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Abstract: This document provides the final report on the project.

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Executive Summary

This report provides the final report of the CONCLORE project, covering the overall project from 1st of March 2005 to 30th November 2007. The purpose of this deliverable is to provide an overview of the COCNLORE objectives, methodology and results.

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1. Introduction

The following report is part of Workpackage 6 and summarises the results of the project as well as the planned exploitation.

1.1. *Structure of document*

This document consists of four chapters, organised as follows:

- **Chapter 1. Introduction**

  Introduction

- **Chapter 2. COCLORE overview**

  This paragraph describes the initial objectives of the project and the methods used to achieve the defined goals.

- **Chapter 3. Progress achieved**

  This paragraph summarises the achieved results and compares them with the initial objectives.

- **Chapter 4. Conclusions**

  Concludes the report and summarises its main findings and results.

2. COCNLORE Overview

2.1. *Project idea*

The ELV (End of Life Vehicle) directive (EU/2000/53) introduced by the EU in 2000 addresses pollution arising from vehicles that have reached the end of their useful life. It aim is to reduce the more than 9 million tons of waste generated by over 12 million cars that become ELVs each year.

The directive specifies thresholds for the reuse, recycling and recovery of materials from ELVs. By 2006 the ratio of materials which should be reused, recycled or recovered aims for 85% of the total vehicle weight and 95% by 2015. The initial recycling ratio of 85% can currently be fulfilled by most manufactures. Keeping up with the quota, however, will become more and more difficult, due to the increased application of polymers. A higher polymer ratio will become increasingly important as it helps save fuel by lowering the overall vehicle weight. This trend will lead from a current average of 13% to a projected average of 15,5% in 2010.

The European project CONCLORE addresses this problem through the development of sustainable 100%-recyclable car interior products for recovery at the end of the useful life of the vehicle, recycling it either for reuse within the automotive industry or in other applications. This goal was achieved through developing single-component thermoplastic sandwich-structures and utilising Product Embedded Identification (PEID) CONCLORE enables the recovery of plastic material and combines it with an enterprise-spanning Product Lifecycle Management concept. To allow for effective recyclning CONCLORE offers identification of recyclable automotive parts as well as classification of material quality.

CONCLORE achieves sustainable products by substituting multi-component structures through single-component thermoplastic sandwich-structures for the production of automotive polymer parts.

CONCLORE defines a new state of the art by establishing an advanced recycling model called the Controlled Closed Loop Recycling (CCLR) geared towards 100% material recovery and remanufacturing of automotive polymer parts.

2.2. CONCLORE Objectives

Polymer automotive parts today are usually multi-component structures (i.e. PES and PUR-foam), due to their low cost and advantageous physical properties. However, material recovery of multi-component polymers is very costly and energy intensive as they are composed of a number of mechanically and chemically bonded materials.

Moreover, multi-component structures are generally thermoset and as such are manufactured based on liquid resins. Thermoset binders pose an environmental and health hazard resulting from exposure to volatile organic compounds emitted both during production as well as in the application phase. Summarising, current state of the art in ELV recycling is not sustainable, due to technical difficulties related to the sorting of polymers from fluff as well as the multi-component nature of polymer automotive parts.

In order to close the loop and achieve practical and cost-effective automotive part production out of material recovered from recycled ELVs, recovered material of continuous quality is necessary. Due to the physical and chemical properties of polymers the quality of the material can degrade over a long time-period, such as the usage period of the average automotive. A car part will be exposed to a number of environmental conditions during its lifetime with potential affect to the material and consequently the quality of the material recovered through recycling.

Even though polymer material of degraded quality can still be recycled it no longer has the physical properties which are characteristic for virgin material. Consequently, continuous quality in material recovered from recycled parts can only be achieved through the removal of contaminants and processing that takes the degradation through external factors into account. Achieving continuous quality in material recovered from recycled polymer parts thus depends on accurate information on the actual properties of the recovered material. CONCLORE will derive this information gathered using Radio Frequency Identification (RFID) integrated into automotive parts. This approach allows for a radical advancement of state of the art in recycling and continuous quality reprocessing based on the use of RFID in combination with advanced sensors and planning functionality to allow for automated identification, sorting, classification, and routing during dismantling. Embedded in an enterprise-spanning Product Lifecycle Management concept this will enable enhanced sustainability of automotive parts. This motivation led to the definition of the following listed objectives.

2.2.1. *Closed loop in the automotive lifecycle for cost-effective recycling and sustainable production*

CONCLORE innovation within the forward supply chain will focus on a higher recycling ratio by processing a blend of virgin material and materials of disassembled ELVs reintegrated back into the production process after recycling. Material flows at floor level will have to be reviewed and adapted. To achieve continuous product quality, recipe adaptation based on product life-cycle information on the recycled material and data stored in the enterprise PLM is foreseen in order to cope with varying properties of the material. CONCLORE innovation in the reverse supply chain focuses on intelligent dismantling, classification and sorting in order to achieve high recycling ratios of the dismantled material, based on its characteristics and product life-cycle data.

2.2.2. *Fully recyclable automotive plastic components*

CONCLORE aims to substitute multi-component structures through single-component thermoplastic sandwich-structures for the production of automotive polymer parts. The proposed sandwich-structure will be composed of a number of layers of non-woven thermoplastic fibres. A promising material for single-component parts is PET or in special cases PP.

The single-component interior part can be made up of different types of non-wovens, utilising a sandwich construction. The functionality of this solution will be demonstrated on a dash insulator. The goal is to achieve acoustic, mechanic properties and resistance to heat and solvents (water, oil, fuel, etc.) comparable to the current used multi-component materials. To minimise the production related waste the current production pathways have to be switched to the use single-component sandwich roll-good materials. Currently there is no existing process chain to produce the intended one-component multi-layer part.

