Sustainable Vehicles with Recycled Plastic

Project report: SVE-REP

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Preface

The project "Sustainable Vehicles with Recycled Plastics (SVE-REP)" has been financed by the innovation program RE:Source, managed by the Swedish Energy Agency. The project started in August 2020 and ended in May 2023. RISE has managed the project. A number of companies in the vehicle industry and plastic industry have been partners and contributed with work in the project. The companies are Volvo Car Corporation, Volvo Global Truck Technology, Plasman, KB Components, Albis, Biesterfield, DOW Europe and Rondoplast. The collaboration and knowledge sharing in the project group have been very fruitful and contributed to good results.

Content

1. Summary

The production of vehicles is one of the most resource-intensive industries. 10 % of the overall consumption of plastics, 6 million tonnes/year is used by the European vehicle industry[1]. Increase the use of recycled plastics in vehicles is one of the key challenges for sustainable transformation of the vehicle industry as it plays an important role in saving resources and reducing greenhouse emissions.

The main goal of this project was to contribute to increased use of recycled plastic in the Swedish vehicle industry. Volvo Cars goal is that 25 % of the plastic used in cars should be recycled or biobased by 2025. The goal will most probably be reached according to Volvo Cars. Volvo group has the goal to be fossil neutral, which requires recycled material in the truck components.

The recycled plastics evaluated in the project came from both post industrial waste (PIR) and post consumer waste (PCR). Rondo Plast, Polykemi, Albis, Mocom, Biesterfield, Borealis, Sabic, Total and LG Chem have supplied recycled and virgin plastics tested in the project. The plastics we have focusing on in this project were polypropylene (PP) plastics (homo- and copolymer) and PC/ABS plastic compounds. Thus, these plastics are most used in vehicle components and recycled PP plastics are more accessible than the other plastics that can be used in vehicles. Analysis and evaluation of recycled plastics have been performed by RISE. Also, long term ageing and recyclability studies have been performed. A study to upgrade PP plastic recycled from packaging (PCR) with additives from DOW and Rondo Plast were performed.

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[1] https://environment.ec.europa.eu/publications/proposal-regulation-circularity-requirements-vehicle-design-and-management-end-life-vehicles_en

The components produced in the pilot trials have been tested and validated by KB Components, Plasman, IAC, Volvo Cars and Volvo Truck. 19 test runs to produce car components with recycled plastic were made and 10 test runs to produce truck components. Test plaques have also been produced. Paintability and paint adhesion have been evaluated.

Some findings when injection moulding components with recycled plastics were:

- Recycled PP tested from packaging and film had lower viscosity, resulting in lower injection pressure.
- Some recycled materials had better surface finish after injection molding and were easier to process than virgin material.
- Part geometry often differ when using recycled plastic. However, it has not been a problem in the trials performed in this project.

Some findings for the component produced with recycled plastics:

- Most of the recycled materials tested had good performance.
- Paintability and paint adhesion was expected to be problematic but were not. However, PVD surface coating is “mirror-like”, an even the smallest contamination in the surface becomes visible.
- The unpainted surfaces were more sensitive to defects. Blisters after moisture test was observed for some components with recycled material.

The project has shown that recycled plastic in significant amounts can be implemented in vehicle components, also in parts with high demands on safety and surface finish.

Panel tailgate and hatch warning triangle for Volvo Cars produced by KB Components with 30 % recycled plastic, are now approved for implementation in Volvo XC60 and battery box and lid with 30 % recycled plastic are approved for implementation in XC60 and XC90. A and B pillars for Volvo Cars with 50 % recycled plastic were approved in all the tests but Volvo Cars is not ready to implement recycled plastic in the safety related parts. Recycled plastic is also implemented in bumpers and connected parts produced by Plasman. Components for Volvo Truck, bumper corner and door extension extenders have been produced successfully by Plasman and tested with good results and also the SID panel inboard produced by IAC.

The work forward is to go on and implement recycled plastic in car and truck components. The main challenge is to find enough recycled plastic of the right type and quality to scale up and implement in all the vehicles. Increased demand on implementation of more recycled plastic will most likely lead to increase prices. It will also most likely lead to increased recycling of plastic from vehicles into new vehicle components.

2. Sammanfattning

Tillverkning av fordon är en av de mest resurskrävande industrierna. 10 % av den totala förbrukningen av plast, 6 miljoner ton/år, använder den europeiska fordonsindustrin. Ökad användningen av återvunnen plast i fordon är en viktig del i omställningen till en hållbar fordonsindustri. Det är viktig för att öka resurseffektiviteten, minska behovet att använda fossil råvara och för att minska växthusgas-emissionerna som bidrar till klimatförändringar.

Projektets huvudsakliga mål var att bidra till ökad användning av återvunnen plast i svensk fordonsindustri. Volvo Cars mål är att 25 % av plasten som används i bilarna ska vara återvunnen eller biobaserad från och med år 2025. Målet kommer troligtvis att kunna uppnås enligt Volvo Cars. Volvo har som mål är att bli fossilneutral, vilket också kräver återvunnen plast i lastbils komponenterna.

Den återvunna plast som testats i projektet kom från både industriellt spill (PIR) och konsumentavfall (PCR). Rondo Plast, Albis, Mocom, Biesterfield, Borealis, Sabic, Total och LG Chem har levererat återvunnen och jungfrulig plast till försöken i projektet. Plasterna vi valt att testa i komponenter var återvunnen polypropen (PP), homo- och sampolymer, med tillsatser som slagseghetsmodifierare, fyllmedel och förstärkningsfiber samt återvunnen PC/ABS. Dessa plaster är de mest använda i fordonskomponenter och återvunnen PP är mer lättillgänglig än övriga plaster som kan användas i fordonskomponenter. Volvo Cars har också som strategi att öka användningen av PP i bilkomponenter.

Analyser och utvärderingar av återvunna plastkompound har utförts av RISE. Även långtidsåldring, klimatcyklingar och återvinningsbarhetsstudier har utförts. En studie genomfördes också för att uppgradera PP PCR-plast med tillsatser (slagseghetsmodifierare och kopplingsagenter) från DOW och Rondo Plast.

19 testomgångar har utförts att producera bilkomponenter med olika återvunna material och 10 testomgångar att tillverka lastbilskomponenter. Provstavar och provplattor har också tillverkats för att utvärdera det återvunna materialens egenskaper, ytegenskaper, lackerbarhet och lackens vidhäftning. De tillverkade komponenterna har testats och validerats av KB Components, Plasman, IAC, Volvo Cars och av Volvo.

Pilotförsöken visade att:

- Återvunnen PP testad från förpackning och film hade lägre viskositet jämfört med standardmaterialen vilket resulterade i lägre insprutningstryck och god formfyllnad.
- En del av återvunna PP materialen hade bättre ytfinish på grund av den lägre viskositeten och var lättare att bearbeta än jungfruligt material.
- Geometrin på formsprutade komponenter kan skilja sig vid användning av återvunnen plast men var inte ett problem i de försök som utförts inom projektet.

Tester av de återvunna materialen och tillverkade komponenten visade att:

- De flesta av de testade återvunna materialen hade bra prestanda.
- Lackerbarhet och lackvidhäftning förväntades vara problematiskt då återvunna material används men var det inte.
- Olackerade ytor var mer känsliga för små föroreningar, då de var lättare att se.
- Blåsor efter fukttest observerades för något av de återvunna PP materialen.
- PVD-ytbeläggning är "spegelliknande" och även den minsta förorening blir synlig.

Projektet har visat att återvunnen plast i betydande mängder kan implementeras i fordonskomponenter, även i delar med höga krav på säkerhet och ytfinish.

Bakluckspanelen (Panel tailgate) och luckan för varningstriangel till Volvo Cars tillverkade av KB Components med 30 % återvunnen plast, är nu godkända för implementering i Volvo XC60. Batterilådan och locket med 30 % återvunnen plast är godkända för implementering i XC60 och XC90. A- och B-stolparna för Volvo Cars med 50 % återvunnen plast godkändes i alla tester men kommer inte att implementeras då de är säkerhetskritiska komponenter. Återvunnen plast är också implementerad i stötfångare och anslutande delar som tillverkas av Plasman. Komponenter för Volvolastbilar, stötfångarhörn och dörrförlängare har framgångsrikt producerats av Plasman och testats med goda resultat och även SID panel inboards av IAC.

Arbetet framåt är att implementera de återvunna materialen i bil- och lastbilskomponenter. Den största utmaningen är att hitta tillräckligt med återvunnen plast av rätt typ och kvalitet för att skala upp och implementera i alla fordon. Ökad efterfrågan på återvunnen plast förväntas leda till ökad återvinning av plast från fordon till nya fordonskomponenter.

3.Introduction and background

3.1. Background

Plastic has many advantages in vehicles such as low weight which saves fuel, large design possibilities, low manufacturing costs and corrosion resistance. A car consists today of about 10 % plastic and the amounts of plastic increases. In Europe, the automotive industry uses about 10 % of the plastics produced[2]. Almost all the plastics are produced from fossil sources, crude oil. At end-of-life of the vehicles are usually shredded and the materials are mixed, which make recycling of the plastics very challenging. It is a big loss of economic value and resource when cars are shredded and the plastics get contaminated. It is important to increase the resource efficiency of plastics in vehicles; dismantle and recycle plastics from vehicles and to use recycled plastics in new vehicles.

This project has been focusing on the use of recycled plastic in new vehicles. The project contributes to the environmental goals of sustainable consumption and production as well as sustainable and efficient management of natural resources.

According to the EU's plastic strategy, 10 million tonnes of recycled plastics should be used in 2025[3], thus the automotive industry should use 1 million tonnes. 13 July 2023 EU announced the new End-of-life vehicles (ELV) Regulation[4] that should boost vehicle circularity while pushing ambitious recycled content targets.

Today the car manufacturers are using recycled plastic in some parts, but the recycled plastic represents only a small part of the total content of plastic in a car and it is mainly post-industrial waste (PIR) that is used. Volvo Cars is the car manufacturer with the most progressive strategy to increase the recycled plastic in the cars. By 2025, 25 % of the plastic in the Volvo cars should be recycled or biobased. To realize this, recycled plastic need to be implemented in many of the components that are viable and with high quality demands.

A Volvo car contains today about 125 Kg plastics and the plastic content increases in cars. The choice of plastic type used depends on the required component function, manufacturing specifications, desired aesthetics, price but also the recyclability of the plastic has become important.

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[2] https://plasticseurope.org/knowledge-hub/plastics-the-facts-2022/
[3] https://environment.ec.europa.eu/strategy/plastics-strategy_en
[4] https://environment.ec.europa.eu/publications/proposal-regulation-circularity-requirements-vehicle-design-and-management-end-life-vehicles_en

Polypropylene (PP) is by far the most common plastic type in the cars, both interior and exterior. Both PP homopolymer and copolymers are used, often impact modified, filled with talc or reinforced by glass fibers. Volvo Cars has the goal to use one polymer solution when possible and if possible, use PP based plastic in order to facilitate recycling of the plastic. Also, PC/ABS is commonly used in the exterior parts and in interior parts that requires high stiffness, as the A- and B-pillars.

A Volvo truck contains about 500 kg plastics. As in cars, PP based plastics are most used, especially in the interior parts. Other commonly used plastics are PC/ABS in exterior parts, polyurethane (PUR) in seats, polyester (PET) in carpets, PVC in cables, polyamide (PA) etc.

In this project it was decided to focus on using recycled PP based plastic and PC/ABS plastic.

3.2. Purpose/goals

The main purpose of the project has been to enable implementation of high content recycled plastic in advanced components for cars and trucks. Reduced use of virgin plastic reduces the need to extract fossil raw materials for plastic production. The purpose was to validate recycled plastic in both interior and exterior components with high demands on visual properties, paintabilty and paint adhesion, dimensions, and mechanical properties.

Project goals:

- Find recycled plastic with suitable properties and good quality from stable sources in large quantities and reliable suppliers.
- Test methods and routines enabling quality control of recycled plastic quality.
- Knowledge how to upgrade recycled plastic too get the required properties.
- Tested and validated recycled plastic in 14 vehicle components.
- Verified the long-term durability (life time) of recycled polypropylene compounds used in two vehicle components.
- Demonstrated the recyclability of PC/ABS blends, virgin and recycled, in four cycles.
- Performed 3 case studies to find out the climate impact and economic impact of using recycled PP and PC/ABS based plastics compared to virgin plastics.

- Spread knowledge from project to the vehicle industry and others that want to use recycled plastic in advanced products.
- Contribute to create demand of high quality recyclate plastics that can be used in vehicles or other demanding plastic products.
- In long-term contributed to sustainable competitive vehicle industry in Sweden, with use of 25 % recycled plastic or more.

3.3. Project financing and parties

The project "Sustainable Vehicles with recycled plastics" (SVE-REP) has been financed by the strategic innovation program RE:Source with 3 million Swedish crowns and 4,3 million co-financing from project parties in form of inkind work.

Project partners and their roles in the project:

RISE has coordinated and managed the project. RISE contributed with LCA, material testing and method development, studies of upgrading recycled compounds, studies of recyclability and long-term properties etc.

Rondo Plast, Polykemi, ALBIS, MOCOM and Biesterfeld are material suppliers contributing with material searching and recycled plastic compounds of suitable quality. ALBIS is also a recycling operator (through WIPAG) that recycles plastics from the automotive industry. Rondo Plast/Polykemi contributed with compounding and upgrade the properties of the recycled plastics and with testing.

DOW Europé is also supplier of plastics and of various additives for upgrading recycled plastics and contributes expertise, additives, material and testing.

Plasman and KB Components are subcontractors to Volvo Cars and Volvo Truck and performed pilot-trials to produce components with recycled plastic. Plasman an KB Components set the requirements for the recycled plastics together with Volvo Cars and Volvo Truck. They planned, and performed the production trials, tested and validated components.

Volvo Cars and Volvo, the vehicle manufacturers in the project, contributed with setting the requirements of the components, performed testing and validate the produced components. They also contributed with monitoring news, ongoing activities and projects of interest.

In addition to the above partners, there was also collaboration with other suppliers of recycled plastics like Total, Sabic, Borealis and LG Chem. International Automotive Components (IAC) produced a component for Volvo Truck in recycled plastic and performed testing of the components. There has also been an exchange of knowledge with FFI project Sustainable vehicle interior, managed by RISE.

4. Performance

The work process and performance of the project is here described.

4.1. Work process

The project work structure was divided into six work packages (WP´s):

WP 1. RECYCLED PLASTIC

The work covered searching for recycled plastic raw materials of right type, quality and in large enough quantities. It covered componding and upgrading of the recycled plastics du achieve the right properties. And also testing routines, method development and characterization of recycled plastic compounds. The work was mainly conducted by the material suppliers; Rondo, Albis, Mocom Biesterfield, RondoPlast, DOW, by RISE and the component manufactures Plasman and KB Components.

WP2. PILOT TRIALS

Recycled plastics were tested in several car and truck components. KB Components, Plasman and IAC planned and performed the test-runs. The work was carried out in close collaboration with Volvo Cars and Volvo Trucks who performed most of the component testing and validation. The first step was to identify suitable components, then select recycled plastics of suitable quality, produce samples for testing, produce component, test components, test printability and assembly. Validate the components. This work was repeated for several components and materials until the components were successfully approved.

WP3. LONG-TERM PROPERTIES AND RECYCLABILITY

- Long-term properties of recyclate plastics were tested at RISE. The recycled PP materials used in two of the car components were heat-aged, together with corresponding virgin standard plastics. Heat-ageing was performed at three temperatures and service life was extrapolated for the aged materials.

- Climate cycling were performed on painted PC/ABS plaques and components to evaluate the adhesion of the paints. The work was performed by RISE mainly and involved also Volvo and Plasman.
- Repeated recyclability was tested for recycled and virgin PC/ABS compounds. These was performed by RISE mainly but also involved Volvo and Plasman.
- Long term testing of components in two Volvo cars and a Volvo truck are performed and is still ongoing.

WP4. STANDARDS AND REQUIREMENTS

WP4 evaluated how the components with recycled plastic meet the requirements of the vehicle industry, what deviations there are and assessment of risks. Obstacles in the requirements specifications for the use of recycled plastic were examined, which deviations could be approved. Volvo Cars and Volvo Truck setts the requirements on the components and managed the assessments.

WP5. ENVIRONMENTAL SYSTEM ANALYSIS AND COST ESTIMATIONS

WP5 was carried out to ensure that the environmental impact is positive when changing raw materials and economically sustainable. The work was performed by RISE. The project partners and collaborators contribute with data.

WP6. PROJECT MANAGEMENT AND DISSEMEINATION OF PROJECT RESULTS

Annika Boss at RISE, Dept Polymeric Materials and composites, was project manager, followed up the project and reported to the Energy authority. This work package included also disseminated of project results.

4.2. Recycled plastic

The work of WP1 was to invent secondary plastic raw material of the right type, quality and quantity for use in vehicle components. Quality controls are carried out to ensure homogeneity and purity of the materials.

Upgrading the materials is often required to adapt the properties to the automotive industry's requirements specifications. This may mean that material qualities are mixed or that additives are added to improve properties such as impact strength and durability.

The recycled plastics tested and selected for pilot test are named in part 4.3.

Plastics
Polypropylene plastic (PP) is the most used plastic in cars, in interior and exterior parts, and also one of the most used plastics in trucks. The PP plastic can be homopolymer och copolymer. Talc filler is commonly used and if reinforcement is needed, glass fibers are common. A vehicle is exposed to a wide range of temperatures during use and all components must perform at both high and low temperatures. Thus, impact modifiers are usually added to the PP plastic. Volvo Cars has the strategi of using one polymer solution in car components and use PP based plastic, when possible, to facilitate material recycling from cars but also because secondary raw material of PP is more available than most other plastics used in vehicles.

Polycarbonate/Acrylonitrile Butadiene Styrene plastic (PC/ABS) is also used in many parts of the cars and trucks. PC/ABS is more rigid than PP and is used in components like pillars and exterior panels.

The project group decided to focus on use of recycled PP and PC/ABS in this project.

Sources of recycled plastics
There are two kinds of recycled plastic, post industrial recycled plastic (PIR), e.g. manufacturing scrap, and post consumer recycled plastic (PCR). The PIR plastic is usually well known in composition and properties. The PCR plastic can vary in quality and properties.

