Polypropylene designed for 3D printing

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Conclusion

A design oriented approach revealed material properties for fused filament fabriaction (FFF) printable filaments based on polypropylene copolymers.

Material influencing properties as viscosity, molecular weight and cristallinity were set within narrow limits. The desirability plot of the design space points out a region where to expect desirable ranges of parameters with high probabilities. Optimized polypropylene was then printed and tested.

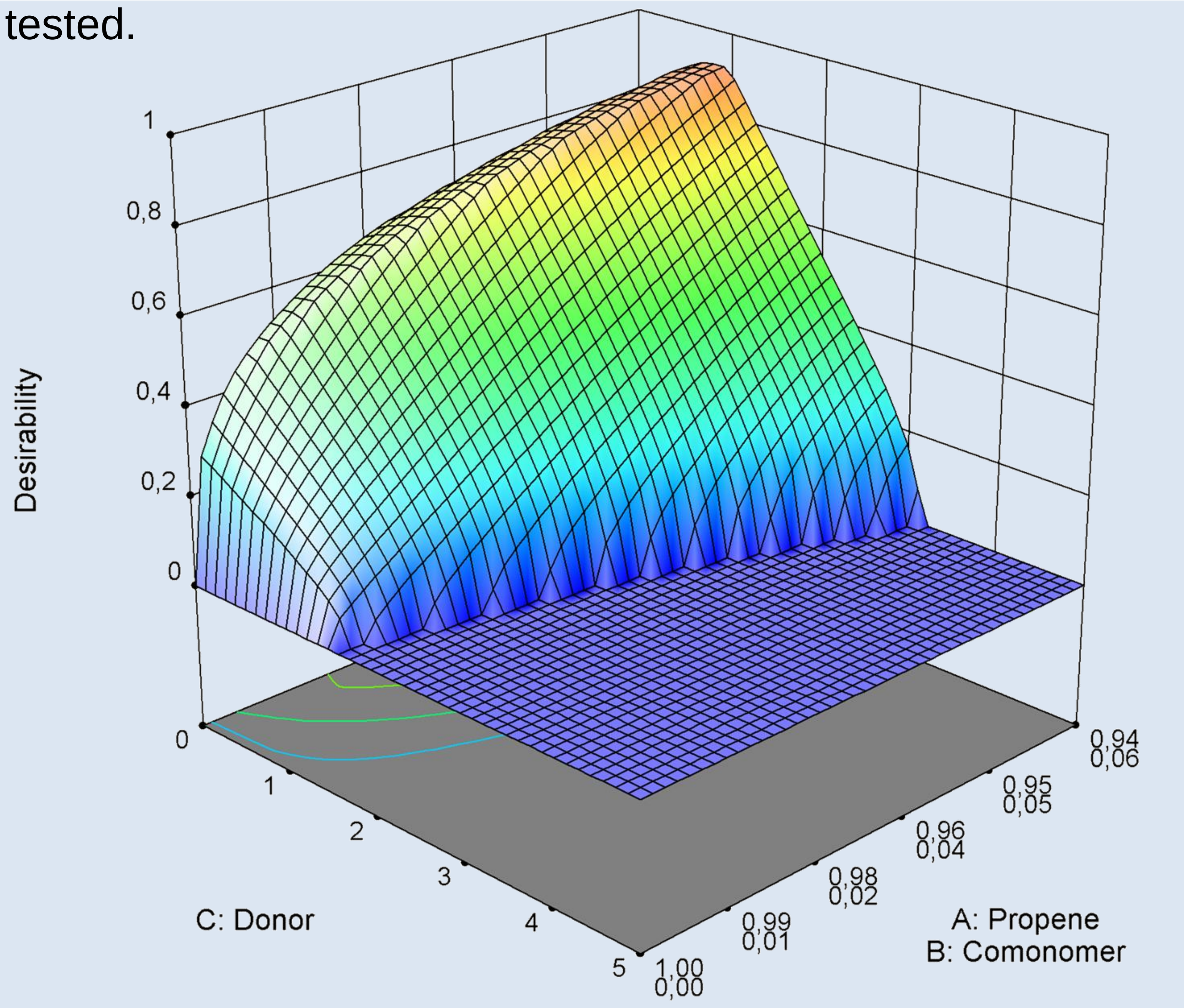

Figure 1: Desirability plot for a Polypropylene-copolymer, which accumulates all measured responses within targeted ranges. The plot describes a set of parameters which correspond to a probability (graph surface) to achieve suitable material properties.