This will enable achieving the objectives of the ELV directive for recycling 95% of a vehicles weight.

2.2.3. *PEID supported dismantling and sorting*

CONCLORE aimed to enhance reliability and minimise operation costs by automating dismantling and sorting through incorporation of Product Embedded Identification (PEID) i.e. Radio Frequency Identification (RFID) tags in automotive interior products during production in a closed loop. Of particular interest is the automated processing of material containing various types of colourings (i.e. particles or chemicals).

2.2.4. *Product life-cycle data supported material evaluation*

PEID allows for the identification of products and retrieval of information on both their production (consistency, contaminants, etc.) as well as their life-cycle (temperature, type of usage, etc.). Such data can be stored during production as well as be gradually accumulated with the help of on-board automotive computer systems. RFID technology will be extended to cover the specific requirements of automotive part production (design, recyclability, reliability, costs).

2.2.5. *Automated decision support in the recycling value chain*

An advanced Supply Chain Planning model based on the CCLR concepts and requirements will be researched and developed in order to automate decision making across the recycling value chain involving all the partners. Advanced functionality such as wireless inventory tracking, material characteristics and quality control monitoring, material classification and sorting, will form the core of the Supply Chain Planning system.

2.2.6. *Classification framework for dismantling and sorting*

To realise the sorting, recycling and reintegration of used polymer materials for the reintegration into the productions process it is mandatory to define classification rules and properties, which allow sorting of components of ELVs especially regarding their suitability for the use in different high quality applications. To capture and provide all information necessary to ensure continuous quality of the recycled material in the controlled closed loop recycling system and to minimise the risk of contamination, furthermore a system platform, software tools and a sorting process basing on the classification system, have to be developed. Of particular importance is the automated processing of material containing contaminants such as colourings and the development of methods for the production of new parts out of this material (i.e. based on the extraction of colourings).

2.2.7. *Decision support for recipe configuration*

The production of automotive parts requires a continuous quality of material. Reprocessing of recovered material into new products requires a way to guarantee continuous quality of the material in spite of any degradation suffered during its life-time. To ensure the continuous quality of the recycled material a decision support system for recipe configuration will be researched and developed. One method of the recipe configuration system could be the use of computational neural networks or statistical based methods.

2.3. *CONCLORE Methology*

CONCLORE innovation will help close the loop and achieve practical and cost-effective automotive part production out of material recovered from recycled ELVs by establishing an advanced recycling model geared towards 100% material recovery and continuous quality reprocessing of automotive polymer parts. The proposed Controlled Closed Loop (CCLR) will integrate Reverse and Forward Supply Chain

Management (SCM) and Product Life-cycle Management (PLM) into a Sustainable Supply Management (SSM) loop using PEID for tracking & tracing.

2.3.1. Design of ully recyclable multilayered single material sandwich structure

Existing solutions are based on foam (Melaminresin or PUR), cotton based felt or glasfiber-felts. Both felt-systems consist of shares of duroplastic binders. The foam-systems have advantages regarding the air sound absorption and have low material densities. On the other hand these materials are expensive and can not be recycled cost-effectively. Parts based on phenolic-cotton-felt are advantageous air-sound-absorption properties. They have typically higher weights (up to 1200g/m²) to reach the mechanical stability. As duroplastic materials their recycling properties are also not sufficient because a material recycling is not possible.

Felts consisting of glasfibres also show good absorption properties. Because of the high stiffness of the glasfibres the weight of those parts is lower than phenolic-felt-parts. The recycling possibilities of the glasfibrematerials with phenolic binder are also low. Moreover the use of these materials causes glas fiber irritation.

In order to fulfil the requirements for automotive parts related to flammability and solvents resistance, additional cover material based on PES or PaNOX are necessary. This leads to multi-material-concepts.

Systems with thermoset binders are always critical during production process for environmental reasons. Emissions during production are a nuisance for the staff and could become dangerous for the health in case of wrong process leading.

Increased requirements regarding the driving comfort, acoustic and recyclability is essential to develop new effective materials for sound absorption and sound insulation in vehicles. For sound absorption and sound insulation traditionally porous materials like fibre felts and foam systems are used to fulfil the customer requirements.

An answer to the aforementioned problems is the usage of PES-fibres. Felts based on PES have also good absorption properties. By further use of high air-flow-resistivity-layers the absorption behaviour becomes excellent. PES-materials are able to fulfil the requirements regarding stiffness, flammability and weight. PES-felts also have defined properties driven by a defined fibre composition and a defined fibre quality. This makes it possible to simulate the mechanical and acoustical properties of PES-fibre-felts more effectively than cotton-fibre-felts. In addition it is possible to develop a single-material-system, by using PES-felt for the cover-layers. In combination with its thermoplastic behaviour, a recycling of these materials is possible on a high level. The PET recycling process has been optimised to recycle bottle grade PET, a high-grade polymer with known specifications into fibre products for a number of different applications. The recycling process is as follows: the bottles are received and washed to remove contaminants like dirt, paper labels and/or glues, the clean bottles are shredded into flakes of area approximately 1 cm² and the flakes processed via a melt extrusion process into fibre.

Today the amount of PES-fibres in automotive vehicles is increasing. Most applications are realized in the passenger and luggage compartment. For acoustic parts in the passenger compartment several PES-products (carpet, cover felt) are used in combination with other materials like foams and cotton felt. Moreover, felts based on 100%-PES are used as absorbing felts, e.g. for cockpit. Furthermore new solutions based on PES are under development for applications in the passenger cabin, e.g. floor insulation, inner dash insulation but are not introduced into the market yet. These new applications are developed for recycling reasons under consideration of reasonable acoustic properties. PES-fibre applications in the engine compartment are limited to decor non-woven materials without acoustic function. Applications based on 100%-PES are not available on the market yet.

