Mat4Rail
a Project of the S2R JU
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Novel EN-45545 compliant composites validated in Mat4Rail project

The composites are based on novel epoxy, benzoxazine and hybrid chemistry resins with improved fire resistance developed in the framework of the project

One of the main objectives of Mat4Rail's materials work stream was to develop novel resins that are suitable for the manufacturing of fibre reinforced composites (FRPs) for railway applications fulfilling all the railway environment requirements regarding Fire, Smoke and Toxicity (FST), mechanical performance and cost effective manufacturing.

Figure 1 Alaitz Rekondo (CIDETEC) presenting the six composite samples at the final joint event with the Shift2Rail Joint Undertaking projects PIVOT, Mat4Rail, RUN2Rail and FAIR Stations

Due to the intrinsic flammability of most of the polymers, it is mandatory to improve first the flame retardant behaviour of the polymeric matrix before composites with good fire retardant performance can be manufactured. Since the resin constitutes between 40 and 60% of the composite volume, it will contribute proportionally to the flame retardant, thermal and mechanical properties of the final composite material.

The novel resin formulations developed in the framework of Mat4Rail project are aimed to be used in fibre reinforced polymer composites in the railway industry as an innovative replacement of metallic structural parts of the carbody shell.

In this sense, one of the main achievements of Mat4Rail project is the development of three novel resin formulations based on three different chemistries (epoxy, benzoxazine and a novel hybrid chemistry) with improved fire resistance. Combining these three novel resins with three different types of fibre reinforcements (carbon, glass and basalt) and after an intense prevalidation phase with the testing of more than 24 different types of composites, six composites where manufactured in the validation phase and fully characterised regarding FST performance and mechanical properties by Mat4Rail partners CIDETEC, AIMPLAS, UNI-HB, HUNTSMAN, CENTEXBEL, COEXPAIR and RISE.

Figure 2 Samples of the carbon, glass and basalt fibres

Table 1 Specifications of the carbon, glass and basalt fibres used in Mat4Rail

Fibre	Fabric	Weight (g/m²)	Density (g/cm³)	Tensile modulus (GPa)	Tensile strength (MPA)	Strain (%)
carbon	woven	200	1,76	230	3530	1,5
glass	woven	390	2,6	73	2600	4
basalt	woven	350	2,67	87	3000	3,15

Five composites achieved HL2 classification for R7, R8 and R17 carbody external applications according to the EN45545-2 standard. The mechanical characterisation of the composites also demonstrated the great potential of these materials for their application in carbody shell parts.

Three of these composites were manufactured by Dynamic Fluid Compression Moulding (DFCM) process which is an improved compression moulding process which allows the manufacturing of high-quality parts (similar to High Pressure RTM) efficiently and robust. The process allows the use of higher fibre volume content as it is processable with RTM.

Table 2 Composition of the six composites developed and validated in Mat4Rail project

Composite	Resin type	Fibre type	Manufacturing process
Composite 1	Epoxy	Basalt	Prepreg+SQ-RTM
Composite 2	Benzoxazine	Basalt	Infusion
Composite 3	Hybrid chemistry	Carbon	DFCM
Composite 4	Benzoxazine	Glass	Infusion
Composite 5	Hybrid chemistry	Basalt	DFCM
Composite 6	Hybrid chemistry	HP Carbon	DFCM

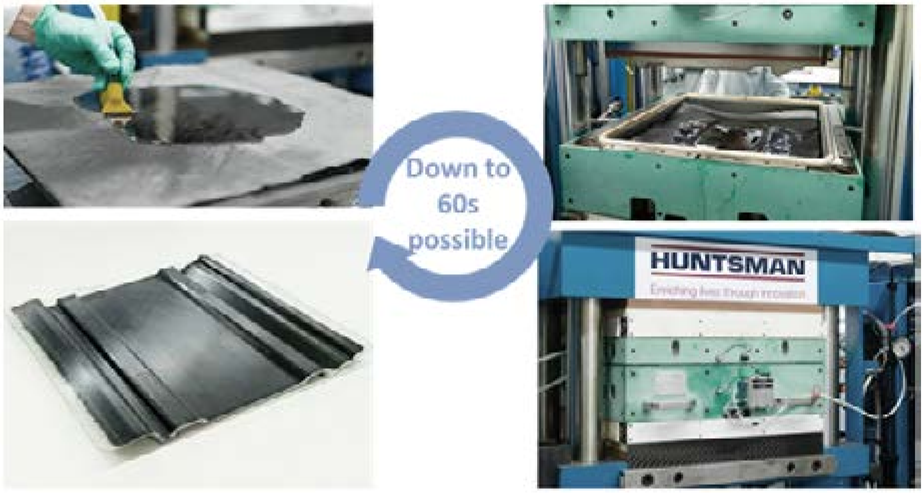

Figure 3 Schematic representation of the Dynamic Fluid Compression Moulding (DFCM) process

