Final Report Summary - COMPAIR (DEVELOPMENT OF A MANUFACTURING PROCESS FOR THE PRODUCTION OF SMALL SIZE COMPLEX-SHAPED STRUCTURAL AIRCRAFT COMPONENTS)

Executive Summary:
European SMEs need innovative products and manufacturing processes to be competitive in the polymer and composite marketplace. One of the industries using increasing volumes of plastic and composite parts is the aerospace industry. This is driven by the use of lightweight structures to reduce fuel consumption, cost and lessen the environmental impact of air travel.

The COMPAIR project has developed of a novel manufacturing technology using the benefits of carbon fibre as reinforcement and a high performance thermoplastic as the matrix material. In addition, we have
utilised the high processing speed of injection moulding to overcoat the components, ensuring that carbon fibres are electrically insulated from the metallic airframe in aerospace applications. This process is currently carried out manually. The output of this project is a lower cost technology for the manufacture of thermoplastic mouldings reinforced with inserted carbon fibre preforms. This will enable the aircraft industry to enhance functionality and reduce environmental impact through weight saving (replacing heavier metal parts) leading to lower fuel consumption.

The project offers European SMEs an opportunity to develop high value manufacturing capabilities not only for aerospace, but also for structural parts in the gas, oil and transport sectors.

The COMPAIR technical work over the period 1st September 2012 to 31st August 2014 has involved the following Work Packages:

Work Package 1: Enhancement of Scientific Knowledge for PPS Sizing Coating
Work Package 2: Development of Fibre/Melt Wet-out System
Work Package 3: Development of Carbon Fibre Preforms
Work Package 4: Development of Moulding Technology Pre Treatment & Overmoulding
Work Package 5: Technology Integration & Validation

A COMPAIR preform manufacturing process has been developed and high quality single part, three-dimensional carbon fibre/PPS preforms produced. The developed preform tooling has worked well, eliminating double curvature features and offering versatility in terms of materials and preform thickness. The tooling concept can be scaled up to produce bracket geometries in various sizes and the process offers high levels of manufacturing consistency. Single piece bracket manufacture offers potential for considerable weight savings.

Theoretical analysis of the preform over-moulding process was performed prior to the detailed design of the injection mould tooling. This estimated deflection caused in the preform due to the high pressures involved in this process and allowed the flow balance to be optimised.

A single cavity prototype injection mould tool has been produced, and integrated manufacturing trials have been completed. Components have been manufactured using a carbon fibre/PPS preform, preform heating and handling robot and injection moulding tooling using a manufacturing process designed to be suitable for the three selected case study components.

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Project Context and Objectives:
The manufacturing of plastic mouldings and assemblies is today dominated by low labour regions. This has led to a fall in the European SME market share for moulded components during the last 10 years. European SMEs within this segment need to develop more innovative products and manufacturing processes to be competitive in the market. One of the industries using increasing volumes of plastic and composite parts is the aerospace industry.

We proposed to develop a novel manufacturing technology using the benefits of carbon fibre as reinforcement and a high performance thermoplastic as the matrix material utilising the high processing speed of injection moulding. The output of this project will be a new technology for making thermoplastic mouldings reinforced with inserted carbon fibre preforms. This will enable the aircraft industry to enhance functionality and reduce environmental impact through weight saving (replacing heavier metal parts) leading to lower fuel consumption. The potential to use thermoplastic components that are easily recyclable provides an additional incentive.

The use of injection moulding as a relatively rapid production process will provide up to 30% cost reduction. The project offers European SMEs an opportunity to develop high value manufacturing capabilities that can compete with low labour cost economies.

We have identified the civil aerospace industry as the primary market for the new technology. We also expect to be able to produce lightweight advanced structural parts for the gas and oil, transport and automotive sectors. We estimate the market opportunity, by penetrating the primary market for the first five years after the project, is equal to €147M of revenue from sales and licensing of the technology. The initial market strategy will be to concentrate on the EC market, where the consortium has a strong market presence and a clear route to market through the partnership with Airbus.