In order to achieve the requirements of the ELV directive regarding the recycling ratios, the use of innovative, thermoplastic single components instead of thermoset material solutions with low recycling capability is essential. A high potential of replacing these materials is given in the engine compartment of vehicles and the passenger cabin.

A potential problem for post-automotive PET is contamination by foreign substances picked up during the lifetime of the product and the likely influence of this contamination on the efficiency of the recycling process. Another issue relates to Intrinsic Viscosity (Iv), the most important parameter considered during the PET recycling process. Generally bottle grade PET is at the high end of the Iv specification hence it is easier to recycle than materials with lower IV values. A major requirement for this project will be the development of a recycling system capable of processing PET with a range of varying IV's and also capable of coping with any contamination in the system.

The current fibre spinning process is optimised for the processing of recycled PET flake of high Iv and virgin chip pellets. It is likely that the PET pellets from automotive components will not meet the same specification as that of bottle flake hence flexibility will have to be built into the current fibre spinning process. This will allow PET of different Iv values and of variable qualities to be processed into fresh fibre the properties of which will be decided by the blends used for the manufacturing recipe. It's possible the recycled PET will need to be blended with some virgin material in order to achieve the final fibre properties required for the products. These blends or manufacturing recipes will need to be established and the appropriate production parameters identified.

Figure 1 Processing of resin to fibres

The intended solution will be realised by a sandwich construction of the above mentioned technologies and therefore consist of different layers. Following manufacturing processes will be researched for drylaid non-wovens, which may be part of the solution:

- Fiber spinning
- Needle punch
- Spundbond
- Meltblown

An approach to increase the absorption properties without decreasing the mechanical stiffness is the development of multi-layer-systems, completely based on PES. These consist of PES-cover-felt, PES-high-air-flow-resistivity-layer, PES-substrate. The aim is to get acoustical effective systems with an increased middle-frequency-absorption under consideration of the general specification requirements. Furthermore, including special fire resistant fibres into the PES-mixtures is an approach for reducing the demands for the covering felts and therefore to use cheaper products.

The following listed attributes have to be considered during the analysis and specification of the new product desing:

- **Stiffness**

  The use of melting or bi-component PET fibres can be added in the matrix in different numbers then creating the stiffness of the end product. Using this solution it is possible to generate soft and flexible wadding, which can be laminated with other textile layers and then moulded into the finished part.

- **Acoustic Performance**

  Traditionally there has been a used heavy layers as absorption material in the auto cabin. The product spectra of PES-fibres has a high degree of diversification. It contains thin, thick, helicoidal, short and also long fibers. Furthermore fibers with special properties like different Bi-Component-fibers are available. This makes it possible to design materials and parts for several different requirements by using optimised mixtures for absorption or insulation

- **Soft touch**

  To replace PUR foam as a soft touch layer there are different voluminous non-wovens, which could be of interest. Again the polymer must be in PET.

- **Resilience**

  New types of non-wovens with vertically oriented fibres has shown a remarkable capability in resilience and resistance against instant- and permanent deformation with values which are as good or better than PUR foam.

It is necessary to ensure uniform and homogenous fibre for the production of technical textiles hereunder non-wovens. The delicate production equipment will suffer damage or even break down if the raw materials (fibres) are contaminated in any way with alien substances. Other important issue is the fibre size and length of the recycled fibres. If the raw material for the textile production is not uniform in dtex and length it will be difficult or even impossible to produce textiles e.g. non-wovens, which can fulfil the specifications set by the automobile manufactures.

The high temperature application of PES in the engine compartment is an important and innovative aim of the CCLR-project. Achieving this aim leads to new and innovative fibre products. Furthermore, innovation in the field of non-woven production and adapting of the moulding-process-technology for the high-temperature-PES-application will be developed. Parts based on PES-felt are produced within a thermoplastic process. The covering of non-woven is laminated with or without glue in a one-step-process. The solution to get new materials and products for the application engine compartment is to apply existing technology on new PES-felt products with optimised fibre mixtures.

The moulding of the required non-woven sandwich structure will be a challenge because of the conflict between structural stiffness and acoustic properties which can be affected by the moulding process parameters. There has to developed innovative technologies concerning the moulding process. Additionally, the process parameters for moulding of such sandwich structures have to be researched. The press moulding of different layers is complex due to different melt temperatures of the several kinds of fibres. To process with required and continuous quality the press moulding technology has to be researched in respect to existing know-how. To reach the aim a combination of process technologies with different temperature profiles might be a feasible solution. Otherwise innovative technologies have to be developed for products used in high temperature applications like the intended dashboard insulator.

Further potential applications for interior parts are dash inner insulations or door inserts. Today door inserts based on injection moulded parts or thermoformed parts. For these applications the use of PES is an innovation which combines excellent mechanical and acoustical properties.

The research activities will be focussed on the acoustic and mechanical properties of the intended automotive part in dependency to:

- solid, hollow or bicomponent fibres, the cut length, fibre thickness (decitex), crimp levels and fibre finish,
- the number and the composition of the layers required for the sandwich structure,
- the moulding process parameters and/or innovative moulding process technologies.

2.3.2. *Controlled Closed Loop Recycling*

In order to address reverse logistics issues related to on-demand delivery of the required amount, type and quality of material, as well as balancing overall recycling returns and production demand, CONCLORE will define a new state of the art by establishing an advanced recycling model called the Controlled Closed Loop Recycling (CCLR) geared towards 100% material recovery and continuous quality reprocessing of automotive polymer parts.

As manufacturers and suppliers transform from isolated business units to partners of an integrated network, they require effective and efficient Supply Chain Planning (SCP) strategies for materials, components, and products. Advanced planning functionality in the form of a new SCP component to be integrated into the overall Sustainable Supply Management system will help speed up the reverse logistics in the CCLR process by automating decision making across the CCLR value web.