Adhesive bonding is one the key factors to ensure that future railway vehicles will be lighter

Adhesively bonded joints can join dissimilar materials whilst being reliable, efficient, robust, and reparable

The development of new lightweight materials such as fibre reinforced plastics, which cannot be welded, along with the combination of dissimilar materials (e.g. aluminum-composites), require the determination of suitable joining methods. Adhesive bonding technology has the capability of joining dissimilar materials, as well as unique characteristics such as lower manufacturing costs, damage tolerance, design flexibility, enhanced fatigue endurance and load transfer efficiency. In the Mat4Rail project, two classes of adhesives were investigated aiming to cover both primary and secondary structures of railway vehicles: structural adhesives (applied for primary structures) and elastic adhesives (applied for secondary structures).

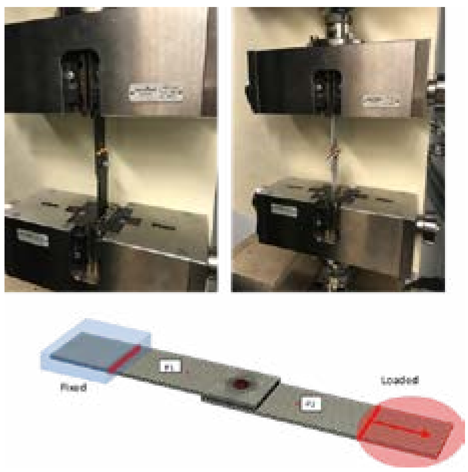

Figure 5 Testing and finite element analysis of hybrid joints

Figure 4 Multi-material joint with aluminium and FRP developed in the Mat4Rail project

Joining concepts were developed including aspects such as the selection of adhesives, joint design, surface preparation, manufacturing, automation, quality assurance, and multi-material joining.

Due to the requirements of repair, maintenance, refitting and recyclability, solutions to obtain dismountable adhesive joints were analysed. These solutions include the combination of adhesive bonding with mechanical fastening (i.e. hybrid joining) aiming to profit from the benefits of both joining methods.

The static and fatigue strength assessment is very important for the design and safety of railway structures since it can provide a direct relationship between materials' mechanical properties, the loads being applied and the geometry of the component. In the Mat4Rail project adhesive joints were used as an example to propose how to extend the homologation procedures with respect to the physics of deformation and damage accumulation in polymeric materials. By addressing the limitations of current methods, the fatigue assessment approach proposed by Mat4Rail will be able to validate and homologate the new materials which will constitute the next generation of the carbodies.

A component-like homologation sample was constructed based on the corners of the windows of a railway vehicle. The final validation of the operational strength was carried out by fatigue testing the component-like homologation sample under variable amplitude load spectrum. Predictions were in very good agreement with experimental results evidencing the effectiveness of the fatigue assessment approach.

The load spectrum was defined based on a method developed within Mat4Rail, which allows the determination of homologation load spectra from standardised load cases. The analysis of the spectrum was carried out using Rain flow Counting techniques.

