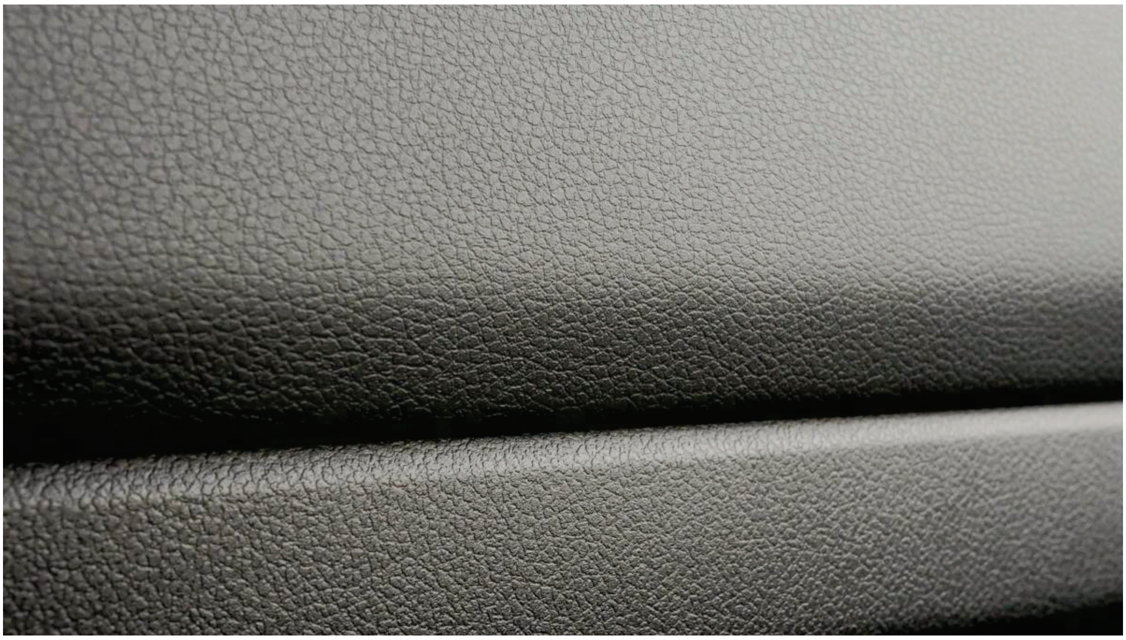
Robust texture design for circular polymers 2

Public report



Project within FFI Circularity

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Fordonsstrategisk
Forskning och
Innovation

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FFI in short

FFI, Strategic Vehicle Research and Innovation, is a joint program between the state and the automotive industry running since 2009. FFI promotes and finances research and innovation to sustainable road transport.

For more information: www.ffisweden.se

1. Summary

The ROPY2 project was conducted within the FFI Circularity programme. The project objective was to develop methods, tools and guidelines that help OEMs develop products that are attractive to users and at the same time allow increased amounts of recycled material to be used and thereby enable circular material flows. Variations in recycled materials create uncertainty in surface-replication outcomes, and the project therefore investigated how robust surface-texture specifications could support predictable manufacturing results and quality assessments. Work centred around two research questions: (1) identifying desired surface properties and (2) determining achievable manufacturing outcomes. Four work packages addressed quality-assessment modelling, replication modelling, industrial guidelines, and project management.

An experimental campaign was conducted where samples were manufactured using PP and ABS with varying recycled content and evaluated through quality assessments, digital images, measurement of gloss, micro-gloss variation, and surface topography. Modelling examined relationships between material composition, process conditions, and both measured and perceived quality. Key findings showed that differences in small-scale topographical features strongly influence gloss and perception, and that recycled materials behave similarly to virgin materials in this regard. No single model was optimal across all cases. Coarse textures were easier to classify with regard to defects and fine textures depended on a few topographical parameters. Defect detection using weakly supervised learning proved effective. The project also highlighted the need for harmonised terminology and structured data collection.

Although the variation in experimental results limited predictive accuracy, the project produced valuable insights and practical guidelines supporting further work towards increased use of recycled polymers in high-quality interior components.