To enable this, the specific scientific objectives of the work were to:

- Development of sizing agents specifically optimised to promote adhesion between the carbon fibre filaments and the PPS matrix
- Further our understanding of selective microwave heating of fibre reinforcement to aid the fibre wetting process
- Determine the critical parameters for the combined process of laminating and thermoforming PPS impregnated carbon fibre sheets to produce preforms.
- Optimise & validate the manufacturing process of the PPS/carbon fibre preforms.
- Develop a moulding process with optimised adhesion between the preform and the matrix to contribute to maximising final part properties.
- To develop an infrared heating device to heat the preform to the desired temperature for over-moulding with the PPS matrix material. It will be integrated with a pick and place robot that will position the preform in the mould.
- Develop a mould design and process whereby the preform is held in the correct position to ±1mm in the
• Develop a mould design and process whereby the preform is held in the correct position to ±1mm in the mould whilst the matrix material is moulded around it on both sides.
• To integrate the technology components into a fully functional manufacturing technology and create a prototype process.
• To validate both the process and final product against the set target specification and the aircraft industry requirements.

Project Results:
The technical work over the period 1st September 2012 to 31st August 2014 has involved the following Work Packages:

Work Package 1: Enhancement of Scientific Knowledge for PPS Sizing Coating
Work Package 2: Development of Fibre/Melt Wet-out System
Work Package 3: Development of Carbon Fibre Preforms
Work Package 4: Development of Moulding Technology Pre Treatment & Overmoulding
Work Package 5: Technology Integration & Validation

The objective of Work Package 1 was to develop a new sizing agent specifically for the application to carbon fibre to optimise the bond with a polyphenylene sulphide (PPS) thermoplastic matrix. Through the development of new size formulations and a treatment line the aim was to increase adhesion between the carbon fibre and the PPS matrix such that notched Izod impact tests showed failure by the whole composite structure fracturing rather than by fibre pull-out.

A prototype sizing application and drying line was designed, manufactured and validated. The line was used to treat unidirectional carbon fibre fabric with a selection of aqueous candidate size systems. The treated fabrics were then combined with extruded polyphenylene sulphide films to form composite test panels. Following mechanical testing it was concluded that a polyimide size gave the best physical performance.

The aim of Work Package 2 was to investigate selective microwave preheating of carbon fibres to aid the fibre wetting process with the PPS matrix. The microwave trials showed a beneficial effect of size treatment removal which offers good potential for fibre pre-treatment where alternative sizing material needs to be used. A prototype continuous single emitter microwave system was designed and manufactured. Semipreg materials were then produced using extruded film of PPS combined with microwave preheated carbon fibre reinforcement. This was found to be a convenient method of producing semipregs since film production and incorporation of reinforcement layers can be combined in a single step, and a good PPS ‘wet-out’ performance was achieved.

The next phase of the development was to design and construct an ultrasonic wet-out system. This comprised of an ultrasonic control unit, ultrasonic stack, film die, extruder, chill stack roller system and haul off unit. The application of ultrasonic agitation to molten PPS (and polyetherether ketone (PEEK) at the request of the Consortium) demonstrated a marked decrease in melt pressure and hence melt viscosity. This was confirmed by using pressure transducers immediately before and after the ultrasonic stack so that the effect could be quantified.
The system was incorporated into a Boston Matthews extruder fitted with a film die, allowing the production of PPS film. Carbon fibre reinforcement fabrics were passed through the chill stack roller with the molten polymer to be consolidated and chilled. The effect of applying ultrasonic energy to a Ticona grade of PPS showed improved resin penetration into the selected fabrics. The prototype ultrasonic wet-out system demonstrated good potential as a method to manufacture carbon fibre/PPS semipreg materials. However, in order to advance the COMPAIR development the Consortium took the decision early in Reporting Period 2 to continue the project using a commercially available aerospace qualified semipreg material from Tencate.

The COMPAIR project concept was to produce a single part, three dimensional preform and then achieve electrical insulation by over-coating with PPS in an injection moulding tool. It was recognised that the Airbus bracket component was essentially a box corner. This component has a double curvature that cannot be produced by conventional means. The COMPAIR Consortium selected this three-dimensional box corner geometry on which to base the three case studies.

