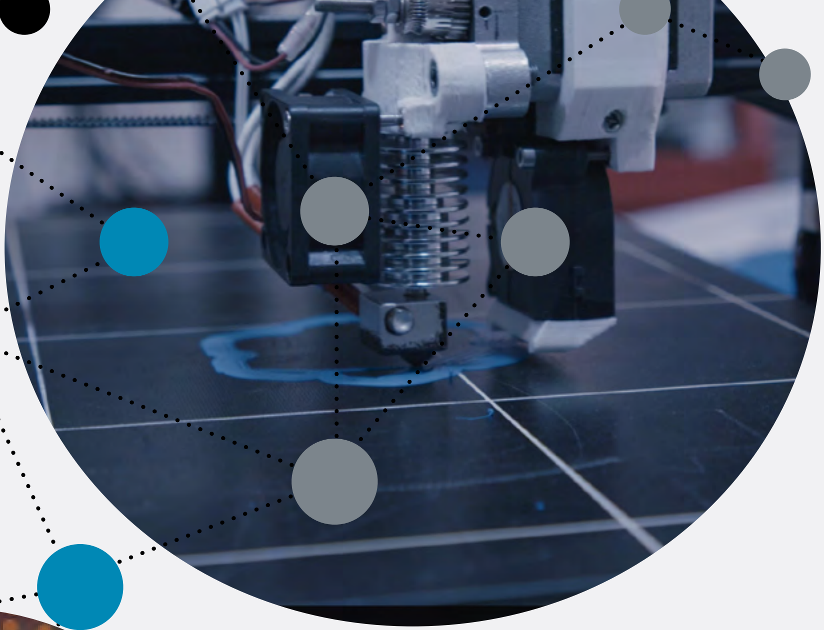
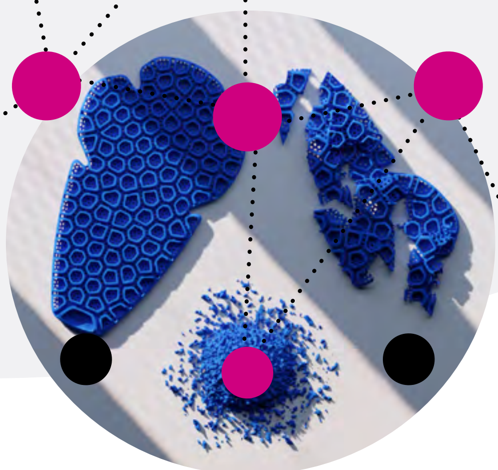


NICER PROGRAMME & INNOVATE UK

CIRCULAR ECONOMY FOR SMEs

RHEON Labs



UKRI Interdisciplinary Centre for Circular Chemical Economy

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RE-RHEON 3D

The Challenge: What We Were Trying to Achieve

At the core of RHEON™ technology is a reactive polymer that intelligently strengthens when subjected to force. The technology can control energy of any amplitude or frequency – from small vibrations to life-threatening single impacts. Thus, the main use of RHEON™ parts is in helmets and other life-saving applications. Our parts are manufactured using traditional injection moulding, and thus create polymer waste in the process. While injection moulding is the method of choice for mass manufacturing simple geometries, we currently cannot reuse injection moulding waste and sprues in our production facilities in the UK. It is crucial to develop a process to re-incorporate this material waste into useful end-user parts, creating an environmental and economic benefit. In addition, we currently face customer requirements around lightweight parts with complex geometries, especially in the helmet industry, which we cannot meet using injection moulding. This project aims to address on the one hand the reuse of RHEON™ waste created in our manufacturing facilities, and on the other hand enable us to meet customer requirements for bespoke lightweight structures and advanced geometries.

The Approach: How We Tackled the Challenge

This project assessed reusing RHEON™ polymer waste and converting it into useful feedstock for 3D printing via Fused Filament Fabrication (FFF) and Selective Laser Sintering (SLS).

FFF development: The RHEON™ polymer formulation is challenging to 3D print due to its softness, flexibility, and strain-rate sensitivity. Commercial 3D printing heads using Bowden-type extruders were unsuitable for the RHEON™ technology. A commercial direct drive extruder print head was also trialed but found unsuitable. The print head and extruder were redesigned, and the material formulation was optimized to allow for the required flow properties and print quality. The print settings were optimized, and a cooling system was added. The AM-COE developed post-processing methods, e.g., solvent vapor smoothening, to provide parts with a smooth surface finish. Various amounts of recycled material were studied and 3D printing filaments with 0%, 25%, 50%, and 100% recycled RHEON™ material were produced. The performance of these 3D parts was studied, showing negligible influence of the percentage of recycled material on mechanical properties or impact performance. The mechanical and impact performance of 3D printed parts was benchmarked against injection molded geometries, displaying comparable performance.