Introduction

Production methodologies are changing and with it material diversity and requirements are increasing. 3D printing is an uprising technique which is perfect for rapid prototyping and small series.

Concerning the fused filament fabrication process the most commonly used filament materials are primarily acrylonitrile-butadiene-styrene (ABS) and polylactic acid (PLA).

Advantages of Polyolefins are their low cost, as can their properties be varied over a broad range and therefore designed for a specific application. The applicability of polyolefin based materials is likely to enrich the 3D printing sector.

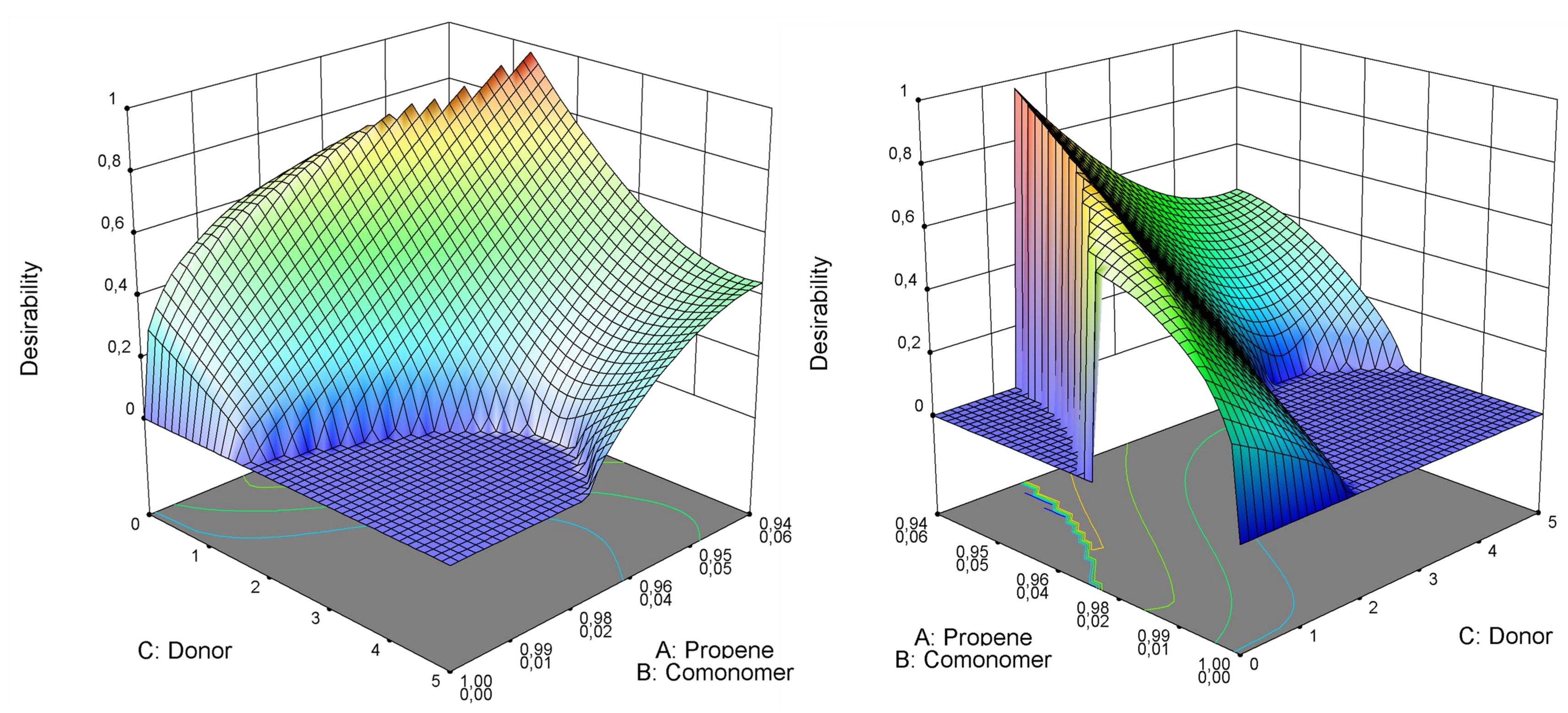

Figure 2: Desirability plots for the second comonomer type, the right illustration is turned by 90°C in order to visualize the narrow path (projected lines) between achievable und desired properties.