Within Work Package 3 an optimised COMPAIR preform manufacturing process was designed and developed and high quality single part, three dimensional CF/PPS preforms produced. The developed pyramidal tooling worked well, eliminating double curvature features and offering versatility in terms of materials (prepregs, semipregs and film stacking) and preform thickness. Microscopic evaluation revealed that the PPS matrix had penetrated well around the carbon fibres and mechanical properties were found to meet the requirements.

The tooling concept can be scaled up to produce bracket geometries for wing structural applications in various sizes and the process offers high levels of manufacturing consistency. Single piece bracket manufacture offers potential for considerable weight savings. Further, the fibre orientation is constant around all radii and can be varied by the end user according to layup specifications. This cannot be achieved by draping fabrics since the weave density varies according to the deformation which occurs during the draping process.

To ensure that the PPS flows well around the preform in the over-moulding stage, the preform is pre-heated before it is placed into the tool. This helps to reduce any tendency for the flow front to freeze during the injection phase and helps to promote adhesion between the CF/PPS preform and the final layer of PPS. Optimisation of the preheating step was carried out as part of Work Package 4 by means of numerical tools, specifically Finite Element Method (FEM) analysis. A FEA model of the 3D box corner was developed and the preheating process applicable to the 3 selected case study components was optimised and finalised. The final design uses the optimum sequence of robotic movements for one single lamp mounted on the robot and three fixed lamps mounted on the bottom part of the pre-heating tool.

Theoretical analysis of the preform over-moulding process was performed prior to the detailed design of the injection mould tooling. This estimated deflection caused in the preform due to the high pressures involved in this process and allowed the flow balance to be optimised with a constant thickness of 1 mm. It also highlighted the requirement for the apex of the preform to be modified. This analysis concluded that a one shot injection with stand offs can be possible from a theoretical point of view if a perfect flow balance is achieved.
A single cavity prototype injection mould tool was designed and manufactured. Components were manufactured using a preform, multifunctional preform heating and handling robot and injection moulding tooling using a manufacturing process suitable for all 3 case study components. Integrated manufacturing trials have been completed. These trials identified aspects of the over-moulding process that require additional development to achieve the expected quality and ease of manufacture. The trials have also demonstrated the suitability of the CF/PPS preform, and robotic handling system.

The COMPAIR product and technology were validated within Work Package 5. The mechanical performance of the selected 3D box corner case study was analysed both experimentally and through Finite Element (FE) simulations. The preliminary FE simulations performed were very helpful to support the design of the test for the demonstrator part considered in the study, allowing the evaluation of different geometries, materials and test configurations.

The FE simulation developed for the test until failure reproduced adequately the response of the composite box corner obtained experimentally. In this sense, the correlation level obtained was acceptable considering the complexity of the part and the test configuration.

Over-moulding CF/PPS preform with a layer of PPS did not affect the component mechanical response. More so, the over-moulded part presented a slightly higher load capacity for a similar stiffness. This was produced by the reduction of the stress concentrations that were generated in the test near the support ends. It therefore follows that the different COMPAIR case studies would also fulfil the aircraft requirements if the corresponding preforms were manufactured to the same accuracy.

The mechanical tests performed on the box corner preform showed that at a nominal single layer thickness (0.31 mm) the case study fulfils the aircraft requirement in terms of stiffness while the values of maximum flexural stress are just below the minimum value required. A reduction of porosity between the different semipreg layers during the consolidation process would certainly improve the general mechanical behaviour of the part to meet the flexural stress requirements.

The box corner case study was successfully produced from prototype scale manufacturing processes to demonstrate the key benefits of the COMPAIR technology. In order for the COMPAIR case studies to fully meet all of the aircraft requirements post-project optimisation is required.

The Consortium is keen to develop the technology further beyond the project time. To validate the technology in terms of scalability, productivity, energy consumption and safety a review of the individual processing steps and components has been undertaken and recommendations for full commercial process optimisation has been presented.

Potential Impact:
Market Drivers & Size
The economic objective of the COMPAIR project is to improve the competitiveness of the participating SMEs by introducing a new low cost product and manufacturing process into the structural aircraft components market. Current production methods for complex shaped composite parts are labour.
Current production methods for complex-shaped composite parts are labour-intensive. Consequently, all major aircraft manufacturers are sourcing production of structural materials from low wage economies outside the EU.