Most of the recycled plastic used today in the automotive industry is PIR, since the quality is high and properties well known. However, the volumes of PIR materials are very limited and to make a real change to a circular reuse of plastic from end-of-life products, should be used as raw material in new components. But it is more challenging to use PCR plastic. However, there are ways to improve the properties of PCR plastics and mixing with virgin plastic is most common. Additives like impact modifiers, compatibilizers, stabilizers, antioxidants and fillers can also be used to improve the properties of the recycled plastic.

Recycled PP PIR plastic is available as scrap from manufacturing of vehicle components and of other industries with PP scrap. Recycled PC/ABS PIR plastic was only found from one supplier. Recycled PC PIR is available and can be blended with ABS to PC/ABS blends that can be used in vehicle components. The ABS is then virgin.

A big source of PCR plastic could be scrapped cars but the recycling of plastic from cars are still very limited. The amount of plastic in the waste stream from scrapped cars (ELV) in Sweden is estimated at 41 000 tonnes/year[5]. Several studies have shown that parts of the plastic can be dismantled and used for mechanical material recycling, but currently it is not done in Sweden for financial reasons. And there is still no large supply of recycled plastic on the international market from vehicles. Axion in the UK is the largest recycling player producing recycled plastic from ELV. Recycled ABS and PP based plastics are sold by several recyclers. Recycled ABS mainly comes from the recycling of waste from electronic equipment (WEEE) and in some cases from End-of-Life vehicles (ELV). Commercial material grades from some of the recyclers have been tested at RISE. Process properties, mechanical properties and thermal stability were tested. Chemical analyzes were also carried out to ensure that the materials comply with the REACH and RoHS directives.

Packaging is the largest stream of plastic waste. The collection and sorting rate is high. Sorted PP from packaging is one of the interesting, recycled material streams to evaluate for use in vehicle components. However, the requirements on the plastics used for vehicle components are high and usually requires impact modifier, additives and fillers that upgrade the material.

The material suppliers performed monitoring suitable recyclate materials and produced plastic compounds that should fulfill the specifications from the component manufacturers. Plasman and KB Components have investigated recycled compounds from several material supplier.

Material analysis

The recycled plastics selected for pilot trials were tested and evaluated at RISE. The test samples were injection moulded. The method used were:

- MFR, Melt flow rate (ISO1133)
- DSC, Differential Scanning Calorimetry. Analyse melt temperature (°C) and crystallinity ΔH (J/g) of PP materials and to analyse contamination of other polymers (ISO 11357)
- OIT, Oxidative Induction Time of PP materials (ISO 11357-6)
- TGA, polymer and filler contents (ISO 11358)
- FTIR-analysis (Infrared spectroscopy), chemical composition analysis

[5] Naturvårdsverket (2022), Kartläggning av plastflöden i Sverige 2020, online: https://www.naturvardsverket.se/om-oss/publikationer/7000/978-91-620-7038-0/

- Tensile testing, tensile strength, elongation and E-modulus (ISO 527)
- DMTA, Dynamic Mechanical Thermal Analysis, Three-point flexural testing, was used to measure the mechanical properties in a wide temperature range from -90°C to 100°C (ISO 178).
- Impact testing:

  Both pendulum impact testing and falling dart drop was used to evaluate the impact properties of the materials. Pendulum impact testing was performed according to ISO 179. Specimen were machine notched. For dart drop impact test an injection moulded test plate 10 x 10 cm and 2 mm thick was used.

  Impact testing could be a relevant test in material qualification for automotive applications since a vehicle may be exposed to impact for example in a crash accident. Therefore, we have used both the commonly used and standardized pendulum test, Charpy (ISO179) and dart drop test. Testing at RISE was performed at room temperature, 23°C, 50% RH and at approximately -30°C.

  The instrument used for dart drop impact testing at RISE was designed and produced by RISE (former SICOMP) and is mainly used for testing of composites. Figure 1 shows the instrument used for the tests. Sensors measure the break energy and temperature for each sample.

Figure 1. Dart drop test equipment at RISE.

Upgrading recycled plastic

Additives are usually required that adapt/upgrade the properties of the recycled plastic compound so that it can match the requirements of the automotive industry. A study was performed within the project, involving DOW, Rondo Plast, Polykemi and RISE, to investigate the possibilities to improve the impact strength of PCR PP. See the Project Report "Impact modified Polypropylene for automotive applications" in Appendix 9.1.

"Engage" compatibilizers and impact modifiers are manufactured by DOW and are designed for use in recycled polyolefins plastics. Impact properties particularly at low temperatures (-30°C and below) can be improved by the "Engage" additives according to DOW. Also cycle times in the injection moulding process may be shortened as "Engage" facilitates crystallization. The modifier consists of random olefin copolymers and the amount of comonomer can be varied. Increased comonomer increases the impact resistance of the product and decreases the crystallinity. Rondo Plast had also an impact modifier that was tested. Table 1 below summarizes the four tested materials. The plastic compounds were manufactured by Rondo Plast and consist of a quite low grade, recycled PP as matrix material. The PP is 100 % recycled and consist of 20 % talc filler. 10 % of modifier was added.

Sample	Information
Reference sample RT20	PP and 20 % talc. PP mix Homo and co-polymer, 100 % recycled material. A mix between 2/3 industrial scrap and 1/3 post consumer scrap. No modifier added.
IM1, impact modifier (Rondo)	Frequently used modifier at Rondo, 10 % added
IM2, Engage 11527 (DOW)	10 % added, Melt Index 15. Engage is easily distributed in PP matrix. Act as compatibilizer for PE contaminants in PP materials. The additive is PE based. Allow shorter cycle times for injection moulding since shorter cooling times are needed.
IM3, Engage 11567 (DOW)	10 % added, Melt index 1. Same properties as above, except melt index and flow properties.

*IM = Impact Modifier

Table 1. Additives tested.

The properties of the modified blends were tested at RISE and some testing were also performed at RondoPlast and DOW.

Quality assurance
SEMAT/PSE is a Supplier Auditing tool[6], that Volvo Cars plan to implement for suppliers. The tool is used to assess and improve suppliers. Requirements to quality assure recycled plastic materials are defined in a new PSE: Recycled Plastic material. Suppliers will be responsible for sourcing the recycled material suppliers and quality assure the recycled material suppliers. The requirements in the PSE are defined accordingly. Sampling, material batch analysis, analysis methods and documentation are defined.

4.3. Pilot trials

KB Components and Plasman have planned and performed several pilot trials with recycled plastics in interior and exterior components. 6 test runs for Volvo Cars have been performed by KB Components. 13 test runs for Volvo Cars and 7 test runs for Volvo Truck have been performed by Plasman. 3 test runs for Volvo Truck was performed by IAC. And test plaques were also produced of recycled plastic for paintability testing, climate cyclings and paint adhesion testing.

The components to produce with recycled plastic were selected and the recycled materials to use. The components were produced and the process performance was evaluated. Properties of the components were tested and validated according to Volvo Car´s and Volvo´s standards and technical requirements. According to the scheme in figure 2.

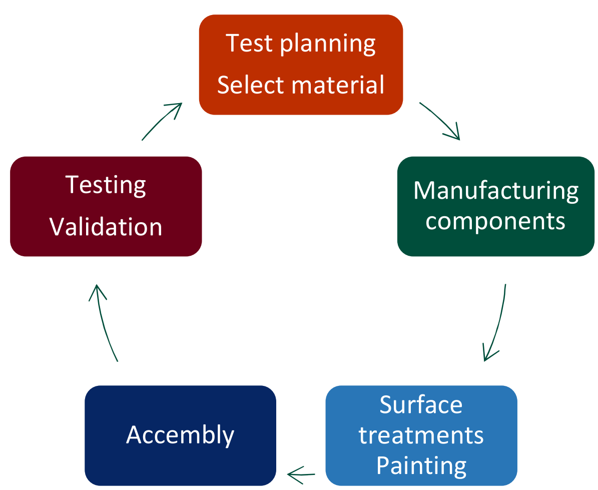

Figure 2. Pilot trials plan.

[6] https://www.volvogroup.com/content/dam/volvo-group/markets/master/suppliers/our-supplier-requirements/SQAM-2019.pdf

4.3.1. Components for Volvo Cars

Components produced by KB Components

Four interior components for Volvo Cars have been produced by KB Components with recycled plastic and two components located under the hood. The project wanted to evaluate the use of recycled plastic in large interior parts with demands on volatile emissions and components with high demands on the mechanical properties like for the A- and B-pillars. Recycled plastic was also tested in two components with high mechanical demands under the hood, Battery Box and Lid. Processability performance and product control; weight, dimensions and appearance were evaluated by KB Components. RISE analyzed the recycled materials. Volvo Cars performed the component testing.

Panel Tailgate

Battery box

Battery lid

Panel Tailgate with
Hatch warning triangle

Figure 5. A-pillar

Figure 6. B-pillar

Figure 3. Components produced by KB Components

Panel Tailgate and Hatch Warning Triangle

The Panel Tailgate and Hatch Warning Triangle were injection moulded in recycled PP with 15 % talc (Omicron) from Biesterfield containing 30 % PIR.

Battery Box and Lid

The Battery Box and Lid were injection moulded in recycled PP with 30 % LGF from Biesterfield containing 50 % PIR.

A and B pillars

A and B pillars were injection moulded in recycled PC/ABS from Biesterfield containing 50 % PIR. The pillars were then laminated with PET textiles.

Components produced by Plasman

Plasman produced 13 injection moulded exterior components for Volvo Cars and also some plaques for paintability testing. The main focus has been to evaluate recycled plastics in components with high demands on appearance and paintability, dimension stability and mechanical properties. See test runs of car components in Table 2. Processability performance and product control; weight, dimensions and appearance were evaluated by Plasman. RISE analyzed the recycled materials. Plasman and Volvo Cars performed the component testing.

Trials	Material	Supplier/grade	Recycled content
Undershield XC90	PP TD20	Crashed bumper	100% PCR
Front bumper cover XC90	PP E/P TD15	Borealis	70% PCR
Front bumper combined Bracket XC90	PP GF30	Borealis	100% PCR
Front bumper fender Bracket XC90	PP TD20	Borealis	30% PCR
Front fender bracket XC40	PP TD20	Rondo	30% PIR
Fog light hatch V60	PP/TPO TD20	Rondo	40 % PIR
Rear trim list V60 CC	PC/ABS	Rondo	30% PIR
Rear insert V90	PP E/P TD20	Total	25% PCR
Roof spolier XC90	PP E/P TD30	Total	20% PCR
Undershield XC90	PP TD20	Rondo	50% PCR
Front bumper cover V60	PP E/P TD15	Borealis	25% PCR
Sillmoulding XC90	PP TD20	Total	30% PCR
Sillmoulding XC90	PP GF30	Total	30% PCR

Table 2. Test runs performed by Plasman for Volvo Cars.

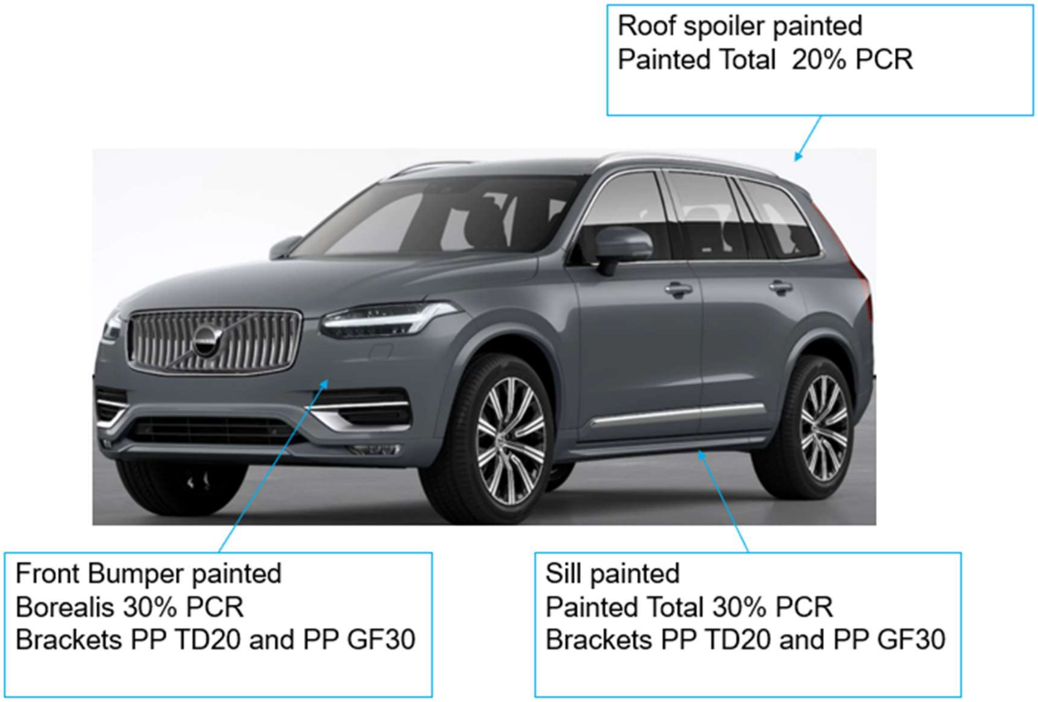

Figure 4. Components tested with recycled plastic.

4.3.2. Components for Volvo Truck

The project has been focusing on both exterior and interior components for trucks, exterior parts in collaboration with Plasman and an interior component in collaboration with IAC. Since visible and painted parts are considered challenging when using recycled plastic (sometimes also when using virgin plastic) the paintability and paint adhesion have been studied.

Front fender and front fender extension

A test run was performed to produce front fender extensions for Volvo trucks early in the project. The material used was a recycled PC/ABS grade from Mocom. Some problems were noted and a new test run was planned but could not be performed due to capacity issues in production. Therefore, tests were performed on plaques and other components produced with recycled PC/ABS materials.

Figure 5. The front fender marked on the Volvo truck.

Paintability tests on plaques

Two different recycled grades of PC/ABS were tested:

- Mocom with mix of 70 % recycled mix of PCR and PIR
- Rondo Plast with 50 % recycled PIR

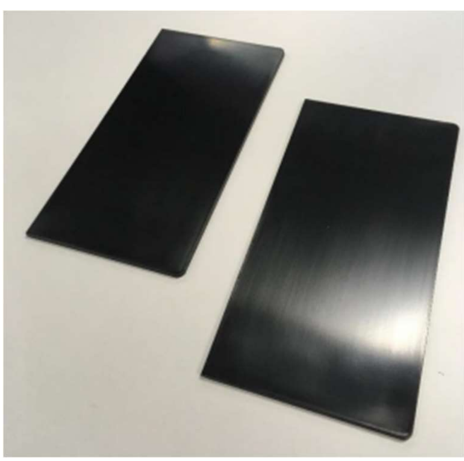

Figure 6. Injection moulded plaques of recycled PC/ABS for printability testing.

The injection moulded plaques were produced by Plasman and the painting and testing were performed in Volvo Trucks paint line in Umeå.

Different pretreatments were tested, different paints (PVD) and top coatings were tested. Appearance of painted plaques, colors, film thickness, resistance to cleaning agents, moisture resistance, adhesion at room temperature, in wet conditions and cold were tested. RISE performed climate cyclings and paint adhesion testing on plaques and on components, see section 4.5.

Bumper Corner

A test run to produce bumper corners for Volvo Trucks was performed by Plasman. The run was performed with recycled PC/ABS with 50 % recycled PIR material from Rondo Plast. The components produced were painted at the Volvo Truck paint line in Umeå.

The process performance of the three recycled material grades in the component, the paintability and visual appearance have been tested. Full component testing is ongoing.

Figure 7. The bumper corners marked on the Volvo truck.

Door Extension Extender

The door extension extenders are two components, the 2K part of medium density polypropylene (PP MD) with TPV sealing welded to a second 1K part in the same PP MD. The test run was performed at Plasman with three different grades of recycled PP from RondoPlast. TR-testing on the components was performed by Plasman. Scratch resistance, appearance testing, sun simulation and climate cycling were performed by Volvo. Field test in cold climate is ongoing, field test in hot climate is planned for summer 2023 and field test long term is ongoing.

Figure 8. Door extension extenders location on the Volvo truck.

Figure 9. Door extension extenders, K1 part and K2 part.

SID Panel Inboard

A test run was performed at IAC of SID panel inboards for Volvo trucks. It is an interior component on the dashboard of the truck, see location in figure below. Recycled PC/ABS grades from two suppliers were tested in the component; LG Chem with 50 % PCR and RondoPlast (same grade as tested in the bumper corner). The injection moulded parts were painted at IAC, painted with both texture and flakes respectively.

Figure 10. SID Panel Inboard location on the Volvo truck.

Figure 11. SID Panel Inboard.

Part information:

- Part weight: 250 g
- Current material: PC/ABS Cycoloy.
- Higher temperature requirements than parts in general due to position on top of IP
- Waterborne paint with both texture and metallic flakes

The processability with the recycled materials and paintability were evaluated by IAC. Surface quality, adhesion test with crosshatch, welding of deco trim, scratch resistance and appearance were tested and evaluated by IAC and Volvo.

4.4. Accelerated ageing and life time prediction

Compared to other materials, for example metals and wood, plastics is still a quite “young” material and many plastics materials have not yet been in use for 100 years. Use of plastics during long period of times and experience from use of recycled plastic in long-term applications is limited. Therefore, we wanted to predict the service life of recycled PP in automotive components and compare to virgin materials life to avoid component failure before a vehicle reach its end-of-life.

Arrhenius equation[7] states that chemical reaction rates increase when the temperature increase and this fact is used in lifetime predictions for plastic materials. Most polymers degrade by oxidation i.e. reaction with oxygen present in the air. The polymer degradation propagates by a large number of chemical reactions and is not yet fully understood. The complex degradation makes service life prediction for plastics an approximation and it is important not to over-estimate the durability. One of the degradation reactions is cleavage of the polymer chains which leads to deterioration of the mechanical properties, the material becomes more brittle. The increased brittleness is observed as decrease of strain at break and decreased impact strength. In a product the brittleness of the material may cause failure of the product.

Use of recycled material is believed to increase the degradation rate of plastic materials, due to contaminations and degradation products from their previous service life.

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[7] https://www.britannica.com/science/Arrhenius-equation

However, antioxidants are added in plastic material formulations to protect the polymer from degradation and as long as the antioxidants are active[8].

In calculation of activation energy and life-time prediction of a material by using Arrhenius equation, accelerated ageing is performed at three elevated temperatures. A material property for example strain-at-break is measured after different exposure times and an end-of-life criterium is set. Usually, 50 % reduction of the initial value of a material property in our case strain-at-break, is set as end of life.

The material deterioration can be described by a differential equation together with Arrhenius equation and by mathematic operations an Arrhenius plot is created, see figure 12.

