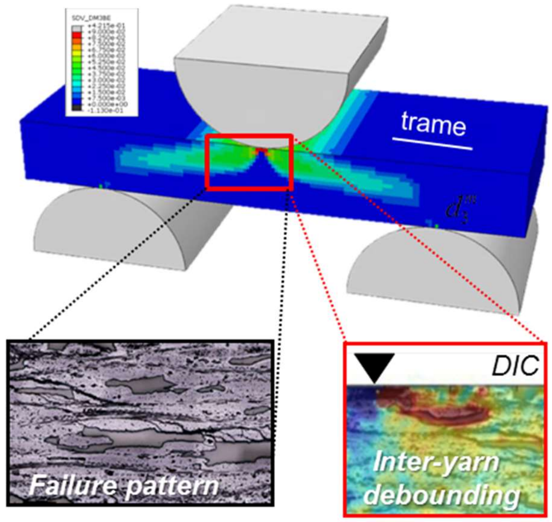


Fig. 6: Modelling of CMC subjected to both mechanical and thermal loading

3.3 SM/EG-46 Characterization and optimization of shock absorbers for civil aircraft fuselages

Commonly adopted shock absorbers and, in general, crashworthy structural components, based on sandwich structural concepts and/or complex damping mechanisms generally are characterized by high volumes and significant additional mass. This research activity is focused on the investigation of the feasibility and effectiveness of novel thin additive manufactured hybrid metal/composite lattice structures as lightweight shock absorbing devices for application to structural key components in impact events (Fig 7). These hybrid structures would represent a real step beyond the state of the art of shock absorbers being characterized by an additive manufactured metal lattice core, able to maximize the absorbed energy by plastic deformations and, at the same time, by a composite skin/cohesive coating, fully integrated with the internal metal lattice structure, able to lower the global weight and increase the stiffness and strength of the shock absorber. The hybrid shock absorbers must be able to reduce the peak acceleration transferred on the main structure, ensuring the integrity of the core structure and, eventually, the safety of the passengers.

The following activities are planned:

- Investigation on the key components which require the integration with shock absorber;
- Identification and classification of the shock absorbers (material and geometry);
- Material investigation (Alternative materials, Hybridization);
- Integration strategies;
- Analytical methods for designing hybrid shock absorber;
- Numerical analysis and design;
- Unit cell optimization (weight minimization and/or shock absorbing capability maximization);
- Thermal stress analysis;
- Experimental tests and validation;
- Certification issues;
- Definition of guidelines for an effective integration in each scenario;

Starting from the above considerations, the Exploratory Group SM-EG 46 is preparing an Action

Group proposal focused on “Characterization and optimization of shock absorbers for industrial applications”. This proposal is planned to be ready mid-2022.

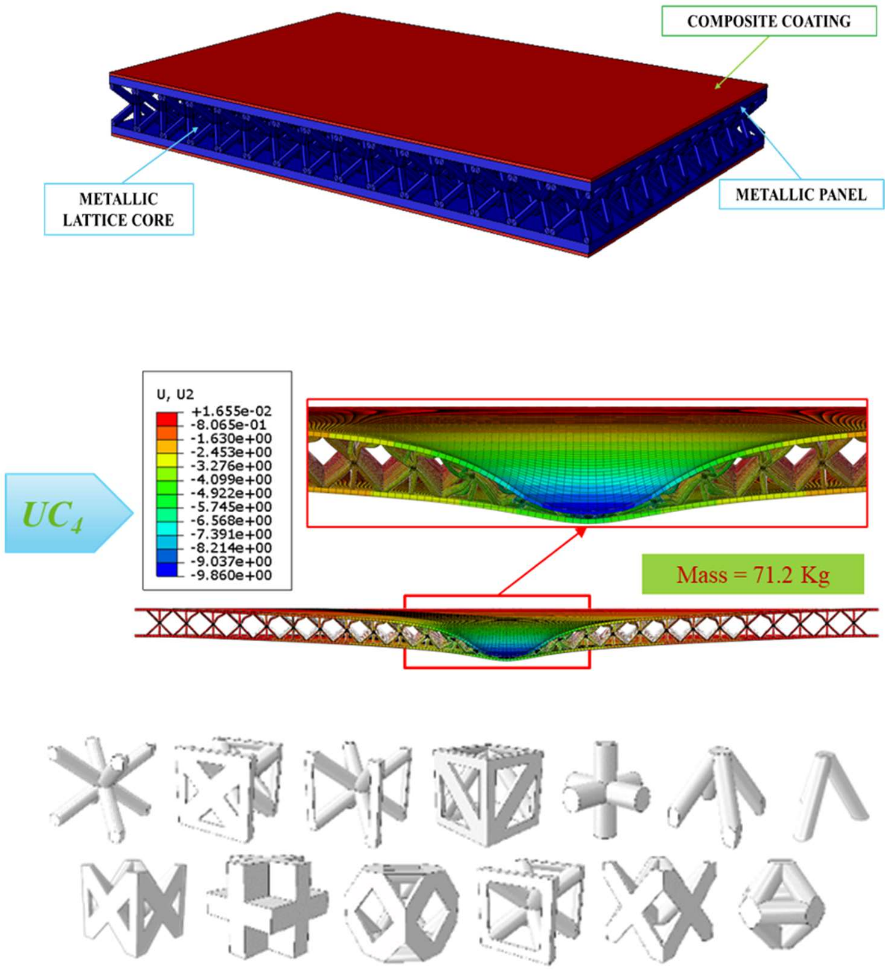


Fig. 7: Different shock absorber concepts

SM/EG-48 Structural Health Monitoring for hydrogen aircraft tanks
In order to drastically reduce CO2 emissions in aircraft, liquid hydrogen is an interesting alternative solution for the production and storage of energy. Regarding the storage, the best option consists in liquefying the hydrogen at a temperature around -253°C. For aerospace application composite materials and metals are being considered for the cryogenic tank. One of the topics related to the development and application of a composite tank is the ability to detect initiation of any damage.

Structural Health Monitoring (SHM) methods, consisting of integrating sensors in or on the composite structure, can then used. However, few studies are dedicated to SHM methods under such extremely low temperatures. The objective of the group will be to work on the design of SHM systems dedicated to composite parts under cryogenic temperatures, including the study of the durability of such systems.

The exploratory group started their activities in the beginning of 2022 and will prepare for an action group at the end of 2022.