COMPAIR is a new technology for the manufacture of thermoplastic composites which will enable the aerospace industry to enhance functionality and reduce environmental impact of currently used equivalent parts made of metals and thermosetting composites. Furthermore, due to use of a fast forming processes COMPAIR will reduce overall production costs. COMPAIR offers European SMEs the opportunity to develop high value manufacturing capabilities that can compete with low labour cost economies.

The manufacturing technology is targeted primarily and initially at the production of the civil aircraft components. The other potential markets are chemically resistant load bearing materials for the oil & gas industry, lightweight structural composites for transport, automotive and sport industries. According to ASD38 (AeroSpace and Defence Industries Association in Europe) the total European market for civil aircraft structural components made of polymer based composites is valued at €3.2 billion, and the market for the rest of the world is worth €6.2 billion. This market is for a large part driven by policies set by two largest transnational aircraft manufacturers (Airbus and Boeing), though the majority of suppliers are SMEs providing these larger companies with diversity and flexibility.

Airbus is a large end user and will automatically be the route to other customers in the market for the COMPAIR product. They have acted in an advisory role during the project across all of the developmental activities, bringing market and end-user knowledge to the Consortium, as well as their contact with standardisation bodies. The COMPAIR Consortium will use its existing reputation for further promotion of the technology in the market and speed up market penetration potential.

Through consultation with partners and other potential end users COMPAIR has estimated an initial market value/volume of the product. The COMPAIR Consortium has estimated that the total potential volume for parts of only one type (e.g. wing clips, 6000-8000 per aircraft) to be sold into the primary market is 70,000 - 90,000 units a year per supply chain.

Furthermore, up to ten additional supply chains can be created within Europe through licensing of the COMPAIR technology to build 100 large aircraft every year in the first five years post-project. These estimates for the demand from the aircraft market (ca. 20% of aircraft produced annually by Airbus) are based on the advice from Airbus that COMPAIR will be initially implemented for one aircraft family only. This is typical of industry practice - i.e. new developments that appear to meet industry requirements are rarely proposed for the entire industry until the technology is considered to be ‘mature’.

Maturity means confidence that a material will process consistently and within a well-defined processing window to give a flawless structure that performs within design requirements. This confidence is gained through extensive coupon testing, process trials, sub-element tests and experience from production of less critical structures.

Based on the estimated sales price and a market penetration rate of 3% of its primary market, the COMPAIR team expects total European turnover to be €96 million five year’s post-project. For the rest of the global market the COMPAIR team expects a 0.5% market penetration rate by 2017 resulting in a
the global market the COMPAIR team expects a 0.5% market penetration rate by 2017 resulting in a turnover in the region of €31 million.

According to Composites Forecasts and Consulting, the composite structures requirements in 2011 amounted to 6,532 metric tonnes of composites, of which 65% went into commercial and regional aircraft. Other markets include rotorcraft, unmanned systems, military fixed wing and general aviation.

In addition to the primary aerospace market, the COMPAIR team expects to be able to adapt the new technology to produce lightweight advanced structural materials for three other industries:
- Oil & Gas, especially in the field of materials for off shore and deep water constructions, where both weight and excellent chemical resistance are of high importance
- Transport - to produce load bearing components for ship, boat and train structures
- Automotive – to produce high performance structural parts of racing cars
There is currently no estimate for the potential market size for these, although the COMPAIR team sees all three as offering good potential for the future.

Dissemination & Exploitation Activities
Dissemination activities have been undertaken throughout the project duration in order to publicise the COMPAIR project, in particular to Aerospace, Plastics & Composites Interest Groups. The Consortium is keen to develop the technology further beyond the project time and will ascertain the appropriate protection format for the novel preform manufacturing stage and to keep secret that information that should not be put into the public domain.

To validate the technology in terms of scalability, productivity, energy consumption and safety a review of the individual processing steps and components has been undertaken and recommendations for full commercial process optimisation have been presented. Once the production process is commercially established the Consortium plan further exhibitions to promote the new technology throughout Europe and to explore the US aerospace markets with COMPAIR technology as the main driver.

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