Scope of work

Based on a preceding analyses, which focused on material properties influencing printability, a set of factors and ranges for material properties was defined. In the next step a commercial Ziegler-Natta catalyst was screened for its hydrogen response and different external donors. The polymerizations were conducted using an in-house 0.5 L reactor system. After a prepolymerization period of a weighed in monomer/comonomer mixture with hydrogen, the main polymerization lasted for 30 minutes at a temperature of 70 °C.

Materials were then analyzed via SEC, DSC, rheology and XRD. Selected materials were processed into filaments to print test-geometries and specimen.

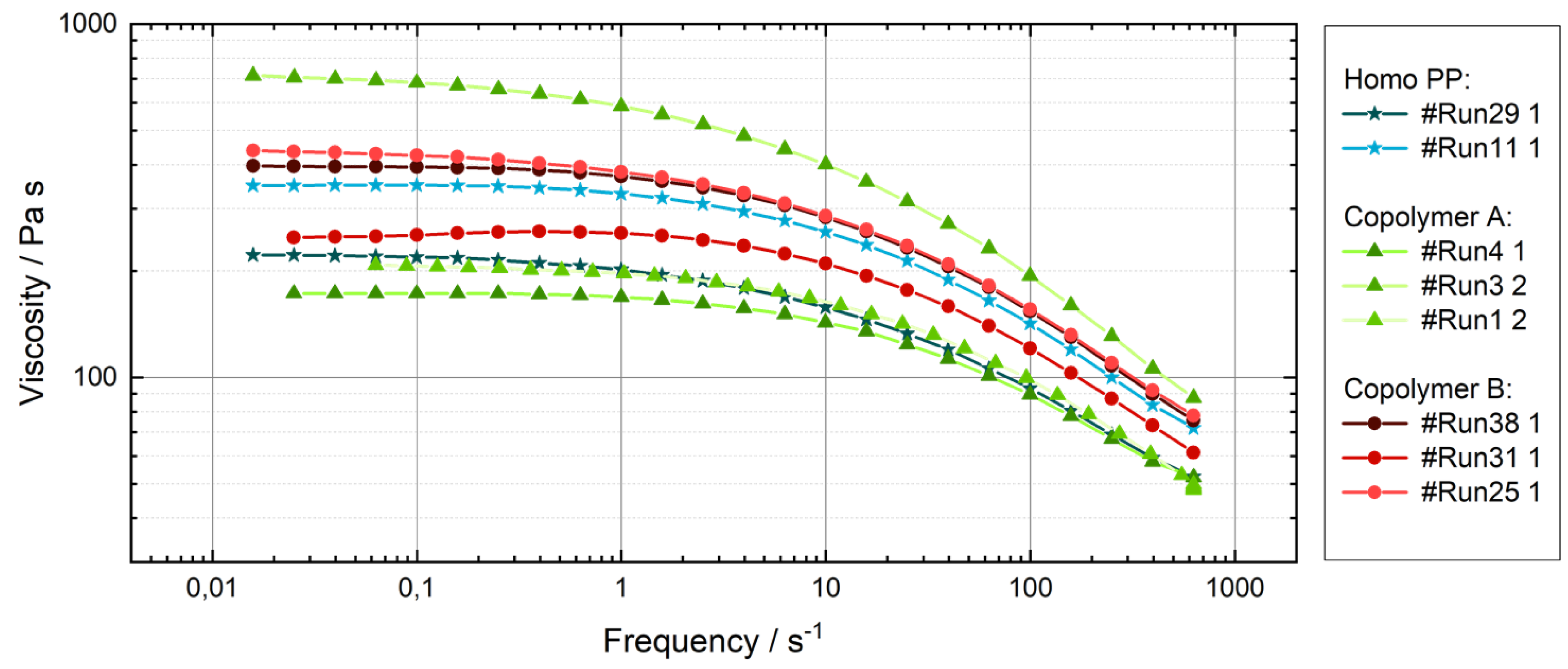

Figure 3: Comparison of viscosity measurements for PP-homopolymers and copolymers.