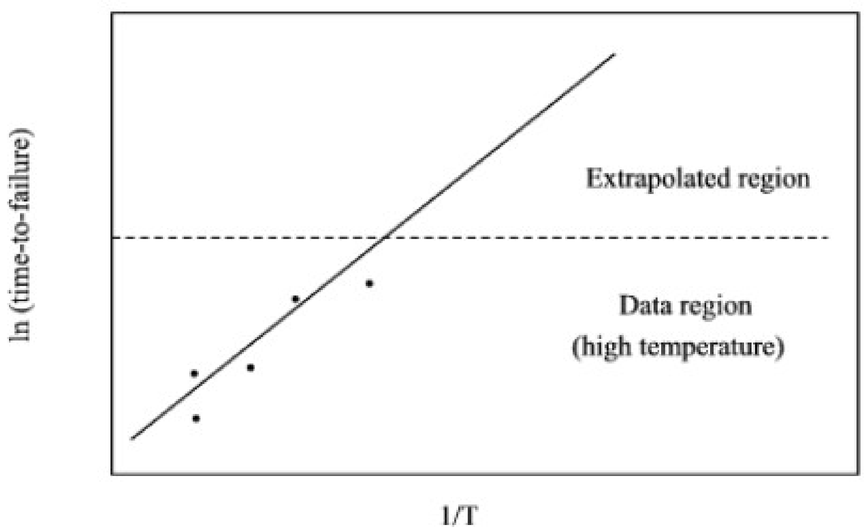


Figure 12. Arrhenius plot - the activation energy allow extrapolation to longer service life for a material.

The activation energy for the investigated material is calculated from the slope of the Arrhenius plot and can be used to extrapolate life-time of a material at ambient service temperature.

Since ageing at three temperatures and Arrhenius calculations are time consuming a “rule of thumb” stating that an increase of 10°C increase the degradation rate by a factor 2-3.

[8] Polymer Degradation and Stability 203 (2022) 110082” Re-stabilization 30 years of research for quality improvement of recycled plastics review” Pfaendner R.

This corresponds to a calculated activation energy of approximately 70 kJ/mol and mainly virgin materials. This is true if the reaction rate increase is linear. At very high exposure temperature the reaction rates for polymer degradation are probably not linear and therefore too high ageing temperatures is not recommended to use.

An accelerated ageing study was performed for PP materials tested in the components; Panel tailgate produced by KB Components and Fog light cover produced by Plasman. PP materials containing recycled PIR and virgin material references were tested in this study. The purpose was to study the long-term properties of PP materials containing recycled plastic and to predict the service life's based on Arrhenius extrapolations.

Materials

The Panel tailgate materials were supplied by KB Components:

- PP virgin Omikron from Biesterfield
- PP recycled Omikron from Biesterfield containing 30 % PIR

The Fog light cover materials supplied by Plasman:

- PP virgin Daplen material from Borealis
- PP recycled REZYcom material from Rondo Plast with 30 % PIR

The test samples were injection moulded.

Accelerated ageing

The dumb-bell shaped samples were placed in cabinet ovens, set to three different temperatures: 90 °C, 100 °C and 110 °C. See Figure X. Three temperatures were used to be able to perform extrapolations of service life time of the studied materials.

Figure 13. Test samples hanging in cabinet oven.

Samples were removed from the cabinets at certain intervals whereafter the thermal stability and tensile properties were tested according to the tests described below until the chosen end-of-life criterion of the materials had been reached. For this study the chosen end-of-life criterion was that the elongation at break had decreased more than 50 % compared to the value measured on new material. When the criterion was reached for a material aged at a certain temperature the ageing of that material at that specific temperature was stopped.

Tensile testing
Tensile testing was performed on injection moulded dumb-bell shaped test specimen according to ISO 527- 1A.

Oxidation induction time
Two samples were taken from each material and the oxidation induction time was measured according to the procedure in SS-EN ISO 11357.

Calculation of activation energy and Life-time prediction
The total ageing time for reaching the end-of-life criterion at each used temperature was used for the calculation of the activation energy and the life-time calculations. The total ageing time for the studied materials has been very long and unfortunately the end-of-life criterion was not reached at 90 °C within the time frame of the project. Hence, only two values had to be used for the calculations for each material. As the recommendation is to use at least three temperatures for these kinds of calculations the results have to be seen as preliminary.

4.5. Climate cycling Painted PC/ABS

The plaques were injection moulded by Plasman. Volvo painted the plaques in Umeå. SID trim panels for trucks, see Figure 15, were produced and painted by IAC. Plaques and SID trim panels were painted and tested.

Placques

- PC-ABS Reference SABIC
- PC-ABS Rondo Plast/Polykemi
- PC-ABS Mocom/Albis Altech

Profiles (SID panels inboard in 3 materials, painted)

- Ref
- Rondo
- LG Chem

Figur 14. Placques

Figur 15. SID panel inboard profile

Performance

Climate cycling was performed according to Volvo Trucks standard, but in 30 cycles instead of 10 cycles (which is standard), see the cycle in Figure 16. The climate cycle was performed in a Weiss WK600 Climate cabinet. The samples were tested after 0, 20 and 30 cycles.

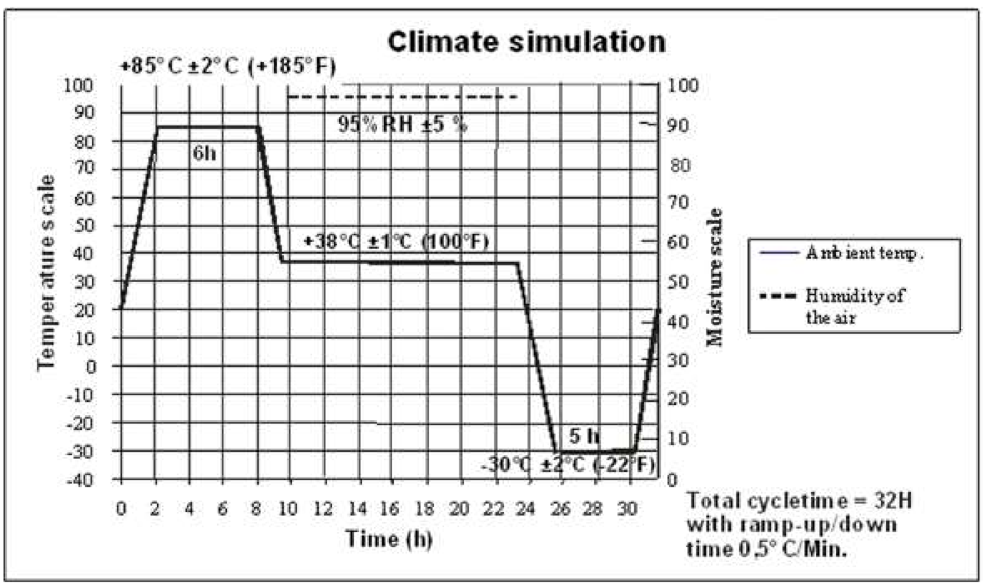


Figure 16. Climate cycle program.

RISE performed a visual examination and paint adhesion measurements according to SS-EN ISO 4624:2016 (Paints and varnishes – Pull-off test for adhesion)

IAC performed adhesion, cross-cut test, according to STD 423-0012

4.6. Repeated recycling of PC/AB

To investigate the recyclability of PC/ABS plastic a study on repeated recycling was performed.

Materials

The reference material used in this study was SABIC CYCOLOY XCY620S and the post-industrial recyclate (PIR) stream used was R85HCL-LB from RondoPlast. The PIR material had a PC/ABS ratio of 73/27 out of which 50 % of the PC came from post-industrial recycled source while the ABS was from virgin sources.

Performance

The studies were carried out using two different methodologies - the first study was a 'reprocessing study' where the PC/ABS was subjected to repeated compounding and the second study was an 'accelerated ageing study' where PC/AS was subjected to reprocessing and ageing. In the first study the material was compounded 6 times and after each compounding step some pellets were used to injection mould test bars for characterization while the rest of the material was re-compounded, as shown in Figure 17a. In the accelerated ageing study, the material was compounded, and injection moulded into test bars. These test bars were aged for 1000 hours at 90 °C after which they were grinded and compounded again. This cycle was carried out three times and the samples were collected for characterization after each injection moulding step and after each ageing step, see Figure 17b.

(a) (b)

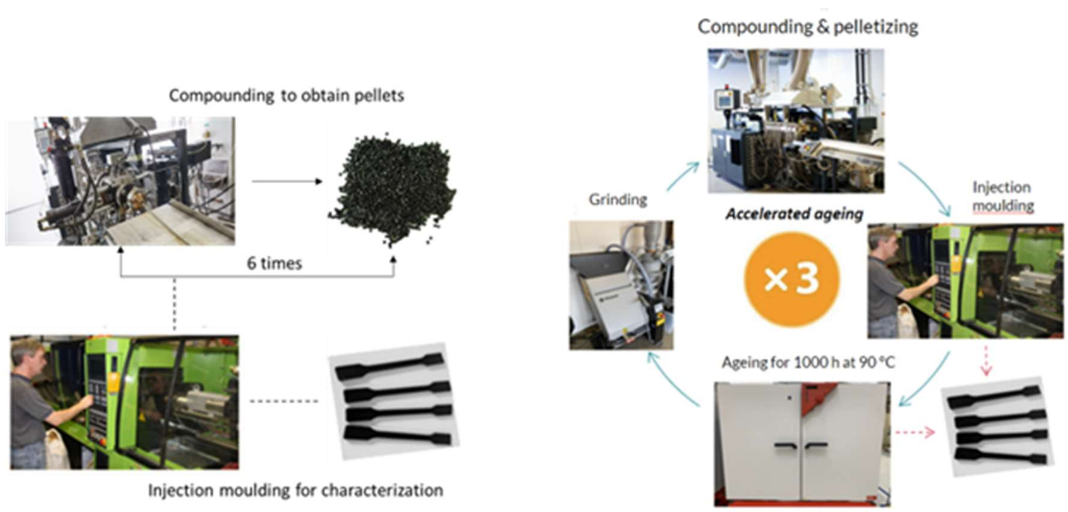


Figure 17. The study methodologies used for the PC/ABS material: (a) Reprocessing study and (b) accelerated ageing study.

The PC/ABS was compounded using a Coperion ZSK 26 K co-rotating twin-screw extruder and injection moulded using an Engel ES 200/110 HL-V Injection moulding-machine into test bars.

Testing

- Tensile testing was performed according to ISO 527.
- Impact testing was performed according to the Charpy test standard with notched specimen according to ISO 179.
- Melt flow Index (MFI) or Melt flow rate (MFR) was performed according to MFI - ISO 1133 at a temperature of at 260 °C using a 5 kg weight.

4.7. Long term testing in vehicles

Two Volvo test cars are running since March 2022 with Panel tailgates in recycled Omicron from Biesterfield, a courier's van and a transport van for transport of quite heavy goods. The tailgates were inspected after one year in March 2023.

A Volvo truck with the door extension extenders produced in recycled polypropylene is running since September 2022.

The vehicle tests will go on for three years.

4.8. Standards and requirement

According to Volvo Cars and Volvo Truck the test methods and technical requirements for the components are same whether the component is made with recycled plastic or not. But deviations are assessed from case to case and are sometimes accepted.

4.9. Environmental and Economic impact

The use of recycled plastic, instead of virgin, saves greenhouse emissions and reduces the climate impact. It is also important that it is economically sustainable to use recycled plastic. It is therefore important to look both at the environmental and economic implications of using recycled plastic. The environmental study was performed by Birgit Brunklaus, LCA expert at RISE. The full study is compiled in the project report "Climate impact of recycled and fossil-based plastic for the automotive industry" is attached in Appendix 3. The economic impact of using recycled plastic was not calculated, since the economic data is confidential and not available. The economic impact could only be estimated.

Purpose and scope

The scope of the environmental study was to get an overview of the climate footprint of using recycled plastic in the automotive industry, including the most important plastic group, such as PP and PC/ABS. The goal of the study was to find out how much climate footprint could be reduced with changing from fossil to recycling plastics used in the automotive industry, including several different recycling rates depended on the quality aspects of the components. The functional unit was kg CO2e per kg plastic.

Method

Life cycle analysis (LCA) based data and methodology were used to measure the climate impact from the recycled and fossil-based plastic. The LCA methodology follows the ISO 14040-44:2006 standard.

Data collection

The data collection for the environmental data was performed by RISE and the material suppliers, RondoPlast, Albis, Mocom, Borealis and Sabic. The calculations were externally reviewed prior to this project. The results were compared between the companies and results were also compared with earlier studies in the literature (and eco-profile data).

The studied recycling rates included in this study are between 25%, 30%, 50% and 70%. The recycling plastic are based on PCR and PIR. The studied plastics were PP (including TPE and PA6) and PC/ABS. The materials and processes included are based on waste to factory gate (cradle to gate).

The data included in the SVEREP project are among others the bumper for Volvo Cars and the trim panel and front fender for Volvo trucks. In total 9 different recycled plastic granulate and compounds with different qualities are included in the environmental study. Table 3 shows the component, plastics and suppliers included.

Bumper for Volvo Cars 	Plastic granulates and compounds (PP with filler): - Rondo Plast (PP, TPE) - Mocom (PA6) - (Borealis, not included) - (Instead SABIC from literature, chemical recycling) Components produced by Plasman.
Front Fender Volvo Truck 	Plastic granulates and compounds (PC/ABS): - Rondo Plast (PC/ABS), only recycled PC, not recycled ABS (due to quality) - Mocom (PC/ABS), only recycled PC, not recycled ABS (due to quality) - SABIC (PC/ABS, virgin), recycled/fossil PC/ABS Components produced by Plasman

Table 3. Components and plastic granulates and compounds included.

Processes included

Figures 18 and 19 show the general flow charts and the system boundaries for PP and PC/ABS. Included processes are the raw materials, the recycling process, and the production to the gate (FU=kg plastic granulates). Data are collected from the plastic granulate producers, the recycling processes and production sites located in the European Union, such as Germany or Netherlands. Not included are the transport to the component production, and the final transport to the Volvo cars/Truck in Sweden.

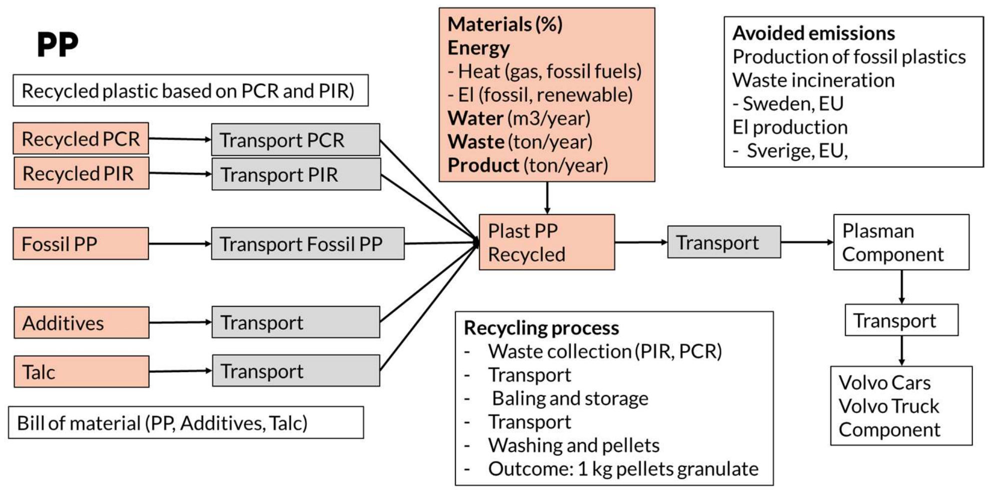


Figure 18. General Flow Chart and System Boundaries for PP (Recycled and Fossil). Included processes are the raw materials (Bill of material), the recycling process, and the production (gate). Not included are the transport after the gate, the component production, and the transport to Volvo Cars/Truck.

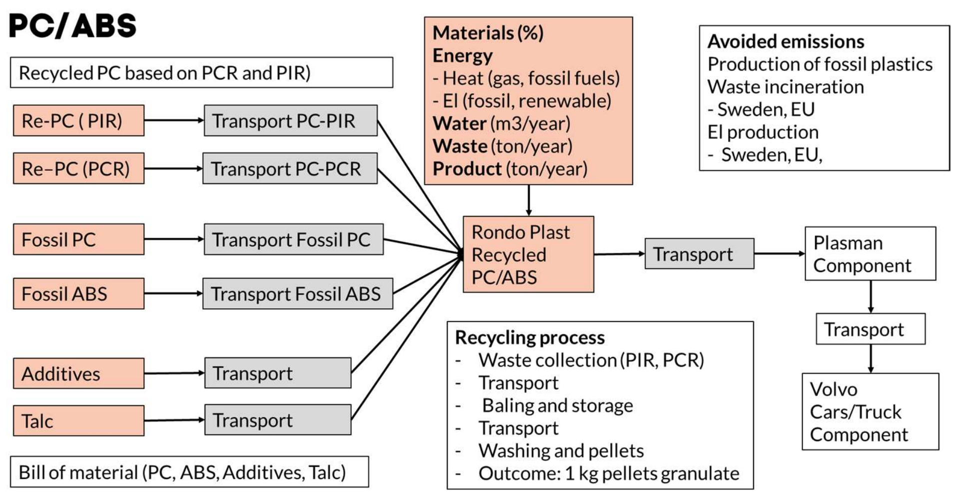


Figure 19. General Flow Chart and System Boundaries for PC/ABS (Recycled and Fossil). Included processes are the raw materials (Bill of material), the recycling process, and the production (gate). Not included are the transport after the gate, the component production, and the transport to Volvo Cars/Truck.

5. Results and discussion

5.1. Recycled plastic

The thermoplastic most used in the Volvo cars and Volvo trucks is PP (homo- and copolymers), often with additives like impact-modifiers, talc, glass fibers. PC/ABS is also used in a large number of components, especially for the trucks. Thera are also demand on other plastics like polyamide (PA), PET etc. but in the project group we decided to focus on PP and PC/ABS. Large volumes of recycled plastics are needed for the automotive industry. As an example, Plasman need annualy volumes of 300 ton per product (big component).

Recycled PP and PC/ABS plastic from different sources and suppliers have been investigated, analyzed and evaluated. The recycled plastic sources av been both post industrial (PIR) scrap and post consumer (PCR). Sources of PP based PCR plastic have been packaging, film, vehicles and PP plastic from hospitals. For PC/ABS, PC was from PIR and ABS from virgin source.