CCLR will thus form a loop integrating

- Advanced PEID enhanced dismantling and sorting process
- Reverse and Forward Supply Chain Management (RSCM & FSCM)
- PEID based tracking & tracing
- Supply Chain Planning (SCP)
- Product Life-cycle Management (PLM)

2.3.3. *RFID supported dismantling and sorting process*

As the ELV directive is slowly passed on to national legislature its impact becomes apparent in all aspects of automotive recycling. Technology and accompanying processes allowing dismantlers to identify individual car interior component and sort them according to their composition based on conventional technology would be far too expensive for commercial usage.

CONCLORE addresses this issue by relieving workers from the responsibility of classifying and sorting based on product ID and quality. Instead the sorting of parts during dismantling will be automated through utilising RFID, incorporated into the automotive components during production. Embedding RFID technology in automotives has already proven to be reliable and is being widely used for security related applications for over a decade. To ensure functionality and enable the extraction during the recycling process, it is mandatory to specify a suitable location within the part, as well as appropriate parts of the assembling and disassembling processes. Back-up modes such as the usage of mobile equipment (i.e. PDAs) semi-automated sorting or generation new RFID-tags on the spot using information retrieved either from vehicle on-board systems or centrally stored configurations, will be devised to compensate for the risk of malfunction due to external influence along its lifetime.

RFID readers and other advanced sensors deployed on a dedicated, automated line will collect product data and pass it on to Supply Chain Planning components integrated into the CONCLORE platform for automated classification, sorting and routing based on product life-cycle data. This approach directly enables further radical advancements of state of the art in recycling and continuous quality reprocessing.

2.3.4. *Reverse and Forward Supply Chain Management and Planning*

The recycling ratios and overall goals described by the ELV directive dictate the necessarity to control the flow of recycled material in respect to the recycling quota, the quality, the quantity and finally the type of the material. Currently both the quality and the quantity of dismantled parts and recovered material are not sufficiently controlled or even tracked by state-of-the-art technology. Therefore the uncertain level of quality, possibility of contamination and large variety of materials make a continuous quality reprocessing based on recycled material quite difficult and not cost-effective.

The CONCLORE SCM system thus has to cater for two sources of supply, one for virgin material and the other for recycled material. Consequently, it has to cope with recovered material of varying quality and types. Orders will be issued according to availability which will be controlled by the Reverse Supply Chain Management (RSCM) module. Managing multiple sources of stock and the uncertain availability and quality of the recycled material introduces a very high level of complexity to the task, insights can be gathered from stock theory, but additional heuristics must be added. The overall performance will be tested by simulation. Furthermore, the integration of tracking and tracing mechanisms (PEID) in the supply chain will provide real-time data allowing for continuous, dynamic monitoring that will make planning more effective, enable pro-active response and allow for improved quality control.

The CONCLORE SCM thus needs to support:

- identification of the incoming material and tracking of the sorted material
- material characteristics and quality control monitoring, material classification and sorting
- correlation of data on the demand and the quality of the material required for production based on data derived from PLM systems

- Automated decision support on dismantling in order to automatically regulate the flow of recovered material

Research issues to be investigated in the context of the SCM are the following:

- *Supply/Demand Balancing:* perhaps the most difficult variable to forecast is the distribution of the returns of end-of-life products over the planning horizon. To use recycled material in production forecasters often face unexpected supply/demand patterns that will depend on their product success in the market and competing products.
- *Accumulation:* there will be accumulations of certain kinds of parts due to uneven market demands for certain components. For instance, there may be higher demands for certain models of product components while other dismantled parts with no demand pile up on the operations floor.
- *Logistical Network:* in a reverse logistics supply chain environment there will be potentially three separate entity type: the assembly plants, the disassembly plants and the recycling plants. Operations therefore have to be planned from a larger perspective that comprises those three entities. The inventory policies will alter in terms of the level and location of buffer stocks. From the supply of products, to collection, to dismantling, to reuse and/or recycling, the inventory of products and components must be properly maintained to balance the supply and demand of resources.

The primary objective of the new SCP will be to provide a cost efficient way in which manufacturers can reclaim products for continuous quality reprocessing. We will assume that the supply of products, which have been disposed of at the end of their lives, is finite. Since shortages in this supply are eminent which, in turn, lead to possible shortages in the supply of components for remanufacturing, the method has to account for the possibility of component inventory and/or ordering additional (new) components to fulfill the demand. After disassembly, unwanted components and materials are sent for recycling or proper disposal. Due to possible deterioration in the conditions of some recovered components, the quality of the components shall be considered in the inventory of the components. The shelf life of each component may vary.

The Supply Chain Planning system will be also integrated with an RFID-Application that will provide the ability to track product or components throughout the entire supply chain of the closed loop recycling process (wireless inventory tracking, material characteristics and quality control monitoring, material classification and sorting). This will lends to improved operational efficiency for all operators within the supply chain, from the product suppliers, manufacturers, distributors and customers. Knowing where the product is and knowing when to expect the product to be delivered, allows for pro-active decision-making, reduced loss of time (and money), improved productivity and effective planning and execution of all processes and activities within the entire supply chain. Moreover, the quality control will become more manageable with the ability to track the events relating to the life-cycle of a component all the way back to its origin.

2.3.5. Classification framework for continuous quality production

The material for the automotive components will be exposed to a number of environmental conditions during its lifetime. Polymers used in car interior components are affected by humidity and/or heat, ultra violet radiation during the lifetime of the car. There is also a high probability of contamination of the component by foreign materials during its use, especially in engine compartment applications. Prior knowledge of any changes in polyester properties or the presence of contamination allows the process to be modified to take these variables into account. The resultant quality of recycled polymer should be higher and be suitable for a wider range of markets.