2. Sammanfattning på svenska

Projektet ROPY2, Robust texture design for circular polymers 2, som genomfördes inom FFI Cirkularitet, behandlade hur önskvärd ytkvalitet hos interiöra fordonskomponenter kan säkerställas när större mängder återvunnen polymer används. Eftersom återvunnet material uppvisar större variationer än jungfruligt material skapas osäkerheter i hur väl en avsedd ytstruktur kan replikeras vid formsprutning. Projektets utgångspunkt var att robusta ytspecifikationer kan möjliggöra ökad cirkularitet. Med 'robusta ytspecifikationer' avses en kravbild som säkerställer önskade egenskaper och som samtidigt sannolikt kan replikeras inom tolerans trots variationer i material och process.

Två huvudsakliga forskningsfrågor har styrt arbetet:

1. vilka ytegenskaper som efterfrågas (perception), och

2. vilka tillverkningsutfall som är troliga (replikering).

Projektet genomfördes i fyra arbetspaket: utveckling av modeller för kvalitetsbedömning (WP1), modeller för replikeringskvalitet (WP2), industriella guidelines (WP3) samt projektledning (WP4).

Experiment utfördes med PP- och ABS-material med olika andelar återvunnet innehåll och varierade processinställningar. Tillverkade provkomponenter bedömdes enligt ett gemensamt definierat protokoll och analyserades med avseende på glans, mikroglansvariation, digitala bilder och ytstrukturmätningar. Utveckling av modellering bedrevs iterativt för att säkerställa industriell relevans. Ytterligare analyser gjordes, bland annat av sambandet mellan uppmätt glans, bedömd glans och småskaliga topografiska egenskaper.

Projektresultat visade att skillnader i yttopografi i småskaliga, högfrekventa strukturer tydligt påverkar både upplevd och uppmätt glans, vilket stämmer väl med tidigare forskning. Projektet kunde också påvisa att de testade återvunna materialen reagerade på liknande sätt som jungfruliga material vid ändrade verktygstemperaturer.

Modellering av kvalitetsbedömningar visade att olika analyser kräver olika modeller. Grova texturer var generellt lättare att klassificera än fina när det gäller defekter. Kombinationer av bilddata och topografidata gav bäst resultat för grova texturer, medan en begränsad uppsättning topografiparametrar räckte för fina texturer. För defektdetektering på PP-komponenter fungerade en metod med 'weakly supervised multiple instance learning' väl.

Även för modellering av tillverkningsutfall krävdes olika modeller beroende på material och typ av ytstruktur. För fina strukturer i PP sågs ett tydligt och närmast linjärt samband mellan Sdr och mängden återvunnet material, medan grova texturer visade mer komplexa samband som kräver mer avancerad modellering och karaktärisering.

Arbetet med industriella guidelines visade behovet av att en gemensam nomenklatur och ontologi utvecklas för att beskriva den avsedda formen på mönster för att möjliggöra effektiv kommunikation och kravsättning. Arbetet visade också att en mer kontinuerlig och strukturerad insamling av data (mätvärden, bilder och expertbedömningar) skulle vara värdefull för framtida utveckling.

Trots att data från experimenten inte motsvarade hela den avsedda variationen och därmed begränsade modellernas prediktiva förmåga, genererade projektet viktiga insikter och etablerade en bra grund för fortsatt forskning.

3. Background

Interior automotive plastic components are often manufactured by injection moulding, since this technique enables cost-efficient manufacturing, a large design freedom, and easy integration of functions. To achieve the intended appearance of the components, they are normally given a texture, in addition to carefully selected colour and gloss properties. Future vehicles will likely be manufactured using larger amounts of recycled materials, including polymers for interior parts with requirements regarding perceived quality. A challenge is that recycled polymers can have varying characteristics, causing uncertainties regarding expected replication results.

4. Purpose, research questions and method

The assumption in the project context was that textures could be designed with robust surface specifications meaning that they have a high probability of being replicated within specification with a variety of polymers, including materials with a large amount of recycled content. Using robust surface texture specifications would enable increased use of recycled material in polymer parts. The overall purpose of the project ROPY2 is to develop methods, tools, and guidelines for robust specification of surface texture to allow design and manufacture of automotive interior polymer components with larger material variations, thereby enabling circular material flows, see Figure 1 below.