Material composition and properties of the recycled plastics selected were analyzed at RISE. The analysis results were reported to the manufacturers and material suppliers involved in the test runs. The full grade names of materials and material composition were in some cases confidential and is therefore not included in the report. However, material information and tested material properties can be available from the suppliers.

The study performed to upgrade recycled PP based PCR plastic with additives is attached this report in Appendix 1, “Project Report, Impact modified Polypropylene for automotive application”.

5.2. Pilot trials

5.2.1. Volvo Car components

Components produced by KB Components
The components were tested and validated by Volvo Cars. The results are presented below.

Panel tailgate
Supplier: KB Components
Vehicle: XC60
Tested in: Vehicle fixture and vehicles
Tested according to: TR 33686284 Luggage trim
Material: Two PP prime and one PP recycled, 30 % PIR

Figure 20. Panel tailgate with Hatch warning triangle.

Tests	Results
Short term heat, 100°C, 6 hours	Approved
Long term heat, 90°C, 1000 hours	Approved
Impact test 5J -30°C	Approved
Appearance approval	Approved
Interior emissions	Approved
Transport vehicle test, 37000-41000 km	Approved

Table 4. Test results Panel tailgate with Hatch warning triangle.

Battery Box and lid
Supplier: KB Components
Vehicle: XC60/XC90
Tested in: One car body fixture
Tested according to: TR 31849501 Engine bay component
Material: PP + PP LGF, recycled 30 % PIR

Figure 21. Battery box on car body fixture.

Figure 22. Battery lids.

Tests	**Results**
Short term heat, 130°C, 100 hours	Approved
Long term heat, 110°C, 1250 hours + Impact 1J -30°C	Approved
Climate change, -30°C 4 hours -> 75°C 4 hours -> 38°C/95% RH, 16 hours, 20 cycles Impact test	Approved

Table 5. Test results for Battery Box on car body fixture.

A and B Pillars

Supplier: KB Components

Vehicle: XC60

Tested in: One car body fixture for B-pillar, A-pillar tested without fixture.

Tested according to: TR 33686284 Pillars trim

Material: B-Pillar upper – PC/ABS recycled 50 % PIR, Charcoal textile
A-Pillar upper PC/ABS recycled 50 % PIR, Blond textile

Figure 23. A and B pillars.

Tests	Results
Short term heat, 95°C A-pillar/85°C B-pillar, 6 hours	Approved
Climate change, -30°C 4 hours -> 75°C 4 hours -> 38°C/95% RH, 16 hours, 10 cycles Impact test	Approved
Ageing in Humidity, high 70°C/55% RH, 1000 hours	Approved
Ageing in Humidity, low 38°C/95% RH, 1000 hours	Approved
Impact test, 1J -30°C	Approved
Interior emissions	Approved
Adhesion tests textile/carrier	Approved with remark
Long term heat, 85°C A-pillar/80°C B-pillar	Approved
Flammability	Approved
Long term heat inflatable curtain, 95 °C A-pillar/ 85°C B-pillar, 3000 h	Approved
Inflatable curtain test	Approved

Table 6. Test results A and B Pillars.

Interior emission tests	Results
Volatile organic components (TVOC C6-C16)	Approved
Specific substances	Approved
BTEXS (Benzene, Toluene…)	Approved
Aldehydes	Approved
Odor test	Approved
Fogging (85°C)	Approved
TVOC (Results in Tables below)	Not approved /Approved
Specific substances/BTEXS/Aldehydes/odor test/fogging	Approved

Table 7. Emission results A and B pillars.

	Requirement for Pillars [μg/m³]	1 Concentration (2kg) [μg/m³]	2 Concentration (2kg) [μg/m³]	3 Concentration (2kg) [μg/m³]	4 Concentration (2kg) [μg/m³]	5 Concentration (2kg) [μg/m³]	6 Concentration (2kg) [μg/m³]
TVOC	10 000	15 700	14 000	9 800*	540	330	770

Additional testing on material level according to VCS 1027,2749

	Requirement for PP and PC/ABS [μgC/g mtrl.]	1 Concentration (2kg) [μgC/g mtrl.]	2 Concentration (2kg) [μgC/g mtrl.]	3 Concentration (2kg) [μgC/g mtrl.]	4 Concentration (2kg) [μgC/g mtrl.]	5 Concentration (2kg) [μgC/g mtrl.]	6 Concentration (2kg) [μgC/g mtrl.]
TVOC	30	41	43	37	27	17	10

Table 8. TVOC results A and B pillars.

Conclusions

- Panel Tailgate and Hatch Warning Triangle are approved with the recycled plastic and will be implementation in XC60.
- A and B-pillar tests were approved but will not be implemented in XC60. Volvo Cars don't are not ready to change material in safety critical components.
- Battery Box and Lid were approved with the recycled plastic and are ready for implementation in XC60 and XC90.

Car components with recycled plastic produced by Plasman

Trials	Material	Supplier/grade	Recycled content
Undershield XC90	PP TD20	Crashed bumper	20 % PCR
Front bumper cover XC90	PP E/P TD15	Borealis	70 % PCR
Front bumper combined Bracket XC90	PP GF30	Borealis	100 % PCR
Front bumper fender Bracket XC90	PP TD20	Borealis	30 % PCR
Front fender bracket XC40	PP TD20	Rondo	30 % PIR
Fog light hatch V60	PP/TPO TD20	Rondo	40 % PIR
Rear trim list V60 CC	PC/ABS	Rondo	30 % PIR
Rear insert V90	PP E/P TD20	Total	25 % PCR
Roof spolier XC90	PP E/P TD30	Total	20 % PCR
Undershield XC90	PP TD20	Rondo	50 % PCR
Front bumper cover V60	PP E/P TD15	Borealis	25 % PCR
Sillmoulding XC90	PP TD20	Total	30 % PCR
Sillmoulding XC90	PP GF30	Total	30 % PCR

Table 9. Test runs performed by Plasman for Volvo Cars.

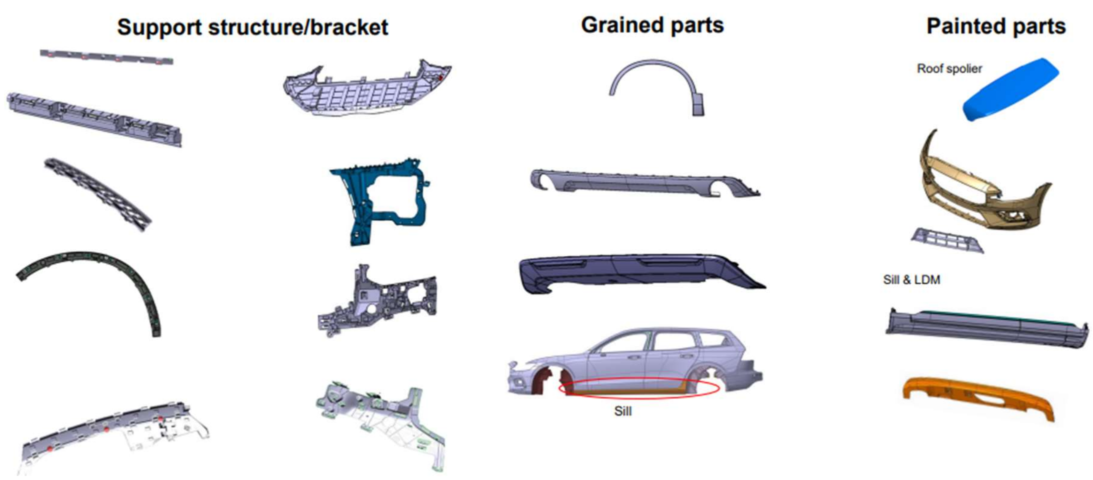


Figure 24. Overview of components tested with recycled plastic.

Undershield XC90
Supplier: Plasman.
Produced at PAGO
Material: PP with talc, 10% and 20% recyclates from crashed bumpers
Testing results Volvo Cars:
TR-tests approved with 20 % recycled plastic from crashed bumpers
Assembly test approved

Front bumper cover
Vehicle: V60
Tested: Loose parts
Material: PP

TR-tests approved

Figure 25. Front bumper cover testing.

Rear Bumper XC90
Produced by Plasman in Arendal
Material: Recycled PP supplied by Borealis
Painted

Figure 26. Painted bumpers XC90.

Paintability testing Rear Bumper XC90

Four painted components were tested with good results.

Figure 27. Painted parts.

Material

PC/ABS for OMNILUXE™

2 recycled materials were tested:

1. PC/ABS MOCOM grade
2. PC/ABS Rondo grade

Test of 5 different pretreatment

PVD+Top coating

Evaluation on plaques

Test of 5 different cleaning agents

Figure 28. Painted plaques.

Evaluation	Performer	Result
Appearance after PVD	Plasman	OK
Adhesion test, dry and HP wash	Plasman	OK
Adhesion Moisture 2 weeks High pressure wash	Plasman	OK

Table 10. Adhesion and appearance test results.

Front bumper V60

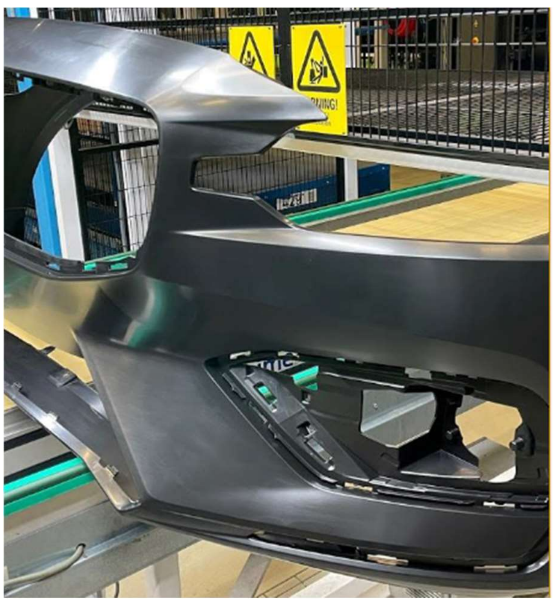


Figure 29. Front bumper V60.

Material

PP supplied by Borealis with 30 % PCR

4 paints tested:

Black solid (019)

Bright silver (711)

Crystal white pearl (707)

Thunder grey (728)

TR-tests	Results
Appearance after painting	Approved
Paint adhesion dry and wet, stone resistance and HP wash	Approved
Moisture resistance	Approved
Flexibility RT and -30 °C	Approved
Chemical resistance	Approved
2 nd round of trials/validation	Approved

Table 11. TR-tests Front bumper V60.

The TR-tests were approved but the recycled material smell somewhat when the parts were produced.

Work forward:
The work for implementation will proceed in a new project.

Rear Insert V90
Material: PP supplied by Total with 25 % recycled PCR
Paint: 4 different colors
The test were stopped.

Fog light hatch V60
Supplier: Plasman
Produced by: Anziplast
Material: PP supplied by Rondo Plast with 40 % PIR
Grained surface – classic black
TR-tests were approved, however some small surface defects were observed.

Figure 30. Fog-light cover.

TR-tests	Results
Resistance to UV, 2000 hrs	Approved
Resistance to scratching	Approved
Abrasion, unpainted	Approved
Tigerstripes 3+3 w	Approved
Smear, unpainted	Approved
Short-term heat	Approved

Table 12. TR-testing Fog-light cover.

Anziplast had some processing issues. The base material in the component is normally ABS or PA. Anziplast was not interested in changing material and produce the component in PP.

Rear trim V60

Material
Recycled PC/ABS supplied by RondoPlast, 30 % PIR

Evaluation
Notches in substrate visible
TR testing PVD part completed:
Scratch, WoM, HP wash, Short, long-term heat etc.
Small surface defects were observed.

Figure 31. Rear trim list.

Figure 32. Surface defects Rear trim list.

5.2.2. Volvo truck componets

The Truck components produced by Plasman are summarized in Table 13.

Trials	Material	Supplier/grade	Recycled content
Front fender extension	PC/ABS	MOCOM Altec	70 % PIR/PCR
Bumper corner	PC/ABS	Rondo REZYcom R85HCI LB	30-40 % PIR
Bumper corner	PC/ABS	Mocom Altech PC + ABS ECO 500/1000	70 % PIR/PCR
Door extension extender	PP TD20	Rondo REZYcom RT20020E30	30-40 % PIR
Door extension extender	PP TD20	Rondo REZYcom R10017R3	30-40 % PIR
Door extension extender	PP TD20	Rondo REZYcom REP317R	30-40 % PIR

Table 13. Volvo Truck components produced with recycled plastic.

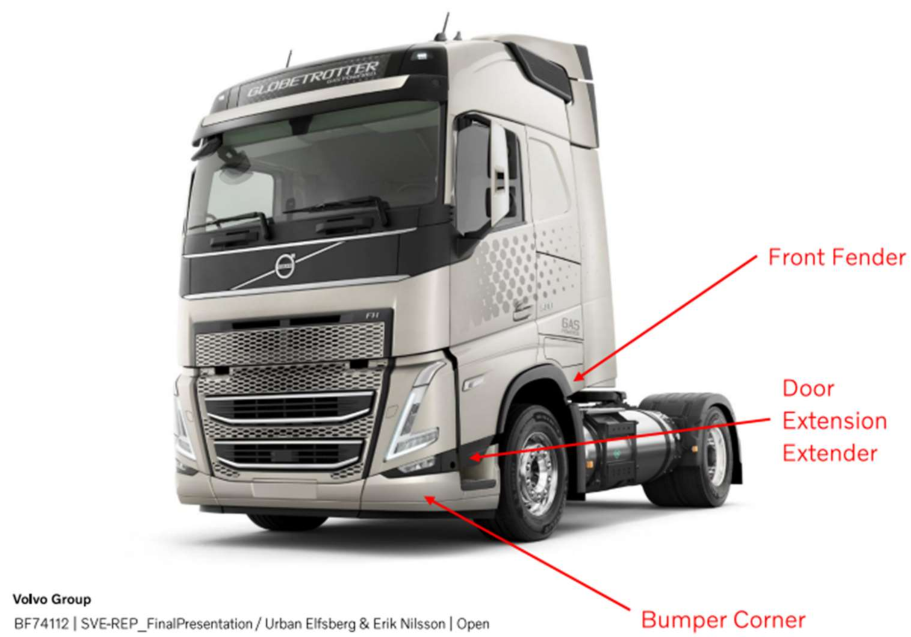


Figure 33. Bumper corner, door extension extender and front fender on a Volvo truck

Front fender and front fender extension

The production trial of Front fender extensions was performed early in the project by Plasman in Arendal.

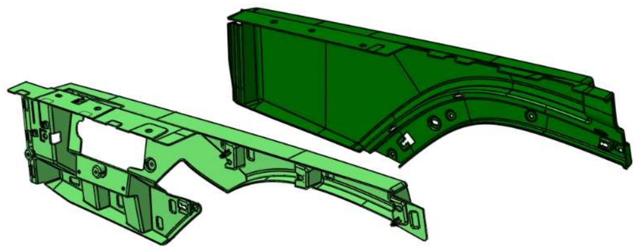


Figure 34. Front fender extension (left) and front fender (right).

Material

Two different PC/ABS grades were evaluated:

- Mocom with mix of 70% recycled mix of PCR and PIR
- Rondo Plast with 50% recycled PIR

The material properties were tested, see Table X.

Material properties

Material	**MVR** *230°C/2,16 kg (cm³/10 min) ISO 1133-2*	**Tensile Modulus** *(2 mm/min) ISO 527*	**Impact Charpy** notched 23°C *(KJ/m²) ISO 179*	**Impact Charpy** un notched 23°C *(KJ/m²) ISO 179*	**Impact Charpy** notched -30°C *(KJ/m²) ISO 179*	**Impact Charpy** un notched -30°C *(KJ/m²) ISO 179*
Mocom PC/ABS 70 % Recycled	14	2400	65	--	16	No Break
Sabic PC/ABS Virgin standard	20	2200	60	No Break	45	No Break

Table 14. Test results on the materials, the recycled PC/ABS from Mocom and the standard material.

There were some differences in mechanical properties. The recycled Mocom material had lower impact resistance at – 30 °C, compared to the standard virgin Sabic material, when the test samples were nothched but none of the un nothched test samples were broken. The melt volume flow rates (MVR) were different, 14 for the recycled material and 20 for the standard material. The MVR influence on the processability.

Process

When injection moulding the front fender extension with the recycled Mocom grade, using same process settings as in current production, the injection molding pressure was lower, 127 bar compared to 200 bar with the virgin material.

Surface appearance

Observations for the injection moulded parts in the recycled plastic:

- The finish was more mate.
- Flow lines and ingate were visible and disturbing.
- Small particles or dots on surfaces were observed.
- Inconsistencies (start/stop)

Figure 35. Some surface defects observed on the parts.

Evaluation

- The geometry deviations were on the same level as for virgin material.
- The recycled material can influence on the injection moulding and assembly processes.
- The recycled material was more process sensitive and scrap level might increase.
- The effects on the surface properties and paintability properties are questioned.

A new production trial is planned for with recycled PC/ABS grades from Rondo Plast and from Mocom Altec but due to high load in production at Plasman the trials have been delayed. The material properties and the paintability have been tested and Bumper corners have been produced.

Paintability tests on plaques

The plaques were injection moulded by Plasman.

Materials
Two recycled grades of PC/ABS were tested:

- Mocom with mix of 70 % recycled mix of PCR and PIR
- Rondo Plast with 50 % recycled PIR

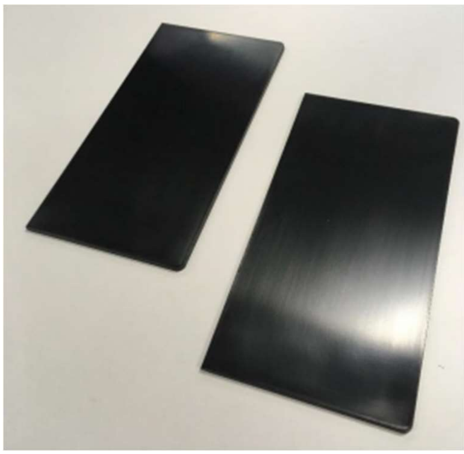


Figure 36. Injection moulded plaques of recycled PC/ABS for printability testing.

Painting was done in pilot line on the injection moulded plaques with same surface as for serial parts. Plasman performed testing of paint adhesion etc, see Table 15. RISE tested long term ageing by climate cycling and measured paint adhesion before and after ageing.