Once at the recycling point the type of polyester in the product will need to be identified and this data will dictate the method of recycling to be used. The system of shredding the component will have to be optimised and a system for converting the shredder residue from a 'fluff' form into pellets will need to be developed. The vital parameter to be managed during the recycling process is the intrinsic viscosity of the polyester. To allow for maximum flexibility of potential markets for the recycled polyester it will be necessary to develop a mechanism for raising the viscosity of the polyester and to build this mechanism into the recycling process. A high polymer intrinsic viscosity will open up the range of markets into which the recycled polymer can be used. To control this property an extruder system allowing control over the level of moisture and the complete mixing of the polyester in the system will need to be developed. Work will also be required to optimise the polyester extrusion system and the mechanism for producing the pellets required for the subsequent processing on the recycled polyester.

To assist the processing of recycled material to ensure a continuous quality a decision support for the recipe preparation must be researched.

3. Progress achieved

The European project CONCLORE developed sustainable 100%-recyclable car interior products for recovery at the end of the useful life of the vehicle, recycling it either for reuse within the automotive industry or in other applications. This goal was achieved through developing single-component thermoplastic sandwich-structures and utilising Product Embedded Identification (PEID) CONCLORE enables the recovery of plastic material at. Combined with an enterprise-spanning Product Lifecycle Management concept CONCLORE offers identification of recyclable automotive parts as well as classification of material quality.

The ELV (End of Life Vehicle) directive (EU/2000/53) introduced by the EU in 2000 addresses pollution arising from vehicles that have reached the end of their useful life. Its aim is to reduce more than 9 million tons of waste generated by over 12 million cars that become ELVs each year.

The directive specifies thresholds for the reuse, recycling and recovery of materials from ELVs. By 2006 the ratio of materials which should be reused, recycled or recovered aims for 85% of the total vehicle weight and 95% by 2015. The initial recycling ratio of 85% can currently be fulfilled by most manufactures. Keeping up with the quota, however, will become more and more difficult, due to the increased application of polymers. A higher polymer ratio will become increasingly important as it helps save fuel by lowering the overall vehicle weight. This trend will lead from a current average of 13% to a projected average of 15,5% in 2010.

3.1. Single Component Automotive Parts

Polymer automotive parts today are due to low costs and advantageous physical properties mostly multi-component composites. However, material recovery of these multi-component polymers is too expensive and energy intensive. Composed of a number of mechanically and chemically bonded materials the separation of different layers is economical impossible.

State of the art ELV recycling starts therefore with the shredding of the entire vehicle and proceeds to separate different kinds of material (i.e. ferrous from non-ferrous metals). The residual material, up to 30% of the weight of the vehicle, is termed Auto Shredder Residue (ASR) or simply “Fluff”. Fluff is composed of 50% polymers as well as rubber, glass and electronic components. The multi-material nature of ASR makes it economically impossible to segregate, recycle and reuse. Fluff is thus usually disposed on landfills or by incineration (thermal recycling).

A prerequisite for recycling is therefore the development of single component automotive parts. The single-component interior part can be made up of different types of non-wovens, utilising a sandwich construction.

Suitable materials for single-component parts, as studies conducted by the consortium have shown, are PET or in special cases PP. PET and PP are two well-known and widely used materials, which are today already being recycled on a large scale, e.g. PET in the beverage industry for bottles. The functionality of this approach has been demonstrated by CONCLORE producing two automotive parts, one from the driver cabin and one from the engine compartment.

For the development of the new mono-material sandwhich-structures for automotive parts different semi-finished products were developed required. The most important requirement is that all products are fully recyclable. In this approach only polyester fibres were used, therefore recyclability is given.

Basically there are five different types of semi-finished products necessary for the production of different sandwich structures to fulfil the specifications regarding the selected automotive parts as described in the Deliverables of Workpacke 2.

- **Cover layer**

  The engine hood insulator needs a cover layer to fulfil the requirement regarding diesel, oil and water repellence. A 1mm standard black polyester nonwoven with 100g/m² of Fibertex is used for this purpose.

- **High loft layer**

  The High Loft layers primary function is to bring the desired volume into the sandwich construction.

- **Glue interface**

  The required interface between different layers must be a pure polyester glue due to the required recyclability. The AB-Tec company for example provides different types of Co-Polyester adhesives which are similar to parallel staple fibre nonwovens. The used product has a surface weight of 20 g/m² and a recommended glue line temperature of 127 - 143 °C.

- **Polyester foil**

  For the Front under carpet part a mass-spring system is designated. State of the Art is to use an EPDM with a density of 1,32 g/cm³. Polyester has with 1,38 g/cm³ a similar density and can substitute EPDM in the mono-material structure. A standard polyester foil from Folienwerk Wolfen with a thickness with 0,4 mm was used for this reason.

- **High Air-flow-resistivity-layer**

  By adding a polyester high-airflow-resistivity layer (HARL) to the sandwhich-structer better acoustic performance can be achieved. This layer is placed between cover layer and the high loft product. Important for utilising an airflow-resistivity layer is its corresponding parameter. If its value is too high, sound waves can not penetrate the structure and will be reflected mostly. If the value is too low, the sound waves will pass through the structure without any effect. There is an optimal range which has to be met to enable the full functionality of this setup.

Especially the High Air-flow-resistivity-layer and the High loft layer needed trials to develop the desired specification and fulfil the requirements for the original parts.

3.1.1. High Air-flow-resistivity-layer

For the CONLCORE project Fibertex produced several types of HARL with different properties. Apart from the acoustic characteristics the processing behaviour is crucial for the selection. The elongation is very important for molding the parts.

The HARL is produced in two steps. First the nonwoven will be laid and needle punched. After that the nonwoven be will be thermally calandered. This changed the semi-finished product properties strongly.