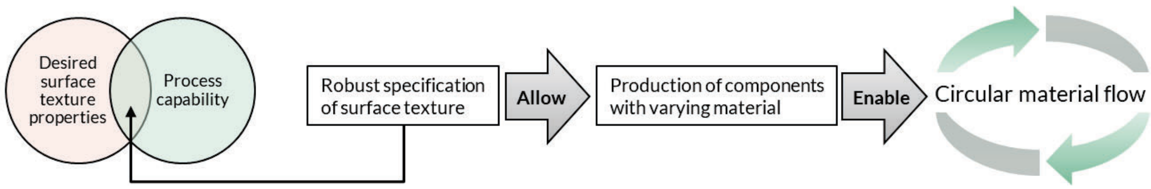


Figure 1: Conceptual illustration of how robust specification of surface texture enables circular material flow.

The two main research questions (RQ) of the project were related to the areas that together define the boundary conditions for the 'robust specifications of surface texture':

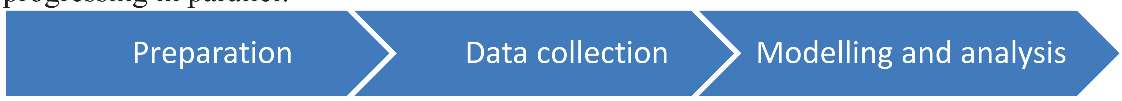
RQ1. What are the desired surface properties?
RQ2. What are the possible manufacturing outcomes?

The project was planned in four work packages.

- WP1 Development of a model for quality assessment
  - WP led by RISE
  - Development of a model to enable prediction of quality assessments based on quantitative data
- WP2 Development of a model for replication quality
  - WP led by Chalmers

    - Development of a predictive model for surface texture replication quality using various process and material related data, in combination with quantitative measurement data and quality assessments
- WP3 Development of industrial guidelines
    - WP led by Scania
    - Summary and compilation of information, methods, and results from WP1 and WP2 into industrial guidelines
- WP4 Project management
    - WP led by RISE
    - Handling of all general project management tasks, including reporting to Vinnova, administration of agreements, project steering, and dissemination

The project work was conducted sequentially in three phases, with all work packages progressing in parallel:



In the preparation phase, the goal was to prepare for experiments and data collection in different ways. The preparation work was done in three tracks with different themes: Perception, New moulding tool, and Material.

- In the track regarding Perception, the focus was on developing a common understanding and nomenclature concerning how surface quality is assessed by the OEMs, which aspects that should be included in the evaluations in the project, a preliminary analysis of already existing perception data, as well as defining a protocol for assessing surface quality in the project.
- In the 'New moulding tool' track, the focus was on designing a new demonstrator, including geometry, surface textures, tooling design, and manufacture of the moulding tool.
- The work in the 'Materials' track was aimed at deciding the materials, material variations, and process conditions that were to be used in the project.

In phase 2, Data collection, the goal was to conduct experiments and collect data for analysis. This was done by the manufacture of samples using the different materials and process conditions, followed by surface quality assessments and different types of measurements. Samples were made with two different material types (PP and ABS) with different amounts of recycled content and some variations in the processing conditions. Following the protocol established during the preparation phase, we evaluated the samples and measured properties including gloss, micro-gloss variation, and surface topography, as well as took digital images. See Figure 2 below for an example of a digital image and a surface topography measurement from a coarse surface texture.

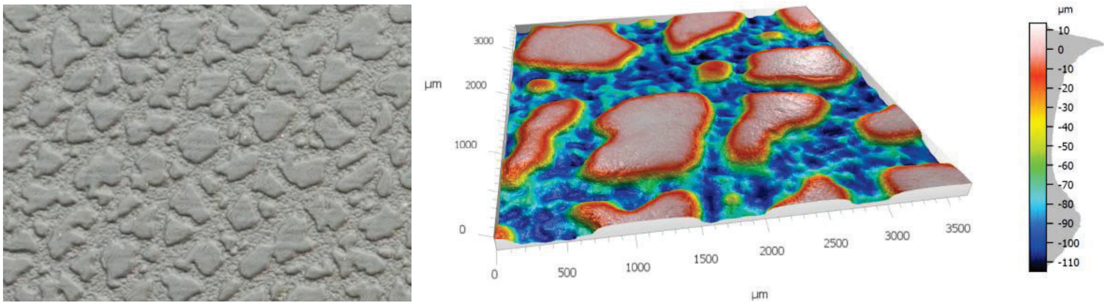


Figure 2: Digital image (left) and surface topography measurement (right) from a PP sample with coarse surface texture.