Substrate/System	PC-ABS #1	PC-ABS #2	ref-labpaneler pc-abs
Complete system			
Film thickness			
Primer	30	30	29
Top coat	32	32	30
Colour			
Deviation visually			
Measuring D65			
dL	-0,44	-0,42	-0,4
da	0,02	0,02	0,02
db	-0,05	-0,08	-0,06
dE	0,32	0,31	0,29
Gloss (STD 423-0023)	87,4	86,6	87,8
Adhesion RT			
Cross-cut (STD 423-0012)	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0
Scrape test (STD 423-0009)	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0
Stone chip (STD 1024,7132)	8A 9AB / 8	8A 10AB / 9	8A 10AB / 9
High pressure test (STD 423-0015)	0 / 0 / 3	0 / 0 / 2	3 / 17 / 0 / 0 / 1
Moisture resistance			
Blistering (STD 420-0001)	(S-)	(S-)	(S-)
Adhesion wet			
Cross-cut (STD 423-0012)	0 / /	0 / /	0 / /
Scrape test (STD 423-0009)	0 / /	0 / /	0 / /
Stone chip (STD 1024,7132)	8A 10AB / 9	7A 9AB / 8	8A 9AB / 9
High pressure test (STD 423-0015)	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0
Adhesion Cold			
Stone chip (STD 1024,7132)	9A 10AB / 9	9A 10AB / 10	9A 10AB / 9

Table 15. Testing painted plaques, performed by Plasman.

Evaluation

- Both recycled grades were approved in the paintability screening.
- Paint adhesion was approved for all plaques, both the recycled materials.

Bumper Corner

The production trials of front fender extensions were performed by Plasman in Arendal. The painting test were performed at Volvo in Umeå.

Materials

- The recycled PC/ABS grades tested:
- Rondo Plast REZYcom R85HCI LB
- Mocom Altech PC + ABS ECO 500/1000

Figure 37. Bumper corner painted in two colors.

Evaluation

- The paintings were approved with same set up as current parts.
- On the painted parts; film thickness, color and adhesion (cross hatch testing) were performed and approved by Volvo.
- Some surface defects were noted on the parts, se Figure X.

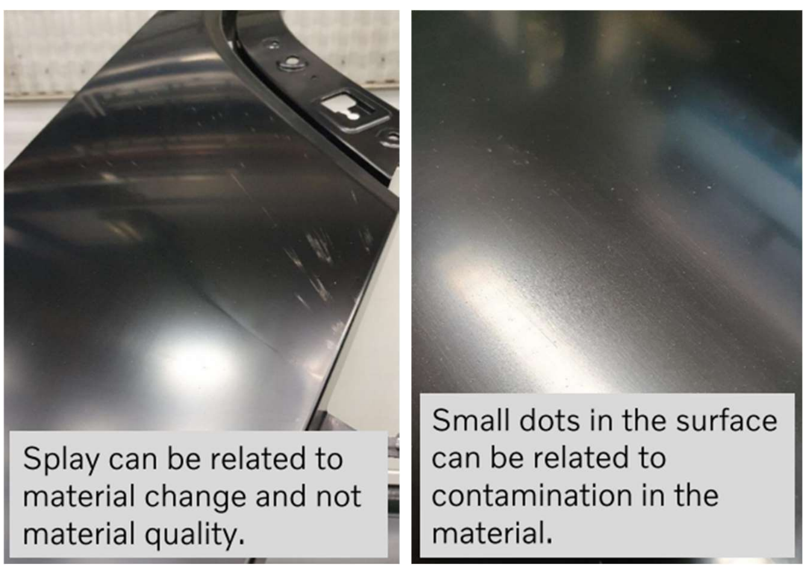


Figure 38. Surface defects on parts.

Door extension extenders – *colored parts*
Trial done on Door Extension Extender:

- Two PP MD parts welded together
- One 2K part with TPV (original, non recycled TPV material)
- One 1K part

Materials
Three PP MD grades of RondoPlast´s REZYcom with 30 – 40 % recycled PIR:

- RT20020E30
- R10017R3
- REP317R

Figure 39. Door extension extender

Test	Results
Heat resistance 85 °C, short term	Approved for all the grades
UV ageing 65 °C/1500 h	Approved for all the grades
Resistance to artificial ageing for exterior parts	Approved for all the grades
Impact resistance	Approved for all the grades
Contact with fluids (Method 1 and 2)	Approved for all grades, but with remark
Rubbing, unpainted plastic parts	Not approved
Appearance	Approved for R10017R3 and RT20020E30, not for REP317R
Rubbing	Approved (some acceptable discoloration)
Scratch resistance (≥ 1,0 N)	Approved for R10017R3, not for REP317R and RT20020E30

Table 16. Test results Door extension extenders.

Evaluation

- No process issues, the recycled materials performed as production material.
- One of three recycled materials were approved in both appearance and scratch resistance.
  - Two materials were approved in appearance
  - Two materials were approved in scratch resistance
- Sun simulation approved
- Climate cycling approved

Field test cold climate, Field test hot climate and Field test long term are still ongoing at the end of this project.

Production IAC – Volvo truck component

SID Panel Inboard

IAC produced SID Panel Inbord parts for Volvo Truck in recycled PC/ABS from two suppliers.

Material

- LG Chem: PC/ABS with 50 % PCR
- Rondo Plast: PC/ABS with 50 % PIR

The parts were painted and tested by IAC. IAC tested the components. RISE also performed long term climate cyclings and tested the paint adhesion.

Figure 40. SID Panel Inbord location in a Volvo Truck.

Evaluation

- No issues to injection mould the parts with existing parameters
- No issues to paint any of the parts made with recycled plastics
- Appearance approved
- Scratch resistance approved, same as for today products
- Welding of deco trim worked well, approved

- RISE and IAC tested adhesion with different technologies
- RISE tested ageing of parts by long term climate cycling followed by adhesion tests:
  - All samples were approved by RISE method
  - IAC test showed failure for one material after the final ageing step

5.2.3. Conclusion summery Pilot trials

PROCESS

- Recycled PP PCR-plastic from packaging and film had lower melt viscosity than the standard PP material qualities for injection moulding. It resulted in a lower injection pressure. Thus, some recycled material had better surface finish was easier to process than virgin materials.

- Some recycled PP materials from PCR and film gave better surface finish of the injection moulded parts than the virgin standard materials. Also, this due to the lower melt viscosity of PCR from packaging and film.

- Part geometry can differ sometimes when using recycled plastic but was not an issue in the trials performed in this project.

PRODUCT

- Most of the recycled materials, PP and PC/ABS had good performance and the component test were approved in most cases.

- Paintability and paint adhesion have not been a problem when using recycled PC/ABS plastics.

- Blisters after moisture test has been observed for some materials.

- PVD surface coating is “mirror-like”, even the smallest contamination in the surface becomes visible.

5.3. Accelerated ageing and service life prediction

The samples exposed to accelerated were the materials tested for Panel tailgate, recycled Omicrone from Biesterfields and virgin Omicrone reference. And the materials tested for Fog light hatch, PP Recycom from RondoPlast and virgin PP Daplen. were aged until the materials reached End-of-life of the material. End-of-life was set to 50 % loss in elongation at break.

Tensile testing - Elongation at break

Elongation at break has reached the end-of-life criterion for the reference samples and the recycled samples aged at 110 °C and 100 °C but not yet at 90 °C. The behaviour of the reference materials and the recycled PP materials are similar.

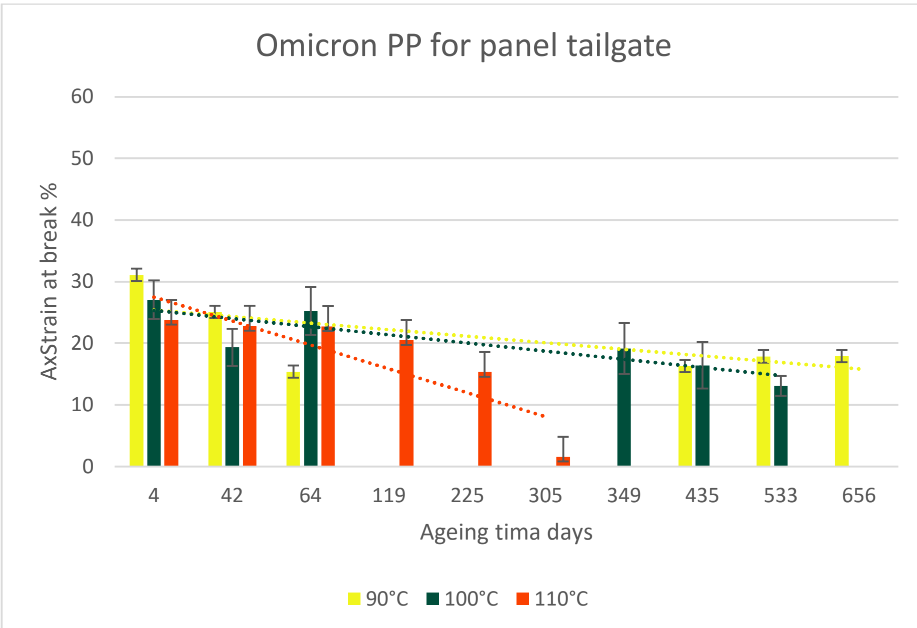


Figure 41. Elongation at break PP reference material for Panel tailgate.

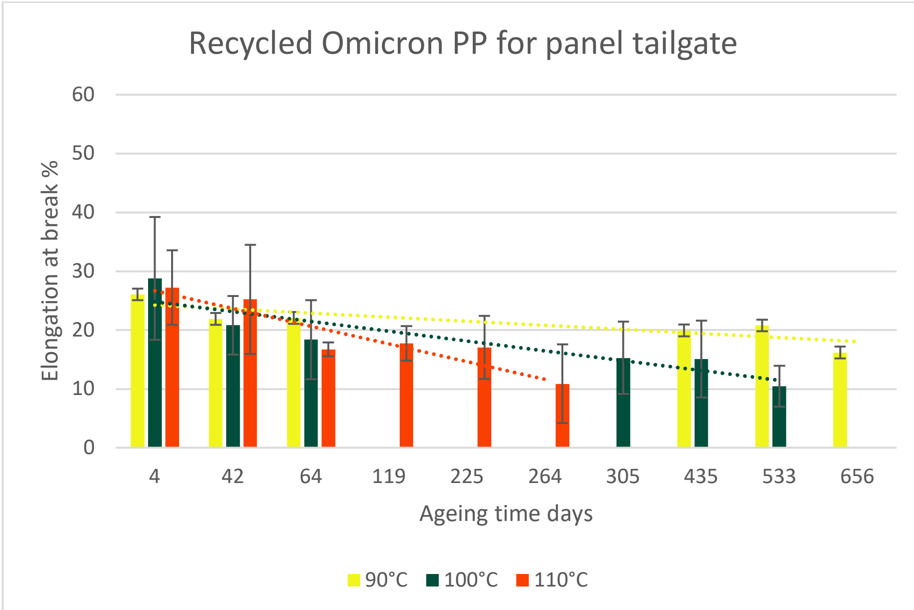


Figure 42. Elongation at break PP recycled material for Panel tailgate.

Elongation at break has reached the end-of-life criterion for the reference samples and the recycled samples aged at 110°C and 100°C but not yet at 90°C. The behaviour of the reference and the recycled PP materials are similar.

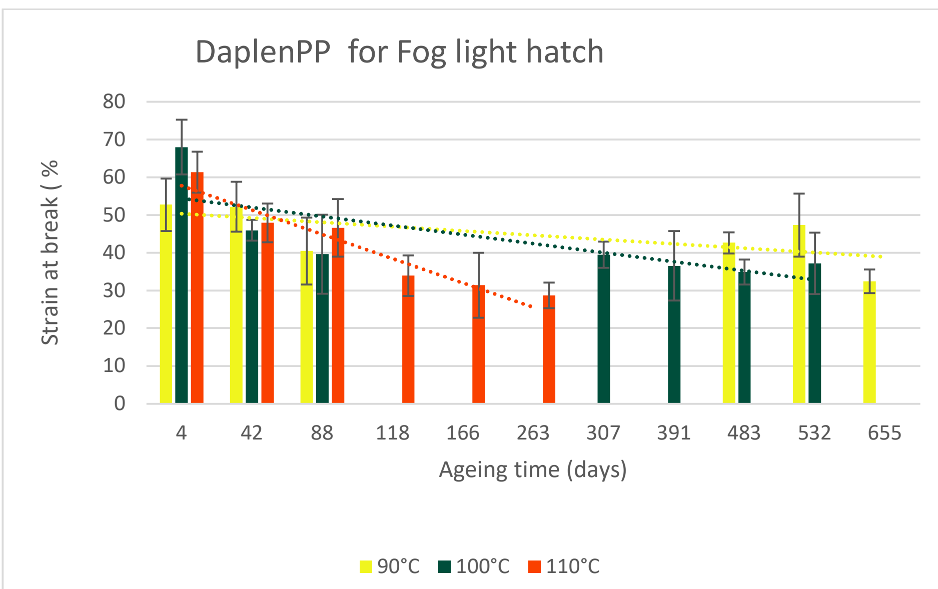


Figure 43. Elongation at break PP reference material for Fog light cover.

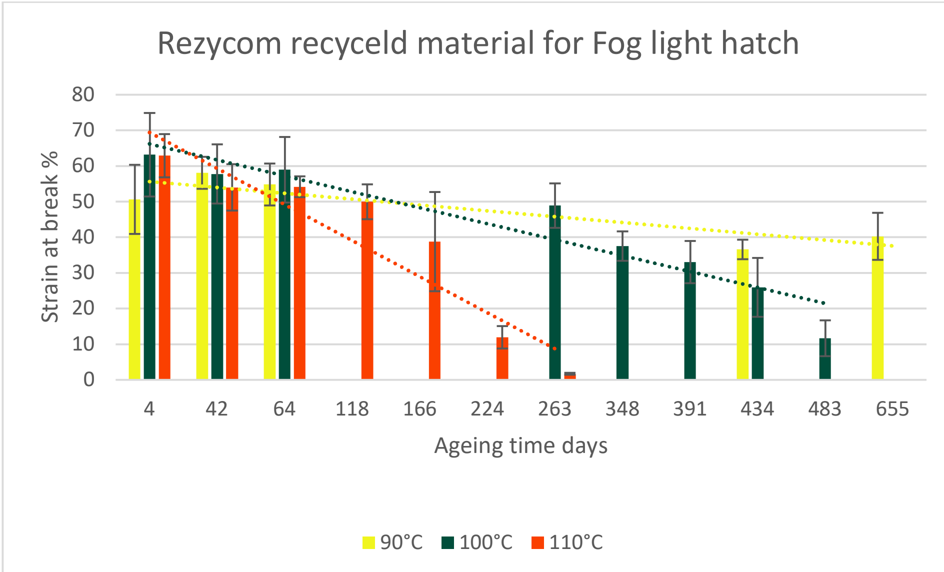
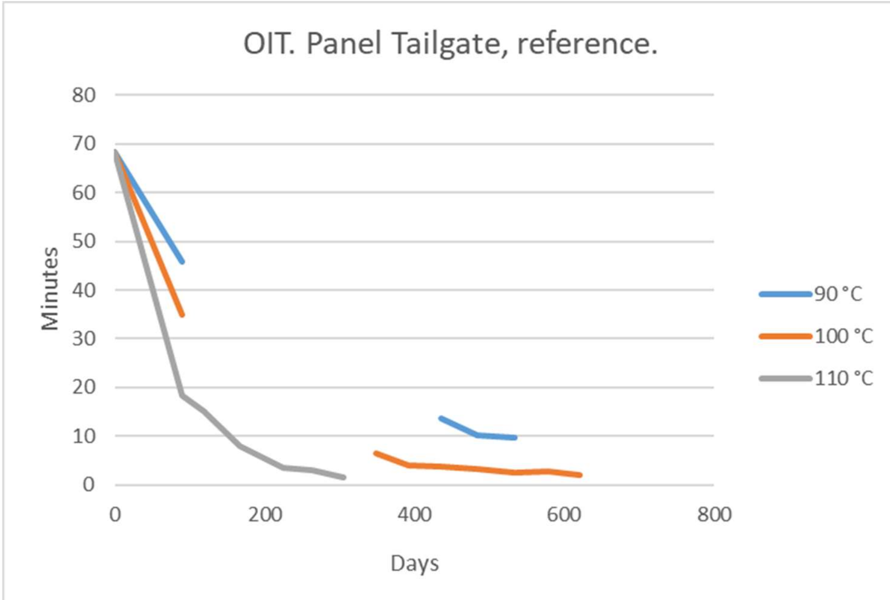


Figure 44. Elongation at break PP recycled material for Fog light cover.

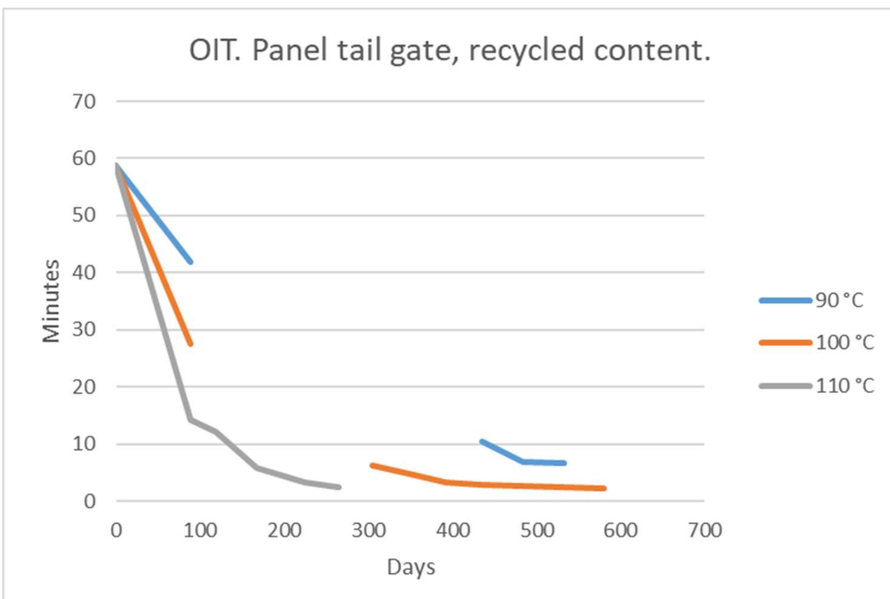
Oxidation Induction Time (OIT)

The gaps in the curves that can be seen in the diagrams are due to no sampling being made in that time region.