Design of Experiments

For this draft a custom split-plot mixture design was set up. This model permitted usage of a hard-to-change factor with factor interdependencies.

The design rests upon a mixture of two components, two numerical and one categoric factors, with an evaluation of eight responses. The results were achieved using 38 experiments, grouped and randomized. For each response the influence of factors as well as factor interactions were evaluated and mathematically described. In an optimization step targeted material properties were set. By adjusting the allowed ranges and importance of the factors, the favored properties were calculated and summed up in a desirability plot.

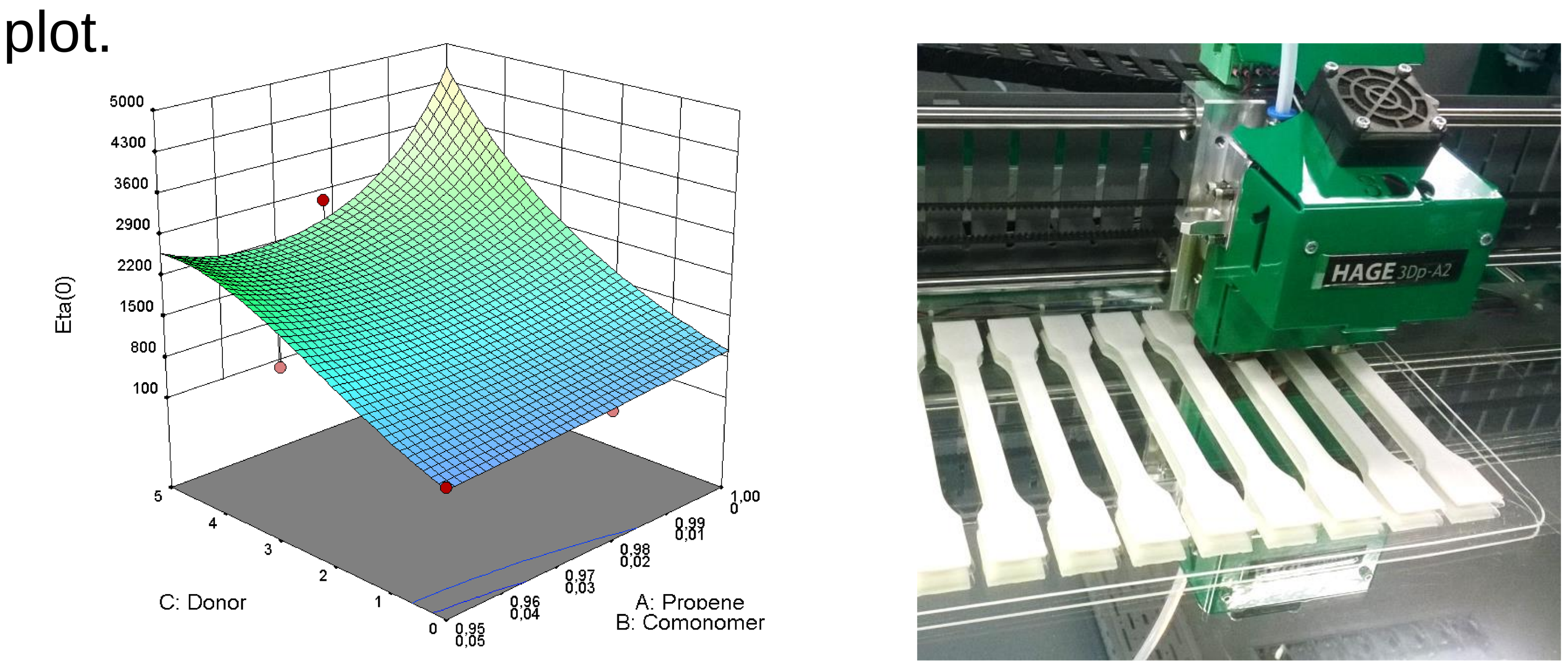

Figure 4: Surface plot of Viscosity η_0 (left) and FFF-printing of tensile test shoulderbars (right).

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