In phase 3, Modelling and analysis, models for perception and for materials and processing conditions were developed respectively. Here, iterative approaches were used, with loops of model development and feedback, to ensure that the models would be useful and relevant. The work progressed through a series of workshops and online meetings. Additional analyses were also carries out, such as evaluation of methods for processing and quantification of topography data, the relation between measured gloss, assessed gloss, and micro-gloss variation. Industrial guidelines were developed through a separate process, via a series of workshops and online meetings. The focus was to formulate a common description of the industrial context where the project results, and future developments of the results, were to be used, identify future needs, and summarize the project results.

5. Objective

The main objective of the project was to develop methods, tools, and guidelines that help OEMs develop products that are attractive to users and at the same time allow recycled material to be used, thereby enabling circular material flow.

6. Results and deliverables

WP1 resulted in several models for predicting quality assessments for different combinations of material composition and types of surface texture. The predictive power of the models varies due to the range and variation of the experimental results. The modelling results confirmed findings from previous projects regarding correlations between, e.g., measured gloss and surface texture. In addition, it led to discussions on new, and more detailed, quantitative measures of surface texture with high relevance for different aspects of the assessments.

WP2 resulted in several models for predicting manufacturing outcomes depending on combinations of processing conditions and material composition. Here as well, the predictive power of the models varies due to the range and variation of the experimental results.

WP3 resulted in a report describing the context where the project results can be industrially used, summaries of the different project results, lessons learned from the project, and remaining needs.

WP4 carried out administrative activities such as reporting to Vinnova, negotiating the project agreement, and planning. In addition, the project was represented and presented at several events such as the CIRP General Assembly part 2 and WIRA SuPRA meetings.

6.1 Key findings

In surface topography investigations, differences were observed mostly in smaller or high-frequency features, which affect both perceived and measured gloss. The surface texture analysis and filtering approaches were aimed at characterizing these smaller-scale features. It was observed that the recycled materials, as shown in Figure 3 and Figure 4, are equally responsive as their virgin counterparts, exhibiting comparable changes in the smaller-scale surface features with varying tool temperatures.

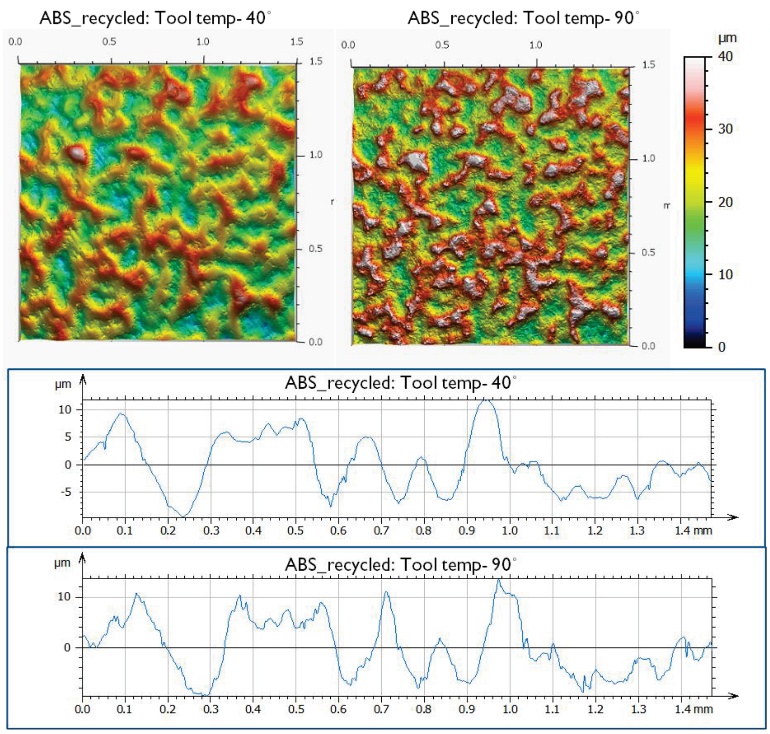


Figure 3: Surface topography and profile maps of injection moulded fine texture recycled ABS surfaces.

