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Manufacturing of Thick Composite Profiles: Pultrusion of Reinforced Thermoplastics

This research project is aimed at determining the feasibility and the limits of using commingled yarns in the thermoplastic pultrusion process for the manufacturing of profiles with diameters greater than 100 mm. The overall objective is to investigate if thermoplastic pultrusion can replace thermoset pultrusion in terms of achievable profile dimensions, material quality and productivity through a combination of physical experimentation and computational modelling.

The manufacturing of large diameter profiles comes with many challenges due to extreme temperature gradients which result in high residual stresses. Furthermore, crystallization of the semi-crystalline thermoplastic polymers may lead to substantial dimensional changes and warping.

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Introduction

Historically, thermoset resins have dominated the pultrusion industry because of their good adhesion to reinforcement fibers and efficient impregnation.
But because of their exothermic behavior during curing, the pultrusion speed and maximum profile thickness is limited.
Non-reactive thermoplastic pultrusion avoids this behavior by using a fully polymerized matrix, which undergo physical, rather than chemical, phase changes during solidification.
However, because of the high viscosities of thermoplastic melts, intermediate materials, such as commingled yarns, will be used to reduce the impregnation time
This project will explore the limits of the producible cross sections, which will be constrained by the heat transfer capabilities of the material as well as the residual stresses created by the large heat gradients during cooling.

Thermoplastic vs thermoset pultrusion

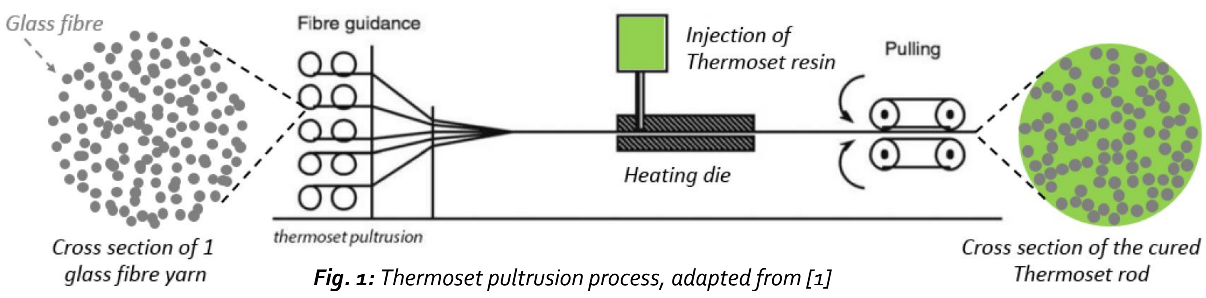

Fig. 1: *Thermoset pultrusion process, adapted from [1]*

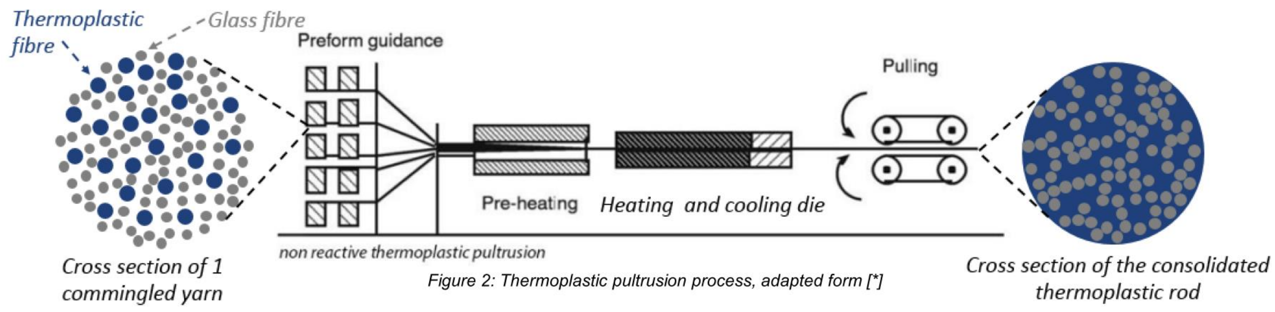

Fig. 2: *Thermoplastic pultrusion process using commingled yarns, adapted from [1]*

Project description

The manufacturing of large thermoplastic profiles using commingled yarns requires very high pulling forces in the order of several tons.
As there is no experimental data available for the manufacturing of thermoplastic profiles with diameters larger than Ø 5 mm, this project will study the pulling forces for increasing profile sections and compare this data to existing numerical models predicting the pulling force.
To determine the ideal pultrusion die design, a Comsol FEM simulation will be implemented to model the hot/cold interface of the die including the phase transitions of the material.
This will be coupled to a mechanical model to investigate the stresses caused by the large temperature gradients on the pultruded rods.
A custom pultrusion machine, tailored to the pultrusion of large section profiles will be developed to experimentally validate the models.

Preliminary pultrusion experiments

Preliminary pultrusion experiments using a conical pultrusion die (Fig. 3) allowed the pultrusion of 20mm rods at 20mm/min with void contents between 1% (Pa12, PP) and 5% (PEI,PC).

Fig. 3: *cut away view of pultrusion die*

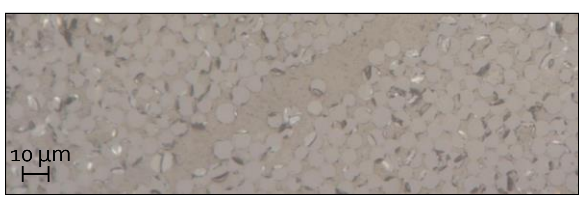

Fig. 4: *micrograph of an pultruded glass/PP profile*

Conclusion and Expected impact

Pultrusion processes based on non-reactive thermoplastic composites over significant benefits over those based on chemically reactive thermoset composites due mainly to the absence of difficult-to-control, exothermic curing reactions.
The ability of the thermoplastic matrix to be melted and reformed opens up new possibilities as a reinforcing structure in an existing thermoplastic component like a car bumper or a standalone component like an anti roll-bar.
Together with fast production speeds and an environmentally friendly, solvent and reaction free process, thermoplastic pultrusion offers a promising way into the future composite manufacturing.

References

[1] Luisier A, Bourban P E and Månson J A E 2003 Reaction injection pultrusion of PA12 composites: process and modelling Compos. Part A Appl. Sci. Manuf. 34 583–95

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