The thermal stability of the virgin material faced a steady decline throughout the total ageing time at all three temperatures. At 110 °C the thermal stability was constantly decreasing until the ageing was finished but at 100 °C the curve lies quite constant at a low value for almost 200 days until the end-of-life criterion of the study is met. At 90 °C the ageing test is still ongoing. For the recycled material the behaviour of the thermal stability looks very similar to the virgin material, the only obvious difference is that the measured values are a somewhat lower compared to the values of the virgin material.



Figur 45. OIT (min) decrease with ageing time for the Panel tailgate reference PP material.

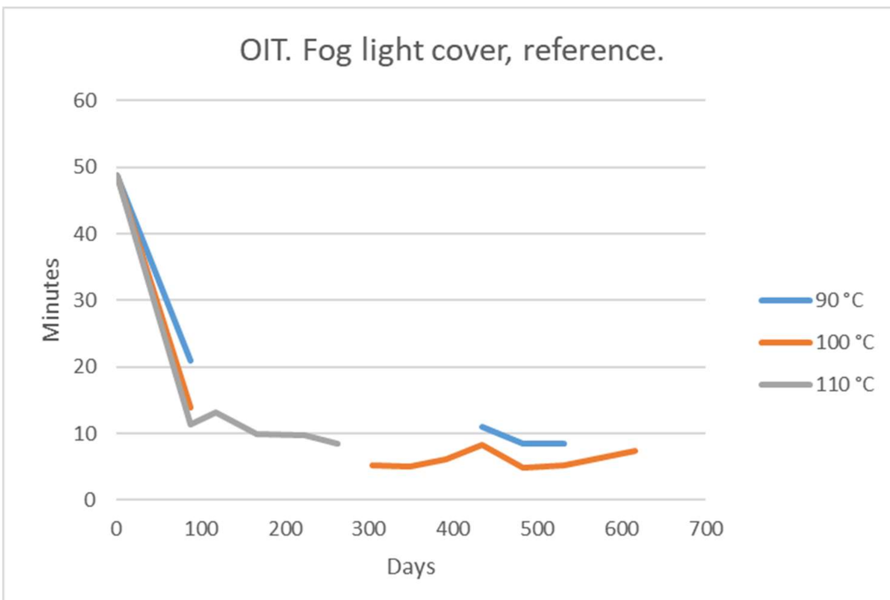


Figur 46. OIT (min) decrease with ageing time for the Panel tailgate recycled PP material.

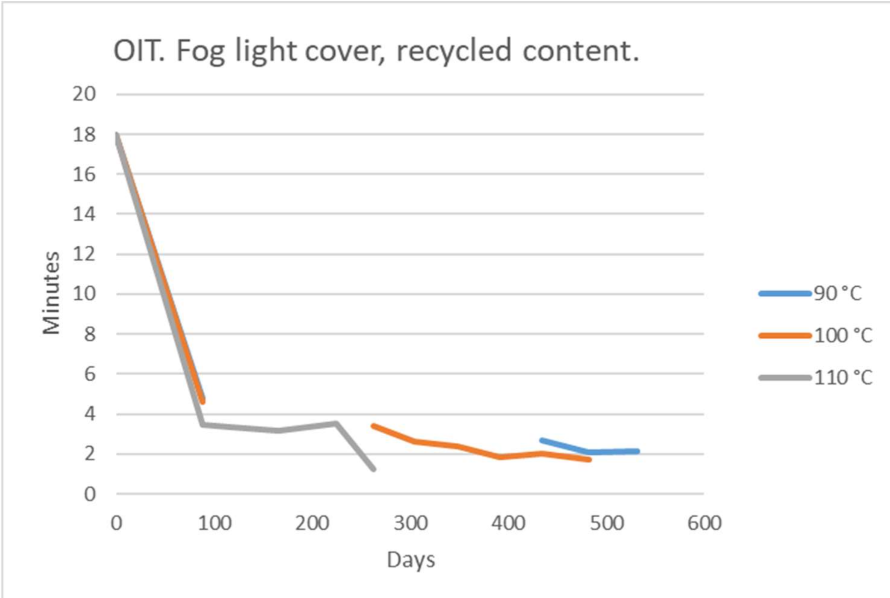
RE:
SOURCE

The fog light cover reference material also faces a steep reduction in thermal stability early during the ageing. The differences between the results at the three studied temperatures is not as spread in the beginning of the ageing process as the panel tail gate materials are. As in the case of the panel tail gate materials the OIT at 100 °C is quite constant at a low value until the end-of-life criterion is met. The measured values of the fog light cover recycled material is significantly lower compared to the results of the three other materials studied. The behaviour of the material during the OIT test was however different, not showing a clear exothermal peak, so the values had to be calculated by using another method. Hence, the values cannot be compared directly with the values of the other three materials and they cannot therefore be seen as less.

The differences between the results of the recycled material at the three temperatures were small in the beginning of the ageing process. The loss in OIT in the first part of the ageing was large, and after the first decline the values were at a very low level for the rest of the ageing time.



Figur 47. OIT (min) decrease with ageing time for the Fog light reference PP material.



Figur 48. OIT (min) decrease with ageing time for the Fog light recycled PP material.

Calculation activation energy and life time prediction

Not all samples reached end of life during the project time and the ageings at 90 °C is still ongoing. Where we have data activation energy was calculated and service life was predicted.

The values where the elongation at break had passed the end-of-life criterion is seen in Table 17 below. These values were used when calculating the lifetime and the activation energy of the studied materials.

Material	Temperature (°C)	Time to End-of-life (days)
Panel tailgate, reference	100	305
	110	579
Panel tailgate, recycled	100	264
	110	533
Fog light cover, reference	100	224
	110	434
Fog light cover, reference	100	224
	110	434

Table 17. Time when 50 % reduction in elongation at break/End-of-life is reached.

The calculated activation energies are summarized in Table 18 below, together with the Arrhenius factor for each material. The Arrhenius factor is calculated by dividing the time to reach the end of life scenario at 100 °C with the time required at 110 °C. The factor describes how much faster the degradation of the material proceeds if You increase the temperature by 10 °C. This factor was used for the service life predictions of each material.

Material	**Activation energy (kJ/mole)**	**Arrhenius factor**
Panel tailgate, reference	76	1,9
Panel tailgate, recycled	84	2,0
Fog light cover, reference	79	1,9
Fog light cover, recycled	79	1,9

Table 18. Activation energy (KJ/mole) and Arrhenius factor.

The calculated activation energies are close to the results of other studies (referenser!!!).

Service life predictions

The service temperature used in the calculations can e.g. be the average temperature of the climate where the material is used. For a car, however, the average temperature is hard to decide as it is dependent on where the car is used globally and where in the car the material is used. As this study is a comparison between two types of materials, the exact temperature used is not of outmost importance, it is more important that the same temperature is used for the materials that are compared.

The temperature chosen when calculating the service life time of the materials was 30 °C. The resulting calculated service life times can be seen in Table.

Material	**Service life time (years)**
Panel tailgate, reference	141
Panel tailgate, recycled	200
Fog light cover, reference	122
Fog light cover, recycled	122

Table 19. Extrapolated service life.

The calculated service time of the materials are preliminary as the ageing at 90 °C is still ongoing. The results might change when the results at 90 °C is included as the Arrhenius extrapolation.

Conclusions

- All materials show good thermal stability, and the materials with recycled content show similar stability as the reference materials. All tested materials seem to have a long and comparable service time.
- The overall conclusion was that the tested materials fulfill ageing properties for automotive applications with good margin.
- Both virgin and recycled materials have reached end-of-life, elongation at break is below 50 % of initial value, at 110 and 100 °C ageings.
- Degradation and decrease of elongation at break seems to follow the ”rule of thumb”, meaning that if the ageing temperature increases by 10 °C the degradation increases by a factor of 2.
- OIT was on a very low level after finished ageing for both the recycled and the virgin materials.
- The samples aged at 90°C still had properties similar to the start values when the project was ended.

5.4. Climate cycling Painted PC/ABS

After finished climate cyclings of the painted PC/ABS plaques and profiles, visual inspection, paint adhesion measurements and cross-cut tests were performed.

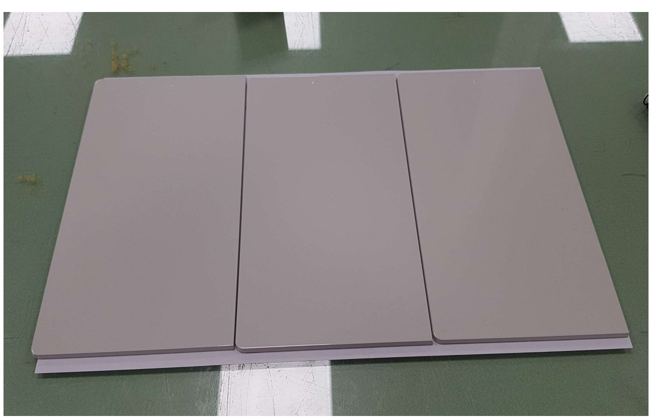


Figure 49. Plaques.

Figure 50. SID panel inbord profiles.

No significant differences in appearance could be seen between the exposed samples and the unexposed references.

The paint adhesion measurements showed overall comparable adhesion results. The results of the recycled materials were comparable to the results of the reference material. However, some of the plaque materials showed a large spread in the results of the unexposed materials and after 20 cycles. This spread is probably due to a variation in the nature of the fracture of these materials. After 30 cycles however the nature of the fracture was more consistent and the spread was smaller.

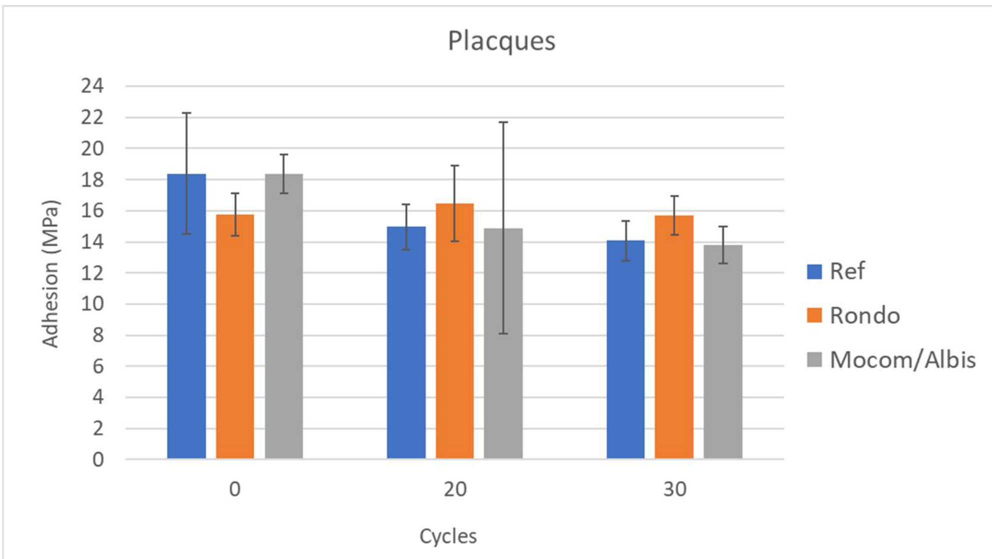


Figure 51. Paint adhesion plaques after 0, 20 and 30 climate cycles.

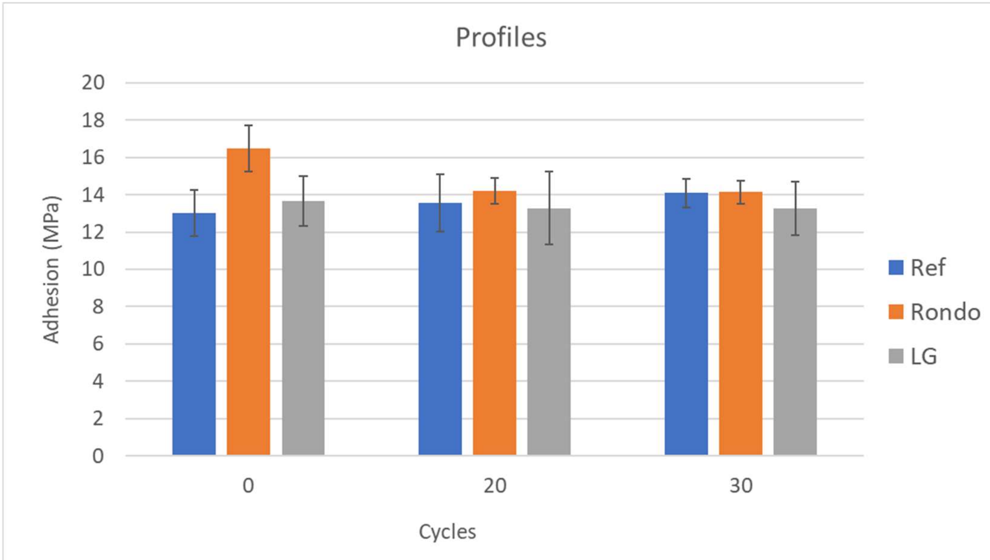


Figure 52. Paint adhesion profiles after 0, 20 and 30 climate cycles.

Adhesion, cross-cut test results on plaques after 30 climate cycles (STD 423-0012) are shown in table 20. All the results were approved.

Plaques	Result (Grade)
Reference	0 (No remarks)
Rondo	0 (No remarks)
Mocom/Albis	0 (No remarks)

Table 20. Cross-cut results plaques.

Adhesion, cross-cut test results on profiles are shown in Table 21. The results were approved except for the Rondo material climate cycled for 30 times.

Profiles	Result (Grade)
Reference, Reference	Grade 0
Reference, 20 cycles	Grade 0/0
Reference, 30 cycles	Grade 0/0
LG, Ref	Grade 0
LG, 20 cycles	Grade 0/0
LG, 30 cycles	Grade 1/0
Rondo, Ref	Grade 0
Rondo, 20 cycles	Grade 0/0
Rondo, 30 cycles	Grade 3/3

Table 21. Cross-cut results profiles.

The reason for the difference between the results at RISE and the results at Volvo of the profile materials has not been found. The tests were not performed on the same position on the samples, so the tested paint layers might have some difference in properties. There were no more samples left to test. However, the standard test is 10 cycles and all materials where ok after 10 cycles, even after 20 cycles. It was first after 30 climate cycles the results failed.

5.5. Long term testing in vehicles

Two courier's vans with Panel tailgates of recycled plastic are running since March 2022 and will go on for 2-3 years. The Panel tailgates were checked in March 2023.

The Volvo truck with Door extension extenders of recycled plastic is running since September 2022.

5.6. Repeated recycling of PC/ABS

The difference in properties based on the chosen method of testing can be seen on the mechanical properties, see Figure 53. The Young's modulus of the PC/ABS material shows minimal variation (< 4 %) and exhibits a plateau after 6 cycles of reprocessing. However, the same material when subjected to a combination of reprocessing and ageing showed an increasing cyclic behaviour and this behaviour was common both for the virgin and PIR based PC/ABS. The material had a stiffening effect after ageing step, approximately 6 %, which disappeared after reprocessing and this trend was seen to repeat over the entire range of experiment.

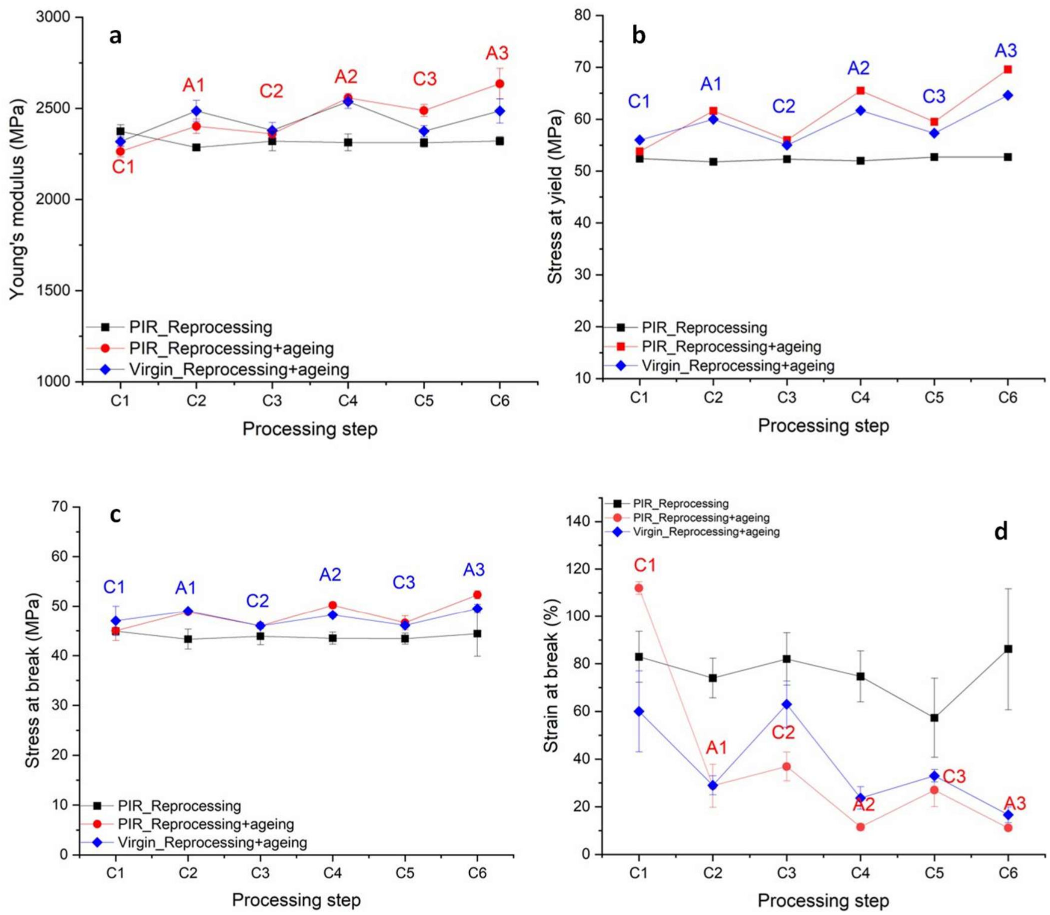


Figure 53. The mechanical properties (a) Young's modulus (b) stress at yield (c) stress at break and (d) strain at break of the PC/ABS material subjected to reprocessing study (black) and accelerated ageing study (red-PIR, blue-virgin).