All fibre compositions were produced without major problems, even sample E. The speed of the line was however rather slow – this needs to be improved before the products can be run in an industrial scale. Further work has also to be done on sample E where the ratio between the strength and elongation values MD/CD has to be improved.

On the off line calander line used for the trials it was rather difficult to process the substrates. The results displayed wrinkles and small folds. The use of newer and more modern calandering equipment in an industrial scale however will eliminate these artefacts.

The first trial productions of the engine hood insulator showed some problems when moulding the parts. Not all outlines were totally moulded. There seemed to be a problem with the elongation of the high-airflow-resistivity layer. Due to this behaviour of the material further trials were conducted.

These trials were made with the same blends as the first trials, but with increased elongation to avoid the delaminating during the moulding process. Several trials were required to achieve the desired increase the elongation by changing process parameters on the line. Finally samples of 7 of the trials were processed.

All samples were processed without problems on the line. As last time the speed of the line was rather slow, which needs to be improved before the products can be run in an industrial scale. The light weight products of 60 and 80 g/m² gave the biggest improvements on the elongation compared to previous samples, but the strength of these products also decreased notetably.

As in the first trials there were difficulties processing the substrates on an off line calander encountered. Again wrinkles and folds appeared in the samples. The products processed at higher temperature are looking most interesting in regards to the air through resistivity properties, and as the elongations are not influenced a lot by the higher temperatures, I will recommend to focus on the samples A1.1 to E1.1 when carrying out the moulding trials.

3.1.2. High Loft Layer

The first prototypes manufactured in the CONCLORE rroject were not stiff enough and had some problems with delamination between the face of the fabric and the air through resistivity layer. Therefore additional trials for this part were conducted.

Compared to the first trials a thinner bicomponent fibre was used to increase the fibre distribution in the product. This enhances the stiffness of the final product.

3.1.3. Engine hood insulator

Figure 2: Front view Engine hood insulator

Figure 3: Back view Engine hood insulator

3.1.4. Front under carpet

Figure 4: Front view Front under carpet

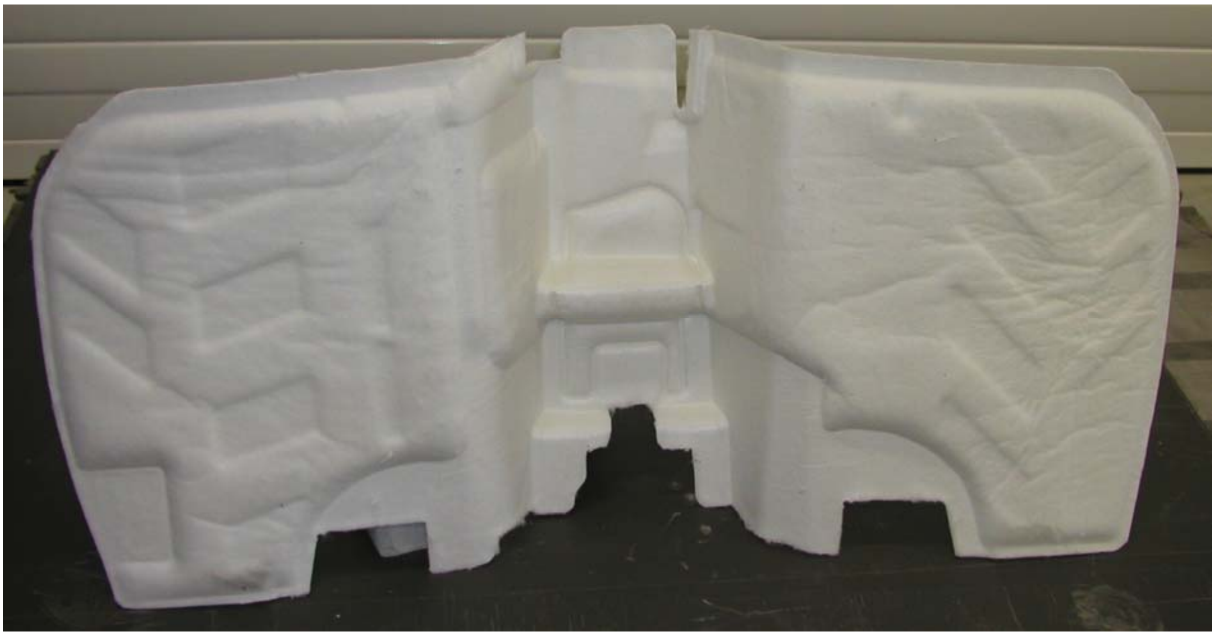

Figure 5: Back view Front under carpet

The front under carpet part is a three layer material construction, also based on fibre felt material, bonded with Polyester-Epoxy resin. The first layer with a weight of 1800 g/m^2 shows a representative thickness of 20mm. Furthermore, the 900 g/m^2 and 5mm thick upper layer mainly influence, in combination with the porous adhesive layer, the acoustic properties regarding the absorption coefficient and the Transmission Loss.

3.2. *Product embedded Identification*

Another important issue regarding Recycling is the identification of recyclable parts and the evaluation of the material quality.

CONCLORE has therefore investigated Radio Frequency Identification (RFID) since it enables identification of components without visual or physical contact. The most critical issue for recycling is the retrieval of recyclable material following the usage of the car. Dismantling enables the easy retrieval of retrieve pure material. CONCLORE aims therefore to minimize operation cost and enhance the reliability during dismantling and sorting through the incorporation of Radio Frequency Identification (RFID) tags into automotive products. RFID Technology enables the identification of recyclable parts prior to dismantling and allows for a continuous data supported material evaluation and automated decision support in the recycling value chain.