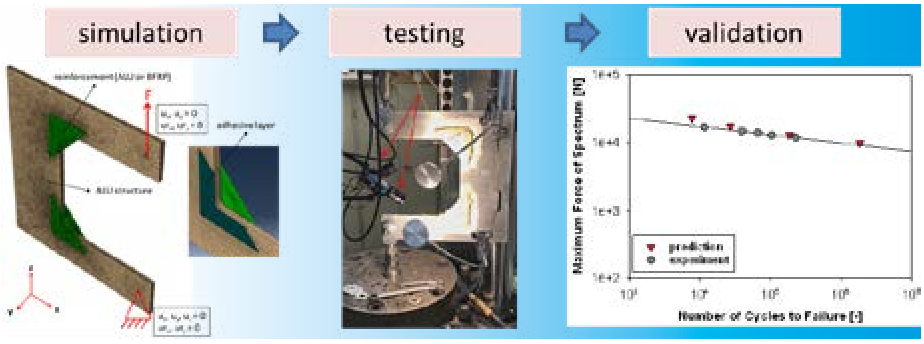

Figure 6 Fatigue strength assessment: simulation, testing and validation

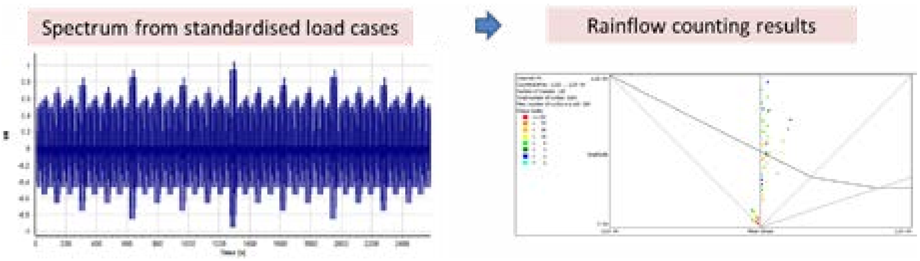

Figure 7 Load spectrum from standardised load cases and rain flow counting

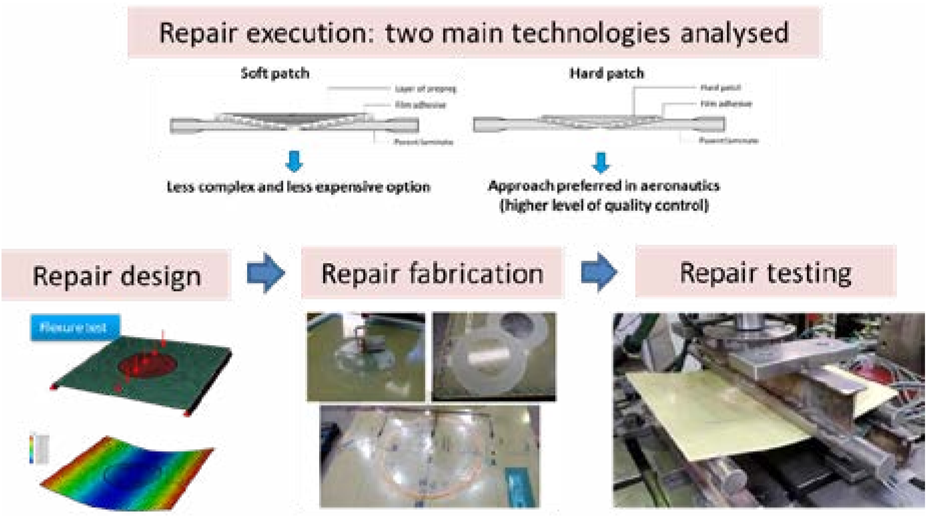

Figure 8 Repair technologies: soft and hard patches - design, fabrication and testing

Maintenance and reparability constitute a key aspect when introducing new material technologies in transport systems. All vehicles require regular inspections with established procedures to ensure structural integrity, efficiency and safety during their service life. In addition, repair strategies are needed to guarantee (or in some cases to extend) the vehicles life.

The work done in Mat4Rail about repair technologies covered these aspects proposing two main repair technologies: soft patch and hard patch. These technologies were validated in terms of design, fabrication and testing ensuring the effectiveness of the proposed solutions.

Three future solutions for innovative train access door systems

Railway door technology in motion

The search for new materials for access door systems (i.e. composites, metallic alloys) and their integration techniques ("one-shot" injection, welding & adhesive processes etc.) were addressed as part of the WP5 Innovative Access Door Systems, through innovative approaches considering relevant criteria, such as production costs, manufacturing aspects and railway constraints. The Mat4Rail project partners' expertise from relevant industrial sectors (e.g. aeronautical) was also implemented to integrate innovative materials and processes for the railway sector.

Figure 9 RTM composite process: the injection and cure of the full structure is done in only one operation

Three concepts of door leaves were proposed and developed by the Mat4Rail partners, COEXPAIR, ITAINNOVA, ASAS and UNI-HB: a composite concept, a metallic one using a new aluminium alloy and a concept made by additive manufacturing. These solutions must meet very stringent requirements and specification provided by PIVOT partners (low cost, FSE behaviour, mechanical strength and vibration behaviour).

Standard methods were used for the design phase while mitigating the main risks linked to manufacturing. For the composite and the aluminium concepts, several tests were successfully conducted, with a sub-scale demonstrator manufactured at the end of the project and presented during the final joint event. The fabrication of a component by additive manufacturing (i.e. with defined high grade of functional specialisation using different natural materials and constructive principles) was not possible in a realistic cost-effective way vs. current state-of-the-art machines.