A similar behavior was observed for the stress at yield and stress at break properties where an increase of approximately 17 % and 10 % of the properties were observed after each ageing step, see Figure 53b and 53c. On the other hand, the strain at break of the material showed a reduction in properties for the PC/ABS material, see Figure 53d. The extent of reduction was rather low for the material when reprocessing methodology compared to the drastic strain reduction when the accelerated ageing methodology was used. In case of the reprocessing the methodology, the decrease in strain at break over the entire range was approximately 31 %. However, for the accelerated ageing methodology the initial drop was drastic where the PIR material exhibited a decrease of 74 % when compared to the 51 % of the virgin material. The strain at break showed a downward cyclic trend with increasing number of cycles for the accelerated ageing studies with strain values dropping to as low as 90 % and 72 % of the original value of the PIR and virgin materials, respectively.

In figure 54, the impact properties of the PC/ABS materials showed an increase in the impact properties by approximately 19 % with increasing reprocessing cycles for the reprocessing study. However, the accelerated ageing studies for the same material showed a decreasing trend with increasing no. of cycles with the properties reducing to as low as 74 % and 70 % of the original values for the PIR and virgin materials, respectively.

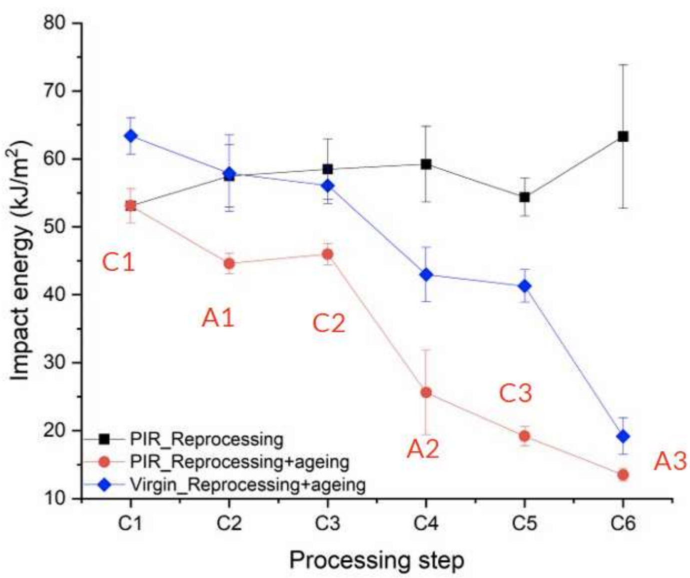


Figure 54. The impact properties of the PC/ABS material subjected to reprocessing study (black) and accelerated ageing study (red-PIR, blue-virgin).

Figure 55 exhibits the variation in MFR values for the PC/ABS material with increasing cycles. It is observed that the virgin material has a relatively higher MFR compared to the PIR material suggesting lower viscosity. Furthermore, the MFR barely changes for the PC/ABS material when subjected to reprocessing studies over 6 cycles while an increase in MFR is observed for the same material when subjected to accelerated ageing studies. The slope of the increase in MFR is steeper for the PIR material when compared to the virgin counterpart. Furthermore, a steep increase is observed in the MFR values for the PIR material after the second ageing step suggesting a possible degradation of the material.

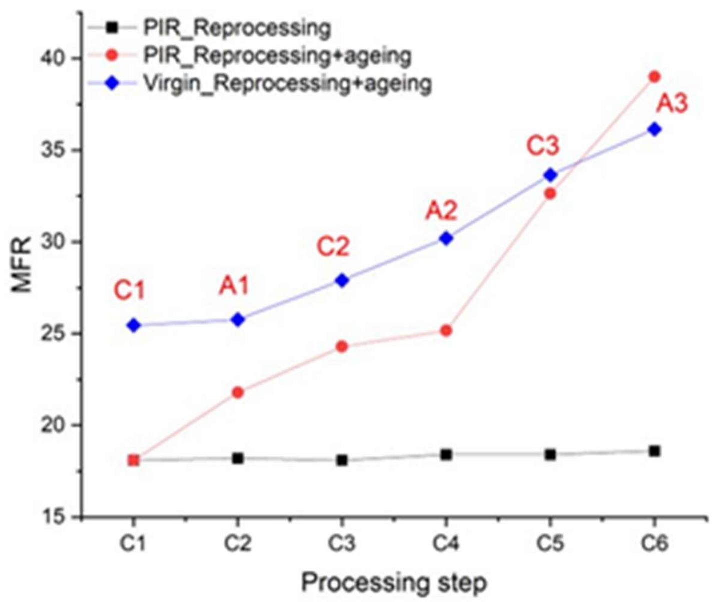


Figure 55. The melt flow rate of the PC/ABS material subjected to reprocessing study (black) and accelerated ageing study (red-PIR, blue-virgin).

Conclusions

The PC/ABS materials, despite being PIR source, still tend to show similar properties to that of the virgin material. The mechanical properties showed a cyclic behavior when subjected to accelerated ageing and this was absent when the material was subjected to just reprocessing. Despite the increase in properties in some cases the extent of degradation and the degradation mechanisms aren't well understood for the PC/ABS materials.

The reprocessing studies led to an overestimation of material properties and can lead to misinterpretation or over-estimation of onset of property reduction. It is vital to consider the need for simulating the use phase of a material using an additional ageing step which could avoid overestimation of the material property. Additionally, the results clearly indicate that reprocessing the material cannot be considered as simulating recycling studies.

5.7. Environmental and Economic impact

Life cycle analysis (LCA) based data and methodology were used to measure the climate impact from the recycled and fossil-based plastic. The data collection includes plastic from different material suppliers, Rondo, Mocom, Sabic and Borealis). The results were compared between plastics and suppliers. The results were also compared with earlier studies in the literature.

The economic implications of using recycled plastic could not be calculated since we did not get the economic data needed for such calculations.

5.7.1. Environmental impact

PP, PA, TPE (Recycling vs Fossil)

Figure 3 and Table 3 shows the results for PP, TPE, PA6, here Rondo and Mocom.

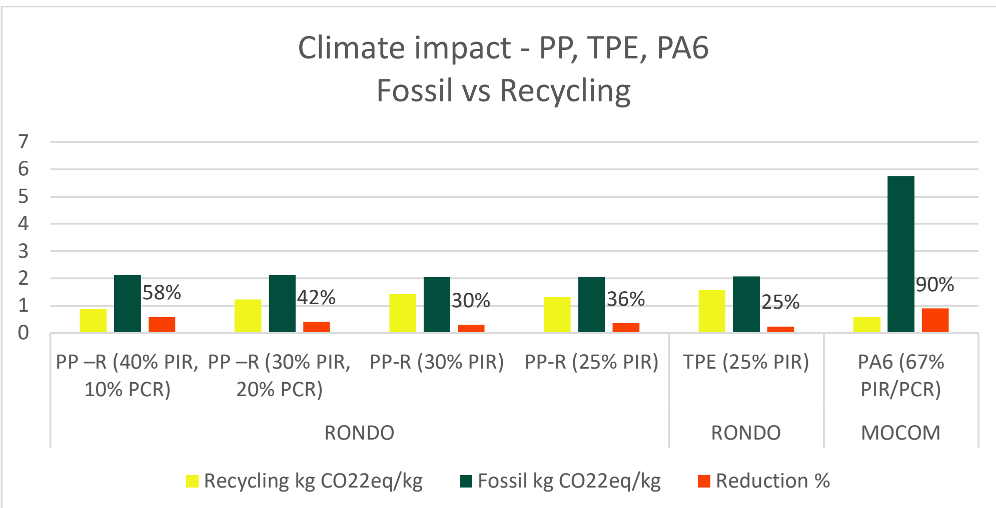


Figure 56. Climate impacts for PP, TPE, PA6 – Plastic (Recycling and fossil).

PP Plastic	Recycling (kg CO2eq/kg)	Fossile (kg CO2eq/kg)	Reduction (%)
PP – R (40% PIR, 10% PCR), RONDO	0,88	2,12	58
PP – R (30% PIR, 20% PCR), RONDO	1,23	2,12	42
PP – R (30% PIR), RONDO	1,43	2,05	30
PP – R (25% PIR), RONDO	1,32	2,07	36
TPE (25% PIR), RONDO	1,57	2,08	25
PA6 (67% of compound PIR/PCR), MOCOM	0,58	5,76	90

Table 22. Climate impacts for PP, TPE, PA6 - Plastic (Recycling and fossil) and reduction potential

PC/ABS (Recycling vs Fossil)

Figure 3.5 and Table 3.5 show the result for PC/ABS, here Rondo, Mocom and Sabic.

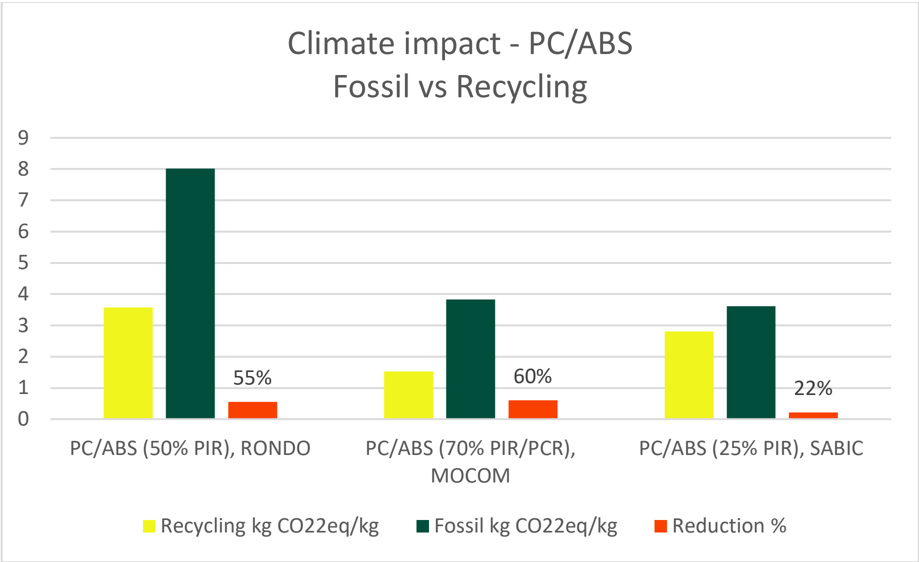


Figure 57. Climate impacts for PC/ABS – Plastic (Recycling and fossil).

PC/ABS Plastic	Recycling (kg CO2eq/kg)	Fossile (kg CO2eq/kg)	Reduction (%)
PC/ABS (50% PIR), RONDO	3,58	8,01	55
PC/ABS (70% PIR/PCR), MOCOM	1,53	3,83	60
PC/ABS (25% PIR), SABIC	2,81	3,62	22

Table 23. Climate impacts for PC/ABS - Plastic (Recycling and fossil) and reduction potential.

General results

The results in general show that recycling plastic have a lower climate impact than fossil-based plastics. Within the area of recycled plastics there are different feedstock possible, such as Post-industrial recycled (PIR) and post-consumer recycled (PCR).

- Recycled PP with 40% PIR and 10% PCR have a climate impact of 0,88 kg CO2e/kg compared to 2,12 kg CO2e/kg. That means a 58% reduction of climate impacts. The use of PIR gives better climate impacts.
- Recycled PP with 30% PIR and 20% PCR have a climate impact of 1,23 kg CO2e/kg compared to 2,12 kg CO2e/kg. That mean a reduction of 42% of the climate impacts. The use of PCR gives less climate reduction.
- The reason for less climate reduction is the higher use of PCR.

In general PIR has a better quality and a better climate performance, since less upcycling processes are needed to get the wanted quality of the plastic. Here we also looked at the results for only using PIR in recycled plastic.

- Recycled PP with 30% PIR have a climate impact of 1,43 kg CO2e/kg compared to 2,05 kg CO2e/kg. That means a 30% reduction of climate impacts.
- Recycled PP with 25% PIR have a climate impact of 1,32 kg CO2e/kg compared to 2,07 kg CO2e/kg. That means a 36% reduction of climate impacts.
- The results show the same % of recycling give the same a % of climate reduction.

Within PP plastics also includes Thermoplastic elastomers (TPE) and Polyamide (PA6).

- Recycled TPE with 25% PIR have a climate impact of 1,57 CO2e/kg compared to 2,08 kg CO2e/kg. That means a 25% reduction of climate impacts.
- Recycled PA6 with 67% PIR/PCR have a climate impact of 0,58 CO2e/kg compared to 5,76 kg CO2e/kg. That means a reduction of 90% of climate impacts. The reason for the high reduction here is based on green electricity, such as wind power and waterpower in the production.

Additionally, the results for a blend of polymers, such as PC/ABS, including Polycarbonate (PC) and Acrylonitrile Butadiene Styrene (ABS).

Recycled PC/ABS with 50% PIR gives a climate impact of 3,58 CO2e/kg compared to 8,01 kg CO2e/kg. That means a reduction of 55% of climate impacts. The results are based on Rondo's production facility in Ystad/Sweden. The reason for the high results in general is partly the processes included due to the quality requirement of the product and partly the use of local energy mix.

- Recycled PC/ABS with 70% PIR gives a climate impact of 1,53 CO2e/kg compared to 3,83 kg CO2e/kg. That means a reduction of 60% of climate impacts. The results are based on Morcom's production facility in Germany. The reasons for the low results in general are the use of green electricity.
- Recycled PC/ABS with 25% PIR gives a climate impact of 2,81 CO2e/kg compared to 3,62 kg CO2e/kg. That means a reduction of 22% of climate impacts. The results are based on SABIC's production facility in the Europe.

There is limited compatibility between materials from different sources due to unknown set of assumptions and methodology in allocating climate impact to the involved chemical processes. The absolute values as stated in this report should not be used as is, but rather show the difference within the specific producer's offerings. Comparability between producer values is not verified in this study.

Discussion
The discussion includes incineration and energy recovery, chemical recycling, LCA-matrix for polymers, recycling, and quality, as well as cut-off rules and recycling.

Recycling or energy recovery

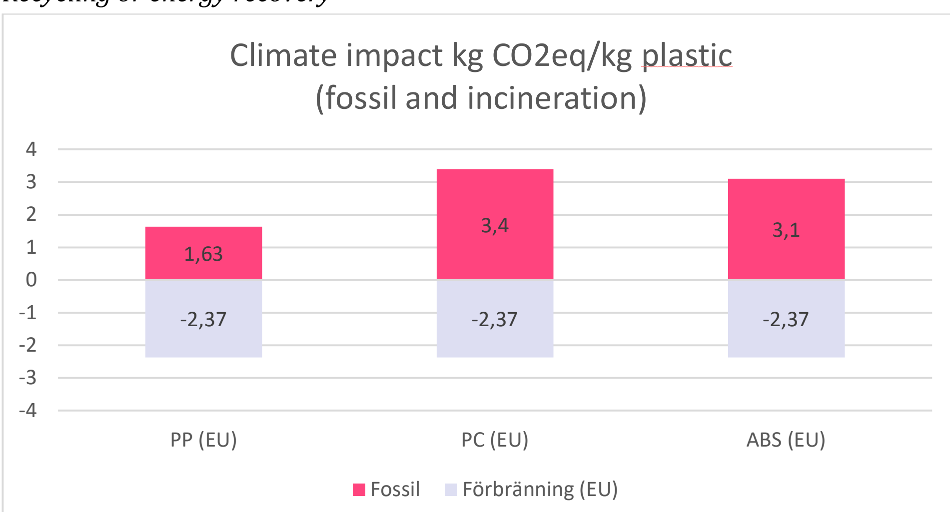


Figure 58. Climate impacts for PP, PC and ABS in production (fossil) and incineration (reduced).

Chemical or mechanical recycling

During the project we have looked at the potential for climate reduction and the recycling of plastics, also for chemical recycling. The chemical recycling is based on a literature study including results from a SABIC production facility (APR 2018; BASF, 2020; Sabic, 2021). Figure 6 shows the result for chemical recycling compared to fossil-based plastics. The mechanical recycling plastic means an -20% reduction in climate impacts. Instead, the chemical recycling means an +20% increase of climate impacts.

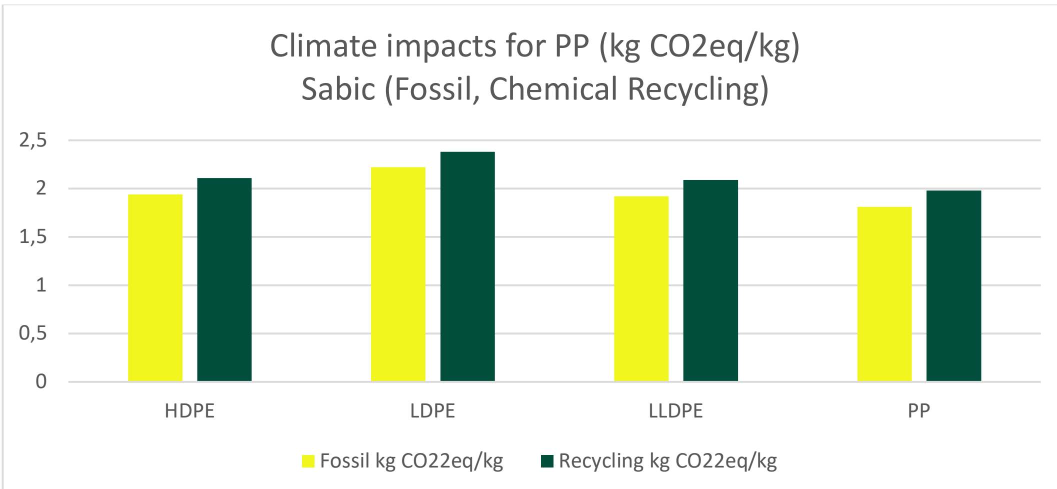


Figure 59. Climate impacts for PP – SABIC Plastic (Fossil and Recycling) – Chemical recycling.

LCA-matrix for polymers and recycling

LCA-matrix model shows that simple polymers, such as PP, show lower values and less energy demanding processes, such as mechanical recycling leads to 1,5-2 kg CO2e/kg.

The chemical processes, such as pyrolysis or gasification leads to 2-3kg CO2e/kg. The energy processes, such as energy recovery or incineration shows 4-5 kg CO2e/kg.The complex polymers, such as PC/ABS shows high values between 8-10 kg CO2e/kg.