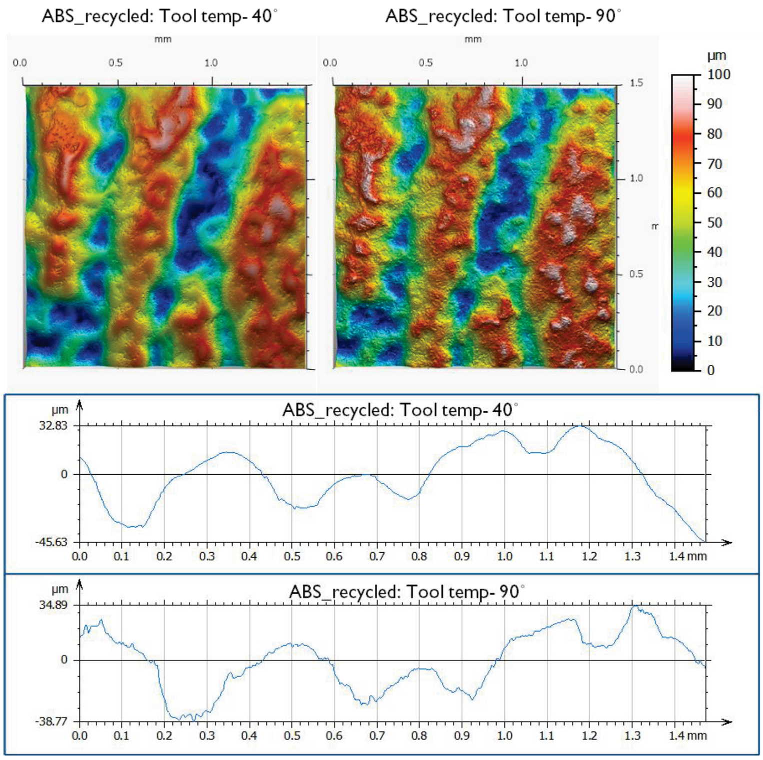


Figure 4: Surface topography and profile maps of injection moulded coarse texture recycled ABS surfaces.

In the modelling of quality assessment and defect detection, it was found that no single model was best for all cases. Different models should be used for different tasks. Furthermore, the coarse textures were generally easier to classify than the fine textures. The coarse textures could best be classified with a fusion of image and topographical data. The fine textures could most efficiently be classified with a small subset of topographical data. For defect detection on PP samples, a weakly supervised multiple instance learning approach was successfully used to classify and locate defects in non-optimized images, see the illustration of the concept in Figure 5 below.

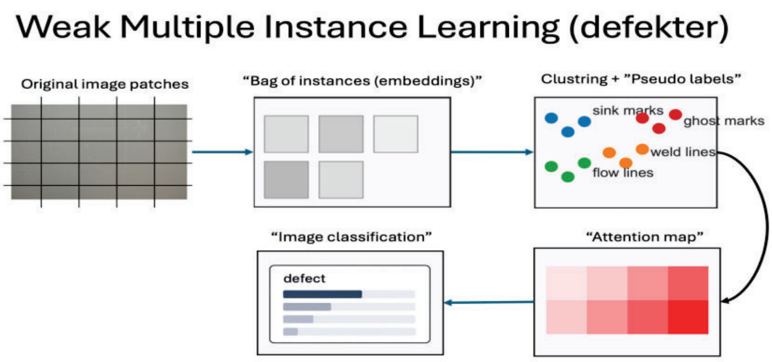


Figure 5: Illustration of the weakly supervised multiple instance learning concept.