Overall, collaboration within Mat4Rail on doors, partnership was fruitful, resulting train door concepts are highly promising. For the composite door leave, the technology seems a promising candidate for upcoming projects if the target cost can be confirmed in the future. However, specific developments would still be required, to strengthen preliminary outputs such as thermal or acoustic attenuation requirements. For the aluminium door leaves, the technology and proposed material are already offering a solution for future doors in the short-term. Regarding the additive manufacturing, the technology is still at an early stage of development (i.e. size and cost competitiveness) but could become a longer-term candidate.

Figure 10 Composite door manufacturing at Coexpair

Figure 11 Metallic door using a new aluminium alloy made by ASAS

Virtual train prototype successfully finalised and presented in Paris

Great feedback from railway industry leaders at the final Mat4Rail event in Paris for the development of the virtual train prototype showing the Innovative Driver's Cabin and the Innovative Plug & Play System

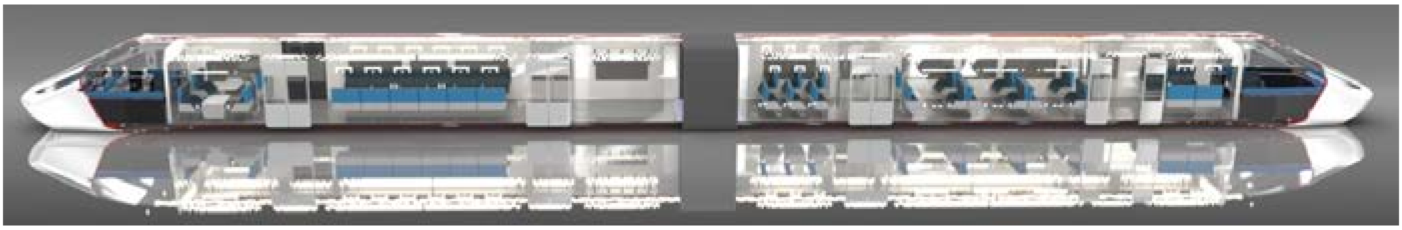

Figure 12 Overview of virtual prototype © Spirit Design – Innovation and Brand GmbH

One final result of Mat4Rail was a virtual prototype of the Innovative Driver's Cabin design developed by Spirit Design (WP8) and the Innovative Plug & Play System developed by NVGTR (WP6).

SPIRIT conceptualised and INDAT constructed a virtual prototype of a completely new train model to showcase the design achievements. A neutral train model was developed in coordination with PIVOT, which is a hybrid between a commuter train and an inter-regional train. It consists of two carriages, each having a driver cabin at the end/front.

To give it a realistic and appealing design, several train interior elements and modules were designed. The design concept of the Innovative Driver's Cabin is based on new stakeholder demands from manufacturers, operators, train personal and passengers. Ongoing and accelerating technological advancements towards the fully automated train operation (ATO) offers new possibilities for functional design for train drivers and passengers alike. The two resulting modes "passenger mode" and "driver mode" are based on the possibilities which are offered by Grade of Automation (GoA) Level 2 & 3:

- GoA 2 is semi-automatic train operation (STO) where starting and stopping is automated, but a driver operates the doors, drives the train if needed and handles emergencies.
- GoA 3 is driverless train operation (DTO) where starting and stopping are automated but a train attendant operates the doors and drives the train in case of emergencies.

Figure 13 Virtual prototype view from passenger cabin into Innovative Driver's Cabin © Spirit Design – Innovation and Brand GmbH

The virtual prototype was designed to showcase the functionalities which enable the two main scenarios of WP8. In “passenger mode” the cabin offers an extension of the conventional passenger cabin, where people can move freely into the driver cabin. Therefore, a glass door can be unlocked and opened completely.

The seats inside the driver cabin are placed on both sides inviting people to relax shortly or stay and travel on their commuting ride. The windows offer an unhindered view to all sides to enjoy the travel in the unique sight. The big augmented reality screen in the front of the cabin can be configured with any contents, such as location based information or advertisement. Below the big augmented reality screen, ambient lighting was placed to give the room a cosy feeling.

When the attention of a driver is required, the drivers’ cabin can be put in “driving mode”. Once driving mode is initiated by the operator, the opaque glass doors automatically close. The two front-facing seats in the driver cabin are hinged on a rail system. The driver seat automatically moves along the rail and positions itself in front of the dashboard.