Climate change (kg CO_2 eq. / kg polymer)		Polyolefins				Monomer forming polymers				Depolymerization/ hydrolysis polymers		
		PP	LDPE	LLDPE	HDPE	PS	EPS	HIPS	PMMA	PA (nylon 6)	PET	PLA
High relative CO_2-eq.	Incineration	5.2	5.3	5.1	5.2	7.0	6.8	7.0	9.4	10.1	5.4	3.2
	Energy recovery	4.3	4.1	3.9	3.9	5.9	5.9	5.9	8.7	9.4	4.7	2.7
	Pyrolysis (Energy)	1.9	1.9	1.7	1.8	3.4	3.2	3.4	7.2	7.5	3.4	3.2
	Gasification (Energy)	1.5	1.7	1.4	1.5	3.6	3.5	3.6	7.0	7.2	3.3	2.3
	Pyrolysis (Wax)	1.6	1.7	1.4	1.5	3.1	3.0	3.1	6.9	7.2	3.0	2.0
	Mechanical (Open loop)	2.0	2.0	1.9	1.9	3.0	2.9	3.0	5.0	5.2	2.5	2.2
	Pyrolysis (Monomers)	1.3	1.4	1.2	1.3	1.5	1.6	1.7	2.7	2.9	2.9	2.5
	Gasification (Monomers)	1.0	1.1	0.8	0.9	2.4	2.3	2.5	6.6	6.9	2.6	2.5
Low relative CO_2-eq	Mechanical (Closed loop)	1.4	1.3	1.3	1.3	1.8	1.8	1.8	2.4	2.6	1.5	1.0
	Dissolution	1.6	1.6	1.6	1.6	1.8	1.8	1.9	2.0	2.2	2.3	-
	Depolymerisation	-	-	-	-	-	-	-	-	1.8	1.3	-
	Hydrolysis	-	-	-	-	-	-	-	-	-	-	1.3

Climate change (kg CO_2 eq. / kg polymer)		Complex polymers												Thermoset polymers	
		ABS	PVC	EVA	EVOH	PA (nylon 66)	PAN	PBT	PC	PEEK	POM	PSU	PTFE	PUR	Epoxy resins
High relative CO_2-eq.	Incineration	7.8	4.0	4.4	7.7	10.6	8.9	5.5	10.3	14.5	3.4	10.7	138.9	6.7	7.6
	Energy recovery	6.8	3.4	3.6	6.8	9.9	8.1	5.0	9.5	13.7	3.0	9.9	138.7	5.8	6.6
	Pyrolysis (Energy)	4.4	2.0	2.3	5.5	8.1	5.6	3.4	8.0	11.6	2.5	7.9	137.4	4.7	5.2
	Gasification (Energy)	4.5	2.0	1.7	5.1	7.7	5.9	3.1	7.8	11.7	1.8	8.2	137.6	4.4	5.1
	Pyrolysis (Wax)	4.1	2.1	2.0	5.1	7.8	5.3	3.0	7.7	11.3	2.2	7.7	137.1	4.3	5.0
	Mechanical (Open loop)	3.5	1.9	1.9	3.9	5.6	4.3	2.6	5.4	7.7	1.7	5.6	83.0	-	-
	Pyrolysis (Monomers)	4.2	2.2	2.0	5.3	7.6	5.1	2.8	7.4	10.9	2.0	7.4	70.6	4.3	4.7
	Gasification (Monomers)	3.9	2.0	1.5	4.7	7.4	5.0	2.7	7.2	10.7	2.0	7.2	137.0	4.0	4.5
Low relative CO_2-eq	Mechanical (Closed loop)	2.0	1.2	1.2	2.1	2.8	2.3	1.8	2.8	3.6	1.1	2.8	33.7	-	-
	Dissolution	1.8	1.5	1.5	1.9	2.2	2.0	1.7	2.3	2.5	1.4	2.3	15.0	1.8	2.0
	Depolymerisation	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hydrolysis	-	-	-	-	-	-	-	-	-	-	-	-	-	-

CO_2 emission reduction: 0% – 100%

Figure 60. Plastic recycling in a circular economy; determining environmental performance through an LCA matrix model approach - ScienceDirect (assessed 2023-03-07).

The results have been presented at internal project meetings and discussed with representative from the plastic industry and the automotive industry. The research project has shown that the replacement of replace fossil plastic to recycling plastic in the Swedish automotive industry is possible. The environmental study has shown that the replacement will lead to reduced carbon emissions in the automotive industry.

The carbon footprint for the transport from plastic production in Europe to the automotive industry in Sweden is very low, around 1-4% of the climate impact from production depending on the type of transport (road cargo or sea cargo) and the type of plastic (2kg CO2e/kg for PP and 3,7 kg CO2 for PC/ABS), while transport from Asia/China means 10-30% depending on the type of sea cargo. (Source: www.transportmeasures.org, road cargo baseline Europe, sea cargo baselines, 2022)

The carbon footprint for injection moulding is also very low, only 1-4% of the climate impact from production depending on the amount of energy used (3,49 kwh/kg) and the type of energy use for moulding (7,26 g CO2e/kwh or 23 g CO2e/kwh). (Sources: Estimating energy consumption of injection moulding for environmental-driven mould design - ScienceDirect) and EPD vattenfall Nordic Hydro Power 2021.pdf, and https://ei.se/bransch/ursprungsmarkning-av-el/residualmix, assessed 2023-03-14)

The potential for climate reduction (recycled plastics) are presented using an average value for plastics weight (261 kg Volvo Car and 500kg Volvo Truck) and average carbon footprint (3 kg CO2/kg plastic) and recent sales data (Volvo Cars, 2021, and Volvo trucks, 2022).

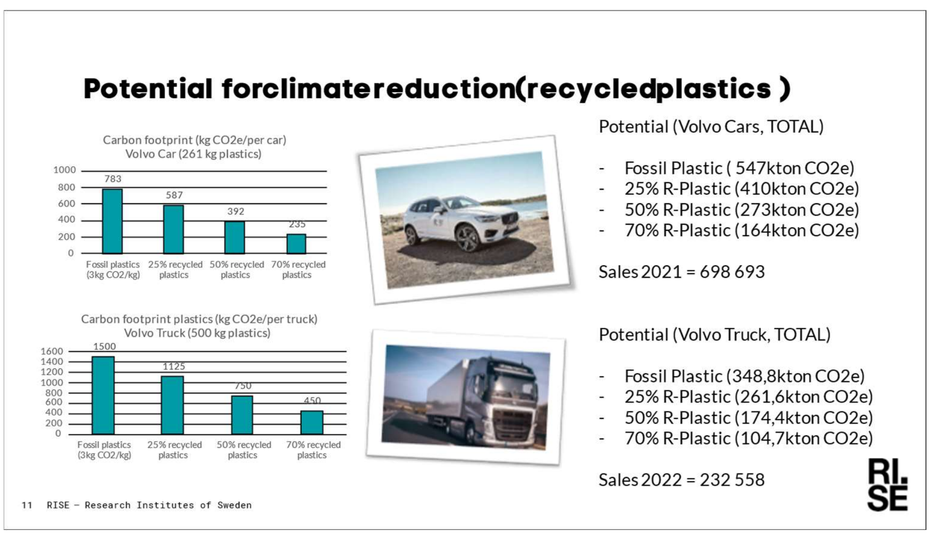


Figure 61. Sources: AB-Volvo-Arsredovisning-2022.pdf (volvogroup.com) and Volvo Car AB (publ) publishes Annual and Sustainability Report 2021 - Volvo Cars Global Media Newsroom (assessed 2023-03-14).

5.7.2. Economic impact

No economic analysis has been performed. None of the partners were not willing to give information about prices and costs. But generally, the price of the recycled plastic lies between 80 % and 100 % of the price of virgin plastics. The price depends on the quality of the recycled plastic, the processes needed to upgrade the plastic to a raw material with the right properties. The production cost depends on if the use of recycled plastic will increase the production time and if more scrap is generated due to defect components. The finding in this project was that the production time was not influenced in the test runs performed,

The availability of high quality recycled plastic is limited. Thus, it is probable that the prices will increase with increased damand on recycled plastics. Most likely the recycling of plastics from vehicles and other sources will increase. The new ELV directive will lead to increased dismantling of plastic components for recycling from crashed cars and end of life cars. However, dismantling of components, transports and the recycling processes is costly. Thus, the recycled material might be on same price level as virgin plastic.

6. Conclusions, making use of results and next step

Main conclusions and outcomes from the project:

- The project has shown that recycled plastic in significant amounts can be implemented in vehicle components, also in parts with high demands on safety and surface finish.
- 19 test runs of car components and 10 test runs of truck components have been performed within the project, most of them with good results.
- Painting of components and plaques of recycled PC/ABS plastic was no issue, The unpainted plain parts were more sensitive to visual defects.
- The recycled PP PIR materials exposed to accelerated ageing are very durable with long service life but heat ageing of PC/ABS degraded the materials tested in short time (both recycled and virgin). The recyclability of PC/ABS is difficult to predict. With different polymers the PC/ABS is more complex than PP.
- Panel tailgates and hatch warning triangles produced by KB Components with 30 % recycled plastic, are now approved for implementation in Volvo XC60.
- Battery box and lid produced by KB Components with 30 % recycled plastic are approved for implementation in Volvo XC60 and Volvo XC90.
- The A and B pillars for Volvo Cars with 50 % recycled plastic were approved in all the tests. However, Volvo Cars is not ready to implement the recycled plastic in the pillars yet for safety reasons.
- Components for Volvo Trucks, bumper corner and door extension extenders have been produced successfully by Plasman and tested with good results. Urban Elfsberg at Volvo sees good opportunities to implement recycled plastic in these components.
- SID panel inboard for Volvo Trucks was successfully produced with approximately 30 % recycled PC/ABS by IAC. The component requirements are fulfilled and Urban Elfsberg at Volvo sees good opportunities to implement recycled plastic in the component.

The collaboration between project partners has been very fruitful. The knowledge generated from test runs and evaluation of recycled plastics are very useful for the work forward with the implementation of recycled plastics in vehicles. The potential for Volvo Cars is to save 137 000 tonnes of CO_{2eq} emissions if 25 % of recycled plastic replace virgin plastic in the cars produced globally and 274 000 tonnes if 50 % is replaced.

The knowledge generated in this project can also be useful for the introduction of recycled plastic in other sectors producing plastic products with high demands on quality and durability, like the building and construction sector. The work forward will be to continue to implement the recycled plastics in car and truck components and increase the use of PCR plastic. The main challenge is to find enough recycled plastic of the right type and quality to scale up and implement. Increased demand of recycled plastic will most likely lead to increase prices. It will also most likely lead to increased dismantling and recycling of plastic from vehicles into new vehicle components.

7. Project communication

To ensure dissemination of the results to stakeholders, the project has been discussed and presented in several contexts. Below is an overview of where the work in the project has been spread.

Seminar and Showroom

- Sustainable Vehicles with Recycled Plastics, at RISE on March 21, 2023.
  Project results and were presented by RISE and the project partners at a open Seminar. The components produced were shown in a Showroom. A Volvo truck and a Volvo car with compoundents of recycled plastics were demonstrated.

Publication

- Framtidens forskning, 15 Juni 2023, Volvo leder vägen mot en cirkulär fordonsindustri - Framtidens forskning)

Presentations

- Presentation Plastteknik exhibition on May 5, 2023.
- Presentation for RISE Network meeting for plastic recycling on May 24, 2023
- Several presentations for project members at RISE.
- Several presentations by the project partners and showing of components.

Social media kanaler

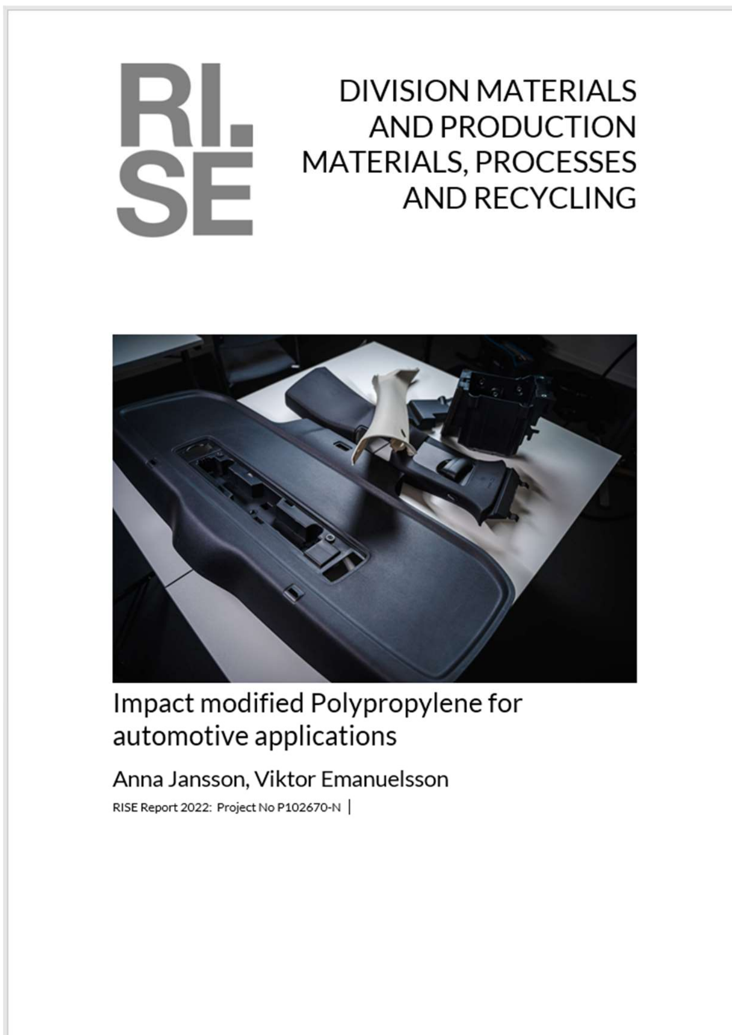
- During the project, several posts were made on social media (i.e. on LinkedIn)

Video

- Filming on the Seminar at RISE, May 21. Film and text is planned to be published in august at the RISE website.

8. Appendix

Appendix 1. Project Report, Impact modified Polypropylene for automotive application.



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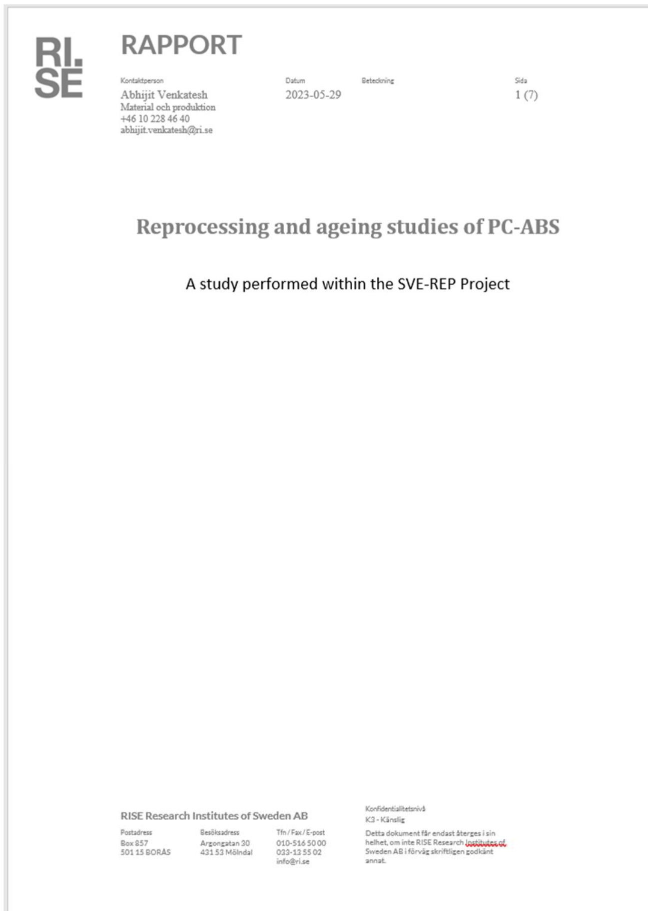
DIVISION MATERIALS
AND PRODUCTION
MATERIALS, PROCESSES
AND RECYCLING

Impact modified Polypropylene for automotive applications

Anna Jansson, Viktor Emanuelsson

RISE Report 2022: Project No P102670-N |

Appendix 2. Project Report, Reprocessing and ageing studies of PC-ABS.



RAPPORT

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Reprocessing and ageing studies of PC-ABS

A study performed within the SVE-REP Project

RISE Research Institutes of Sweden AB

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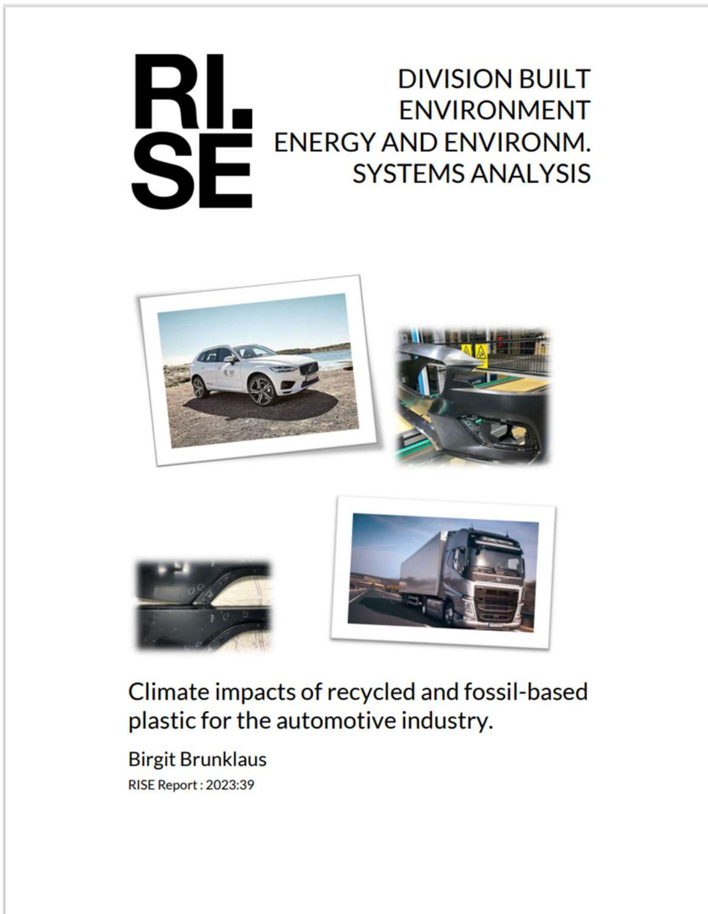
Konfidentialitetsnivå
K3 - Känslig

Detta dokument får endast återges i sin helhet, om inte RISE Research Institutes of Sweden AB i förväg skriftligen godkänt annat.

Appendix 3. Project Report, Climate impact of recycled and fossil-based plastic for the automotive industry.



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Climate impacts of recycled and fossil-based plastic for the automotive industry.

Birgit Brunklaus

RISE Report : 2023:39

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