In the operation of the RFID tags in CONCLORE two distinct processes are distinguished. First the status monitoring phase and second the item marking process.

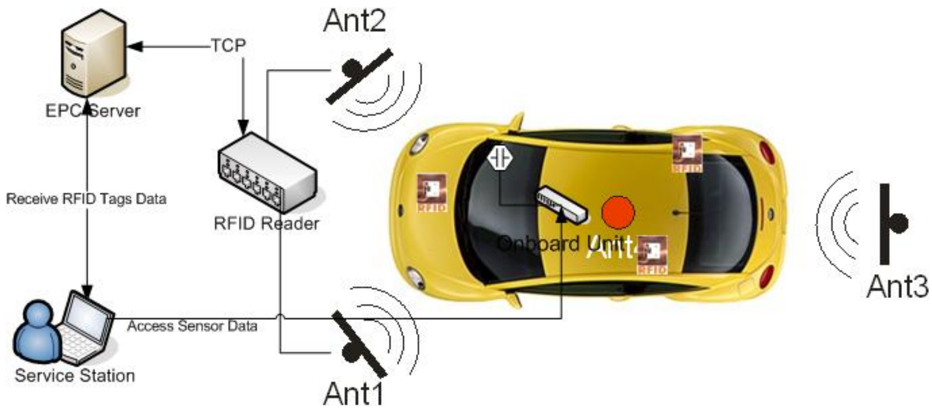

Figure 6: CONCLORE RFID marking process

During status monitoring sensors are deployed for constant periodic or continuous probing of environmental conditions while during item marking a summary of the resulting data is stored for later evaluation. The critical aspect of status monitoring is the identification of factors affecting item quality or status. For PET in specific, the following primary environmental factors responsible for quality degradation have been identified:

- Age
- Humidity
- Temperature
- Ultraviolet Light

Each of these factors tends has a permanent effect to the properties of the PET, but the most important is he age and the original quality of the PET products regarding composition with bicomponent binding fibres for example. In status monitoring different environmental factors are considered depending on the distinct attributes of the item to be marked. For example, PET interior components are less prone to suffer from pollution and ultraviolet light exposure than exterior parts. In the latter case humidity and temperature have a more significant impact on degradation.

3.3. *Classification framework used for sorting*

During investigations focusing on status monitoring of interior car components out of PET temperature and humidity sensors were attached to an on-board computer for periodic or continuous measurements. The data captured by the sensors was analyzed to display the part information and derived part quality:

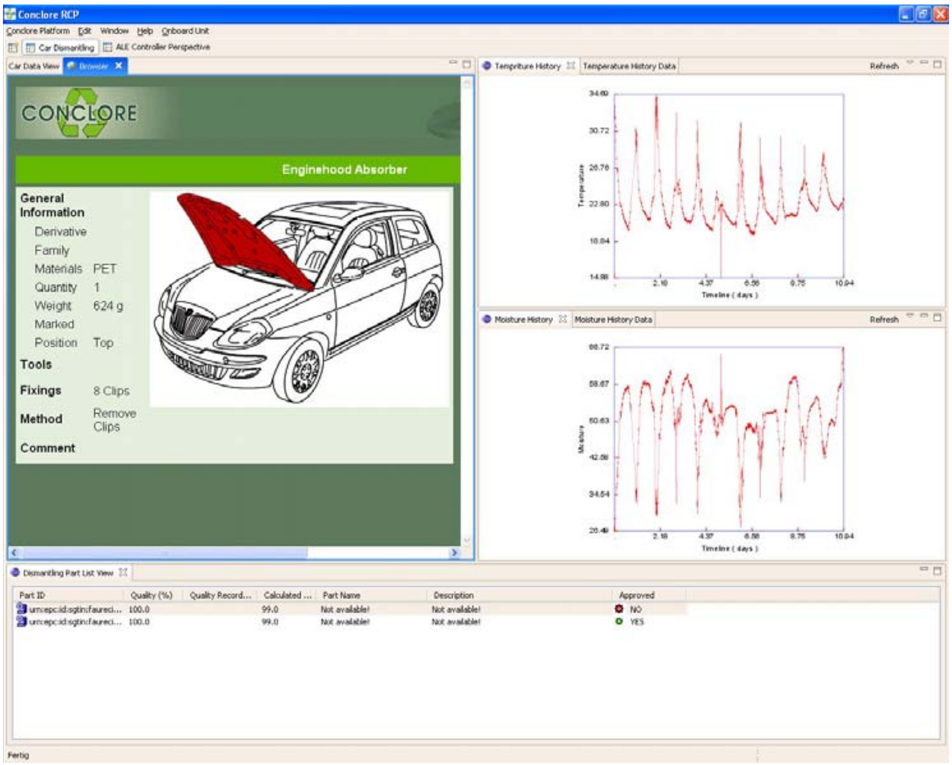

Figure 7: CONCLORE Part identification and evaluation

The requirements for recycling PET automotive parts to high quality products like fibers for the automotive industry were captured and used to implement a Classification framework for sorting. Parts with similar composition and properties are grouped for efficient and cost-effective recycling. The initial information about the material properties is not available after sorting. The Classification framework must therefore capture all relevant details, since all further steps are derived from this stage. Derived from this stage is the mixture of material for recycling. A recipe configuration determines the blend of automotive parts, PET bottle flakes and virgin material required to achieve the desired product quality.

3.4. Decision support for recipe configuration

The main goal of CONCLORE is to identify the material and its quality and reuse it for products of comparable quality. For reprocessing treatment the data of the product life cycle provides advanced information about the characteristics of the material which enables to re-feed the material back into the production process. So far these characteristics could only be estimated. The lack of accuracy hinders recycling and often the material is only used for low quality applications.

All relevant process parameters are therefore captured for recipe configuration. Parts with similar composition and properties are grouped for efficient and cost-effective recycling. The initial information about material properties will not be available after sorting.