The robotic arm below the dashboard appears when the driver approaches with the multifunctional control Human Machine Interface (HMI) tablet. It senses the location of the tablet and places itself beneath the tablet to fixate it firmly. The HMI tablet itself is designed to be highly adaptable to the preferences of the driver, offering many configurable knobs and a big touch screen.

From this moment on, the driver controls the train via the tablet. The augmented reality display shows weather, track and camera information. Additionally, the cabin is equipped with vitality sensors and a head-up display. When driver mode is disengaged, the driver leaves the cabin, the glass door opens and passengers can use the space again.

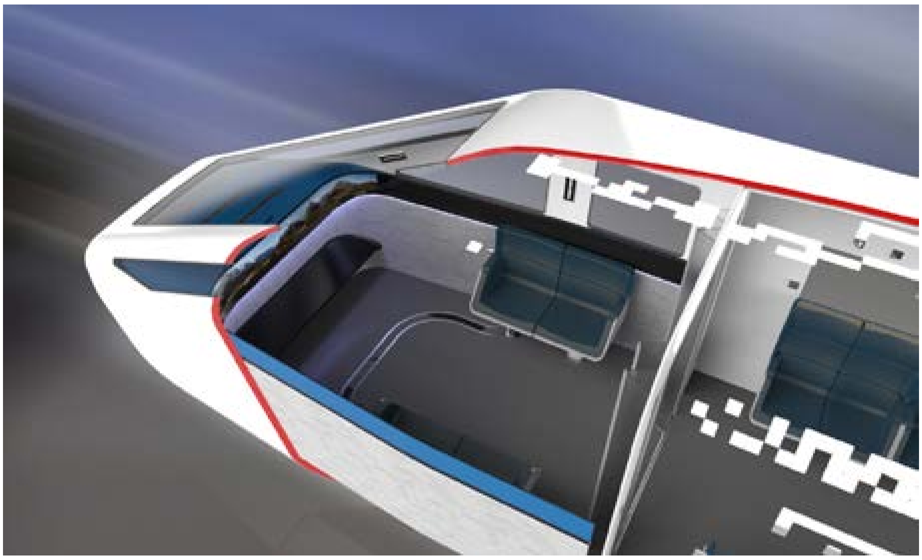

Figure 14 Overview of innovative drivers’ cabin in “passenger mode” © Spirit Design – Innovation and Brand GmbH

Figure 15 Initiating “driver mode” © Spirit Design – Innovation and Brand GmbH

Figure 16 Human Machine Interface innovation © Spirit Design – Innovation and Brand GmbH

Figure 17 Virtual Prototype of WP6 seat group without table © Spirit Design – Innovation and Brand GmbH

Figure 18 Virtual Prototype of WP6 seat group with table © Spirit Design – Innovation and Brand GmbH

Figure 19 Virtual Prototype of WP6 Subway style shoulder by shoulder © Spirit Design - Innovation and Brand GmbH

Figure 20 Virtual Prototype train view down the aisle © Spirit Design - Innovation and Brand GmbH

To illustrate the different set-ups of the innovative Plug & Play system developed in WP6 and the versatile options of applications, different interior scenarios were conceptualised and designed in the virtual prototype (see figures above).

SPIRIT, INDAT and NVGTR are very happy with the final result and the successes which came with it. The feedback for the presentation in Paris 17th September 2019, was very positive among all people present and interest was great to discuss innovative details and quality of the final results.

Figure 21 Wolfgang Fargel (SPIRIT) presenting final virtual prototype at the final joint event (Paris 17.09.2019) © Spirit Design - Innovation and Brand GmbH

Final project event with live Mat4Rail demonstrators held in Paris

In joint collaboration with the Shift2Rail Joint Undertaking projects PIVOT, Mat4Rail, RUN2Rail and FAIR Stations on 17th September 2019

Figure 22 Group photo of the participants from the organising projects PIVOT, Mat4Rail, RUN2Rail and FAIR Stations

After two exciting years of Mat4Rail the final project event was held in collaboration between the Shift2Rail Joint Undertaking projects PIVOT, Mat4Rail, RUN2Rail and FAIR Stations in Paris, France on the 17th September 2019. All four projects presented their developments and main results performed within the Shift2Rail Innovation Programme 1 (IP1) “Cost-efficient and reliable trains, including high-capacity trains and high-speed trains”.