SLS development: This project focused on developing a powder feedstock for SLS using recycled RHEON™ polymer. A commercial SLS 3D printer was modified to allow for rapid formulation screening with small material quantities. Various methods of post-processing and densification were investigated.

Crucial partnerships and collaborations: Collaboration with the Additive Manufacturing Centre of Excellence, who has extensive expertise in 3D printing and specifically in sintering, led to significant contributions to this project. Access to critical specialist equipment to characterize raw materials and powders was also beneficial.

Unexpected Outcomes: What We Learned Along the Way

Filament development: Due to the softness and strain-rate-sensitivity of the RHEON™ polymer formulation, this was extremely challenging. Unexpectedly, a combination of hardware design and material flow optimization allowed us to 3D print the first strain-rate-sensitive polymer. Initially, we focused on increasing the hardness and stiffness of the material formulation, which would have significantly altered the mechanical and impact performance. However, the successful modification of hardware and formulation allowed us to 3D print the softest material currently available on the market.

Effect of recycled material on mechanical and impact performance: We expected a reduced performance of parts produced using high percentages of recycled RHEON™ polymer, however parts with high percentages of recycled materials (up to 100%) displayed a comparable mechanical and impact performance to parts produced with 100% virgin material.

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Performance of 3D printed parts was comparable to injection moulded parts. Thus, this project allowed us to develop a powerful prototyping tool and study new 3D geometries without the requirement for tooling.

Key Learning: What We Would Do Differently Next Time

Feasibility of re-using post-industrial waste: The project's primary insight focused on converting RHEON™ waste from injection moulding production plants into useful feedstock for 3D printing. This process would help reduce the amount of polymer that ends up as landfill to less than 5%. Currently, the team is exploring a similar approach for film manufacturing facilities.

Development of a powerful prototyping tool using 3D printing: The RHEON™ technology is based on using an energy-absorbing strain-rate-sensitive polymer formulation with engineered 3-dimensional geometries. To study new geometries, the team initially uses predictive tools, produces a prototype injection moulding tool, and tests various iterations to find optimized geometry-material combinations, which is a lengthy (4-6 weeks per iteration) and cost-intensive process. The use of 3D printing allows for a rapid iteration of geometries (about 2-3 days per geometry), which can lead to a potentially rapid study and optimization of performance.

Advice for similar initiatives: Due to the project's length, planning all activities and contingency plans are key.

The Outcome: What We Achieved and How It Has Impacted the Business, Society and Key Stakeholders

- Process and methods to re-use and recycle post-industrial RHEON™ waste created in our production facilities by converting it into useful feedstock for 3D printing (upcycling).
- Study of the effect of percentage of recycled material on mechanical and impact performance and thus allowing for the development of a material with the optimized percentage of recycled polymer.
- Thorough performance comparison between 3D printed parts and injection moulded analogues with various amounts of recycled material.
- Learnings from this feasibility study can be applied to other business units, such as our film manufacturing.

Looking Forward: Next Steps and Future Directions

The Innovate UK feasibility study assessed the technical viability of converting post-industrial RHEON™ polymer waste from our injection moulding production facility into useful feedstock for 3D printing (FDM and SLS). We benchmarked and showcased the use of this technology for prototyping novel 3-dimensional geometries developed at RHEON Labs. The effect of the percentage of recycled materials on part performance was studied and a comparison to conventional injection moulded parts was carried out. These studies confirmed the possibility to use 3D printing for prototyping new 3-dimensional RHEON™ designs. This opens a new research avenue around 3D printing, which will initially be used as an internal 3D printing capability but will be further developed to a commercial scale in the future.

The RHEON™ technology combines a highly strain-rate-sensitive polymer with engineered 3-dimensional geometries, resulting in advanced impact protection and energy absorption. Currently, the development of 3-dimensional geometries involves predictive tools, computational design, and prototype moulds for injection moulding. This allows for the fabrication and testing of various iterations of prototype parts, with the prototyping-testing cycle taking between 4-6 weeks, due to tooling fabrication, and being cost-intensive. However, this project enables a considerably faster and more streamlined process for prototyping using 3D printing.

Despite the progress achieved during this project, the 3D printing methods and processes developed are only suitable for prototyping rough geometries. They don't allow for the fabrication of highly accurate parts with intricate geometries. Further work is required to optimize the hardware to achieve accurate, intricate prints with small feature sizes. Additionally, parts displaying curvatures and overhangs 3D printed with FFF require support structures. This becomes challenging when very soft materials with low stiffnesses are used, as a high density of supports is necessary. A 3D printing method using two separate print heads and a soluble filament is required. This project also enabled the development of a proof-of-concept powder material used in SLS. However, extensive optimization is required before commercialization.

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Research was carried out by RHEON Labs with support from the UKRI National Interdisciplinary Centre for the Circular Chemical Economy and the Additive Manufacturing Centre of Excellence.