In CONCLORE rule-based, model-based and case-based approaches of computer-based reasoning as well neuronal networks concept were investigated and evaluated, however the fact that mostly the product composition influences the recycling ratio of the ELV automotive parts made the originally planned system utilising artificial intelligence obsolete. The results of the material trials showed that with the knowledge about material degedation gained within CONCORE the recycling ratio mostly is determined by the percentage of bicomponent fibre used during the part production.

3.5. *CONCLORE approach*

To enhance the recyclability of end of life vehicles multi-material components have to be substituted with single-material components. Electronic identification systems, which are already utilised during production and assembling of vehicles, enable fast and reliable identification of recyclable polymer car components and allow for targeted dismantling and sorting. Product Life Cycle Information allows determining material quality for efficient sorting and recycling, even for high quality application. CONCLORE offers a new holistic approach defining a new state of the art by establishing an advanced recycling model called Controlled Closed Loop Recycling (CCLR). Expanding the Product Life Cycle with the use phase CONCLORE offers a data based solution to identify and assess the quality of polymer automotive parts for recycling. This enables the retrieval of plastic material from ELVs and therefore enhances the sustainability of automotive products.

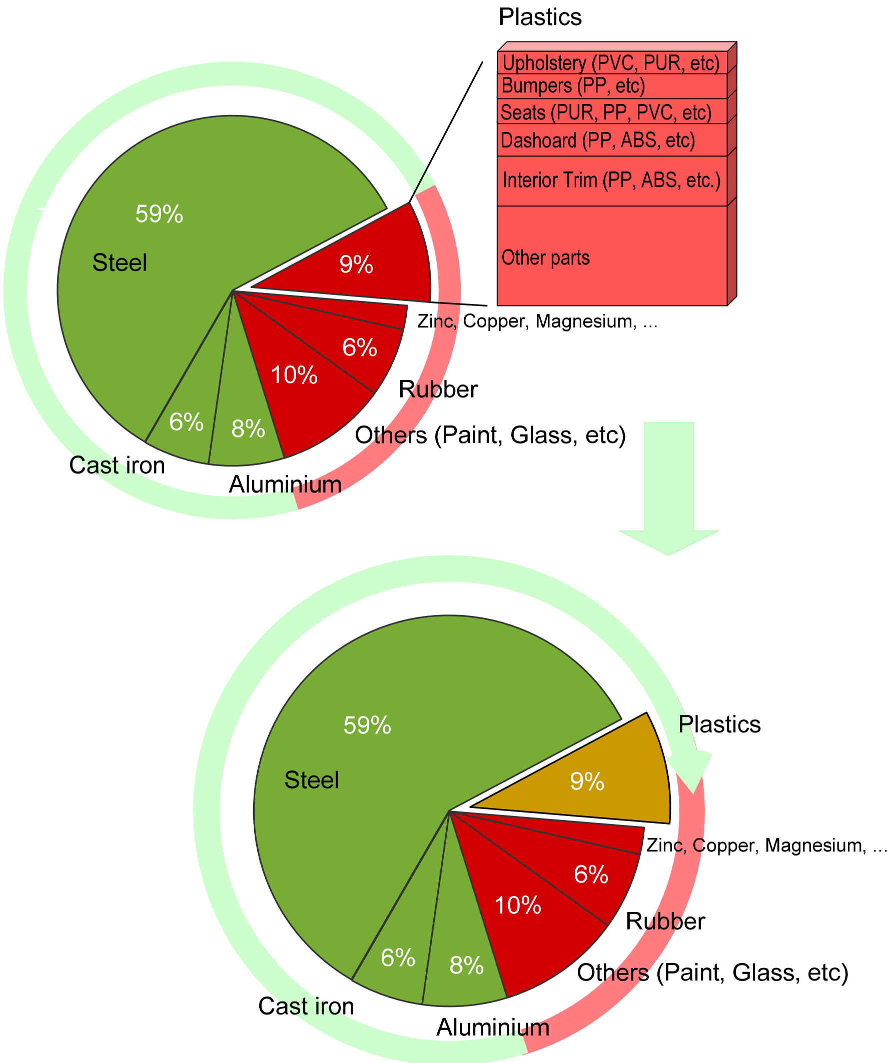

Figure 8: Comparison of sustainability of State-of-the-art automotive parts and the CONCLORE approach

3.6. *Derivations from the description of work*

The work plan as a whole was well scheduled and could with slight timely derivations be kept as planned. Most of the delays of the project were experienced during the conduct of material and production trials, since the trials could not always be conducted just in time and shipment of the trial products had to be arranged.

The following listed Milestones defined in the project plan were all successfully and in timely manner completed:

- M1.1 Completion of Requirements Analysis
- M1.2 Refinement of Requirements
- M2.1 Completion of CCLR-Process-Specification
- M3.1 Completion of the CCLR-Platform-Specification
- M4.1 Live pilot of manufacturing process
- M4.2 Live pilot for ICT-platform
- M5.1 Evaluation of applicability of CCLR-concept
- M6.1Dissemination & use plan – versions 1
- M6.2Dissemination & use plan – versions 2
- M7.1 Final Report

4. Conclusions

The European project CONCLORE developed sustainable 100%-recyclable car interior products for recovery at the end of the useful life of the vehicle, recycling it either for reuse within the automotive industry or in other applications. This goal was achieved through developing single-component thermoplastic sandwich-structures and utilising Product Embedded Identification (PEID) CONCLORE enables the recovery of plastic material at. Combined with an enterprise-spanning Product Lifecycle Management concept CONCLORE offers identification of recyclable automotive parts as well as classification of material quality.

All objectives of the project were achieved, all Milestones and Deliverables were successfully and in timely manner completed.