The event was kicked-off with presentations on the main objectives and the results of the projects, given by the coordinators Paul Böttcher (PIVOT, Bombardier Transportation), Elena Jubete (Mat4Rail, CIDETEC Surface Engineering), Marta Andreoni, (RUN2Rail, UNIFE) and Umberto Battista (FAIR Stations, STAM).

Detailed sessions on each project’s research activities were given within the Technical Demonstrators (TDs) they are involved in as indicated in the Shift2Rail Master Plan namely Car body shell (TD1.3), Running Gear (TD1.4), Brakes (TD1.5), Doors and intelligent access systems (TD1.6) and Train interiors (TD1.7) with eight speakers from Mat4Rail presenting their key achievements on train carbodies, doors and interiors.

A key highlight for the Mat4Rail project were the live demonstrations of the technologies and solutions developed over the course of the project. These included prototypes of the ultra-light seats developed in WP6, the aluminium door manufactured through disruptive methodologies in WP5, the “Plug and Play systems” to improve train connectivity in WP7 and samples of composites that exceed HL2 in fire resistance (WP2), as well as a virtual prototype that shows the versatile modular design for the train cabin within WP8. All these prototypes and demonstrators clearly showed the disruptive results obtained by Mat4Rail for the manufacture of lighter and modular trains.

The event brought together around 90 participants, including producers of technology, materials and components for trains, as well as service providers, large manufacturers and other important companies in the railway world. We would like to thank Shift2Rail, the external participants and the members of the PIVOT, Mat4Rail, RUN2Rail and FAIR Stations projects for a highly interactive and effective final event.

Figure 23 Project Coordinators from left to right; Marta Andreoni (RUN2Rail), Umberto Battista (FAIR Stations), Elena Jubete (Mat4Rail) and Paul Böttcher (PIVOT)

Figure 24 Presentation of the virtual prototypes of the cabin by Wolfgang Fargel (Spirit) (left, WP8) and of the train simulation Stefan Baumgartner (INDAT) (right)

Figure 25 Impressions of the live demonstrations

Figure 26 Demonstrators of the plug and play elements (WP6) and the innovative seats (WP7)

Further planned events

The Mat4Rail project officially ended on the 30th September 2019 but our partners will carry on attending future events to present the results and outcomes from Mat4Rail. Listed below are a number of future events where you have the opportunity to meet representatives of the Mat4Rail project.

- 25th – 26th February 2020, FPRS 2020 - Fire protection of rolling stock, Presentation by RISE related to the work on the composite laminates, both fire performance characterisation and mechanical properties, Berlin, Germany
- 26th – 28th February 2020, Radschiene 17th International Vehicle Railway Conference, Presentation by IMA «Beitrag zur Festlegung von Lastkollektiven für die Auslegung von Wagenkästen im Schienenfahrzeugbau», Dresden, Germany
- 3rd – 5th March 2020, JEC World 2020 leading international composite show, Paris, France, HUNTSMAN to showcase FR Materials
- 30th March – 1st April 2020, VAL4 Fourth International Conference on Material and Component Performance under Variable Amplitude Loading, Presentation by IMA on "Load Spectra for the Design of Railway Car-Bodies", Darmstadt, Germany
- 14th – 17th September 2020, EURADH 2020 – 13th European Adhesion Conference. Presentation by ITAINNOVA, Antibes, France
- 22nd – 25th September 2020, InnoTrans 2020 International trade fair for transport technology, Berlin, Germany
- Planned 2020, Seminar on composites, currently being planned and organised by CENTEXBEL
- Planned 2020, Automotive Suppliers Association of Turkey, ASAS to contribute to the Project Fundings Expertise Group Workshop, Gebze, Kocaeli
- Planned 2020, Anatolian Rail Transportation Systems Cluster, ASAS will join the workshop Çankaya, Ankara

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Designing the railway of the future

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- RISE Research Institutes of Sweden AB (RISE), SE
- AIMPLAS Asociación de Investigación de Materials Plásticos y Conexas (AIMPLAS), ES
- IMA Materialforschung und Anwendungstechnik GmbH (IMA), DE
- Huntsman Advanced Materials GmbH (HUNTSMAN), CH
- Coexpair SA (COEXPAIR), BE
- ASAŞ Alüminyum Sanayi ve Ticaret A.Ş. (ASAS), TR
- NVGTR Gbr (NVGTR), DE
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- Grammer Railway Interior GmbH (GRAMMER), DE
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