Technical Note

A micro tow-impregnation line for the manufacture of continuous fiber filaments for CFAM applications

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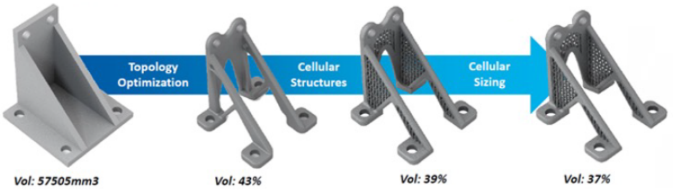
Introduction

Continuous fiber additive manufacturing (CFAM)

Structural, Lightweight and Freeform Composite Parts

- High mechanical strength and stiffness
- Design freedom



Lightweight

- Composite strength to weight ratio 10, 3 and 2 times
  better than respectively steel, aluminum and titanium: 90, 66 and 50 % weight saving respectively Additional weight reduction due to design (smaller volume)

Integration of Components & Functionalities in one shape

- Integration of multiple parts saving weight
  Integration of multiple parts reduces process steps and associated defects
- Enabling new designs of larger parts

Smaller series

- Cost effective production (no molds, faster switching)
  e.g. Airplane sensor rod 100 parts/yr

Time to market

- Faster prototypes, shorter product development cycle

Additive versus Subtractive Manufacturing

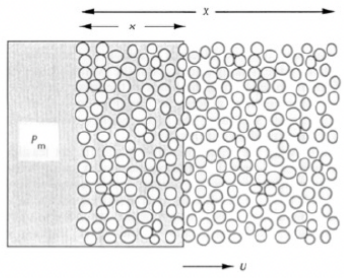
- “Buy-to-fly ratio”: To produce a I kg bracket, it may
  require 10 kg of raw material input into subtractive manufacturing process (e.g. milling)

Objective

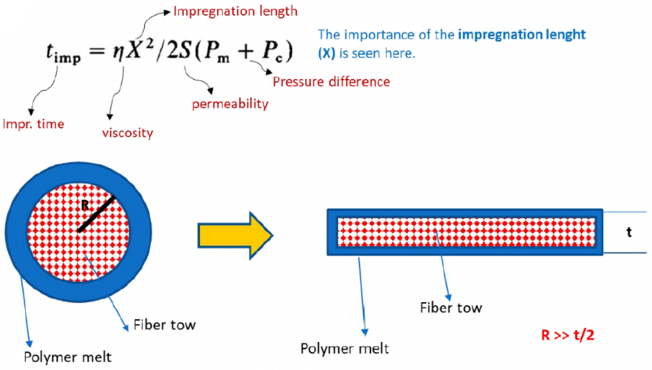
- To develop a lab-scale impregnation process in order to investigate the production of continuous fiber filament materials based on different types of thermoplastics.
- To understand the controlling parameters determining the quality of the continuous fiber filaments.
- To correlate the relationship between impregnation process-printing vs (thermo)mechanical performance in relation to the structure of 3D printed composites.

Impregnation of tows with thermoplastics: ‘**principle**’

Impregnation of a porous fibre bed by resin under an external pressure



$$U = dx/dt = SP/\eta x$$



$$t_{imp} = \eta X^2/2S(P_m + P_c)$$

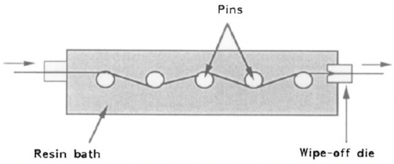
The importance of the **impregnation lenght (X)** is seen here.

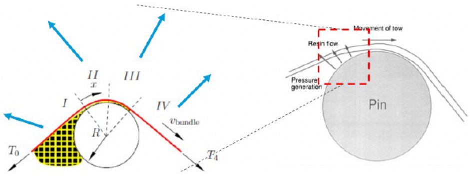
The flow velocity of the resin in the bed can be related by **Darcy ‘s law** to the pressure gradient, where S is the permeability and “u” is the viscosity. The pressure drop, P, can be considered as the work done per unit volume of resin entering the fibre bed.

Here the P’s the sum of the mechanical pressure and the capillary pressure.

Gaymans, Composites Part A 29A (1998) 633-670

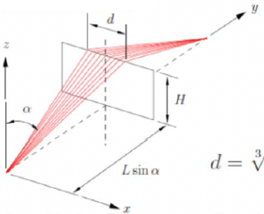
Impregnation unit - pin impregnation process