Also in the modelling of manufacturing outcome, it was found that different models were required for the specific cases depending on processing conditions and material compositions. Two modelling strategies were used: (i) logistic regression for visible defects, and (ii) regression-based models—ordinary linear regression or Gaussian Process Regression (GPR)—for topography values. For fine textures with PP materials, the relationship between Sdr and recycled content was strong and approximately linear, see Figure 6. However, Sdr is sensitive to the instrument's resolution and noise, so this must be considered when using such models. For coarse textures, parameter effects were weaker and more complex, suggesting that another modelling approach should be used, possibly in combination with more complex surface texture characterization.

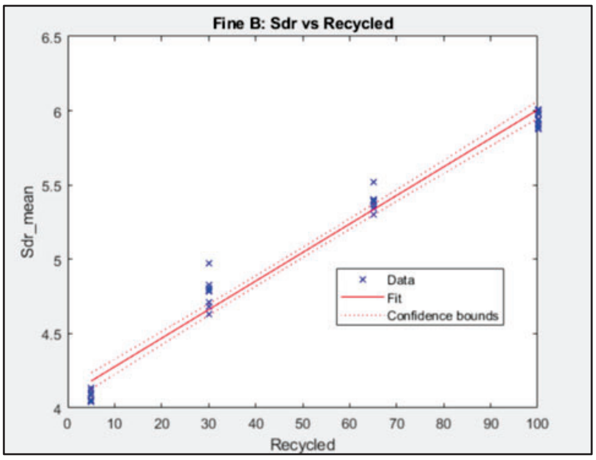


Figure 6: Linear regression between Sdr and amount (%) recycled content for fine texture with PP material.

During the work with industrial guidelines, several key findings were made.

- Even though the involved industries have similar processes for assessing quality, the words used for similar processes or properties vary. Consequently, there is a need for a harmonized nomenclature for efficient continued collaborative work in this field.
- A complementary nomenclature, or ontology, needs to be developed for the description of the intended shape of the surface texture to enable communication in a more specific and unambiguous way.
- It will be valuable for future research and development to continuously collect data from quality assessments in a structured manner. This can include measured values, digital images, and structured expert assessments.

Some concluding comments regarding the results: The experimental results did not cover all the intended range of outcomes. This led to limitations regarding the analyses that the project could perform and the predictive power of the developed models. There were good discussions and several shared learnings regarding the qualitative aspects of the results, but the quantitative parts did not reach the expectations at the start of the project. One of the major learnings was that it is always more challenging than expected to get good experimental results. However, the report developed in WP3 exceeded expectations in terms of scope, content, and usability for future research.

The project results contribute towards FFI's overall impact goals by helping to develop sustainable solutions that can be implemented and accepted by users and society. Regarding the missions of the FFI sub-program Circularity, the project focuses on design for circularity and enabling circular material flows. This will be achieved with tools and guidelines that help product designers develop products that are attractive to users and at the same time allow recycled material to be used. Use of tools and guidelines for design of attractive products with circular materials will accelerate the implementation of sustainable solutions leading to more efficient use of resources.

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	Competence development in both research community and industry which will lead to closer collaboration and continued development ideas.
Be passed on to other advanced technological development projects	X	Several needs for future developments have been identified.
Be passed on to product development projects	X	Methods developed and knowledge gained in the project can be used in future product development.
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions		

7.2 Publications

No publication has been finalized during the project period. However, several publications are in different stages of development.

8. Conclusions and future research

- The project showed that there are gaps regarding the understanding of how quantitative measures of surface topography relate to perceived quality. Some of these gaps were investigated in the project.
- It was also shown that advanced modelling, i.e. including machine learning, can improve the usefulness of captured data.

- Even though the project results did not reach all the expectations at the start, many things were learned and a good foundation was created for further development.

9. Participating parties and contact persons

RISE Research Institutes of Sweden: Johan Fast Berglund (project lead)

Chalmers: Kristina Wärmefjord

Halmstad University: Bengt-Göran Rosén

Polymertekniska Institutet: Joakim Wiedesheim

Scania: Jerpdal Lars

Volvo Technology: Urban Elfsberg

Volvo Cars: Birgitta Carlsson