Differential pressure built-up

Cylindrical spreader

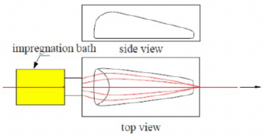


$$d = \sqrt[3]{12AH},$$

where d is the maximum spreading of a fiber bundle with cross section A.*

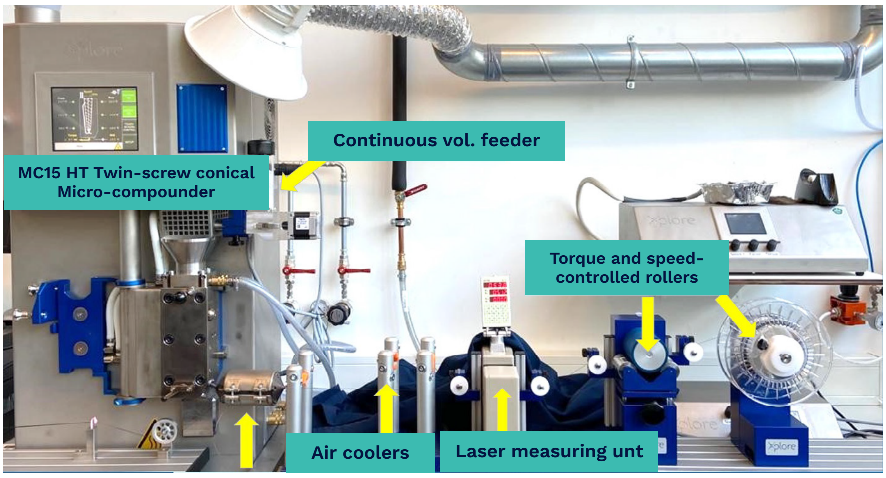
Connical (convex) spreader:

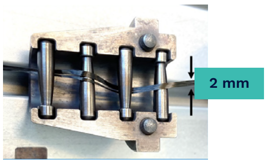
- Fibers can roll to sides and spreads more

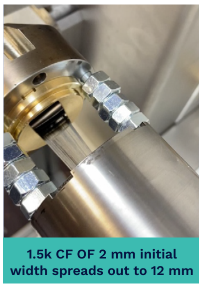


D.R. Wilson. Lateral spreading of fibre tows. *Journal of Engineering Mathematics*, 32:19-26, 1997.
T. WEUSTINK. Development of a Rapid Thermoplastic Impregnation Device, TU/Delft. 2008

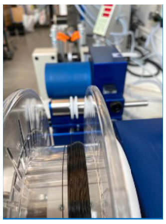
Results

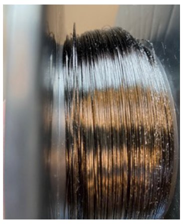


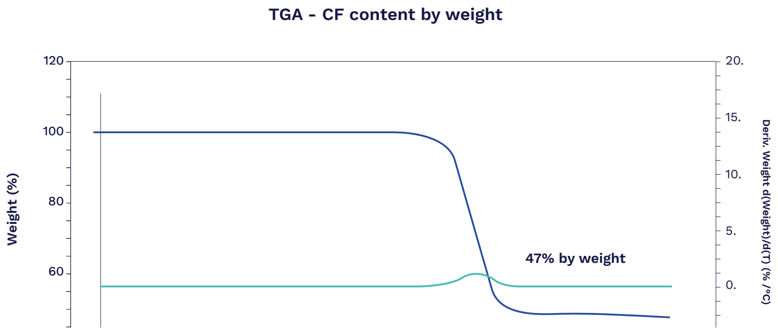


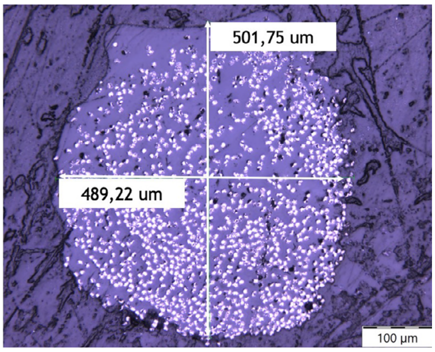


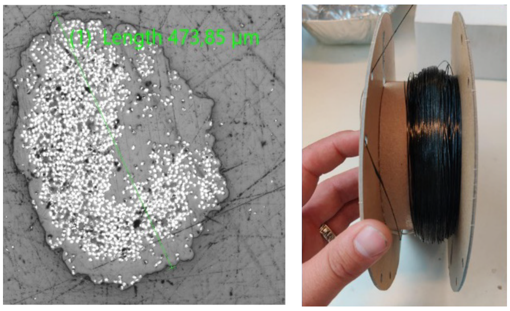
Optimum impregnation conditions: - 260° C - Moderate speed



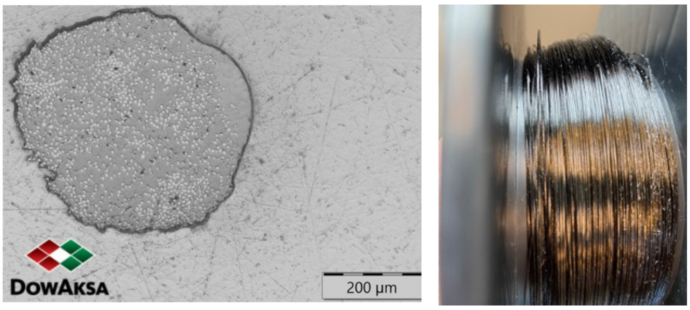








50% CF content



48% CF content

Conclusions

In this work;
The production of continuous carbon fiber filaments via a direct melt impregnation process was demonstrated. It was shown that the impregnation temperature and line speed are two critical parameters that must be optimized. Besides, fiber tension, polymer-fiber compatibility, and the number of spreader bars are other essential parameters yet to be considered. Although there is still room for improvement in the existing impregnation unit, using a lab-scale, innovative impregnation system allowed us to conduct many experiments in a short period.

This study showed us that; - One of the most critical factors for the rapid development of additive manufacturing technology in mobility applications is the ability to provide material diversity to engineers. Direct melt impregnation can help at that point. Some drawbacks are needed to be considered, such as the high costs of the low linear density fibers (1,5K or 3K), which are currently used in commercial composite printers, and the lack of compatible carbon fibers with different thermoplastic resins in the market.

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