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MODELLING OF RECYCLED CARBON FIBRE-REINFORCED 3D-PRINTED THERMOPLASTIC COMPOSITES

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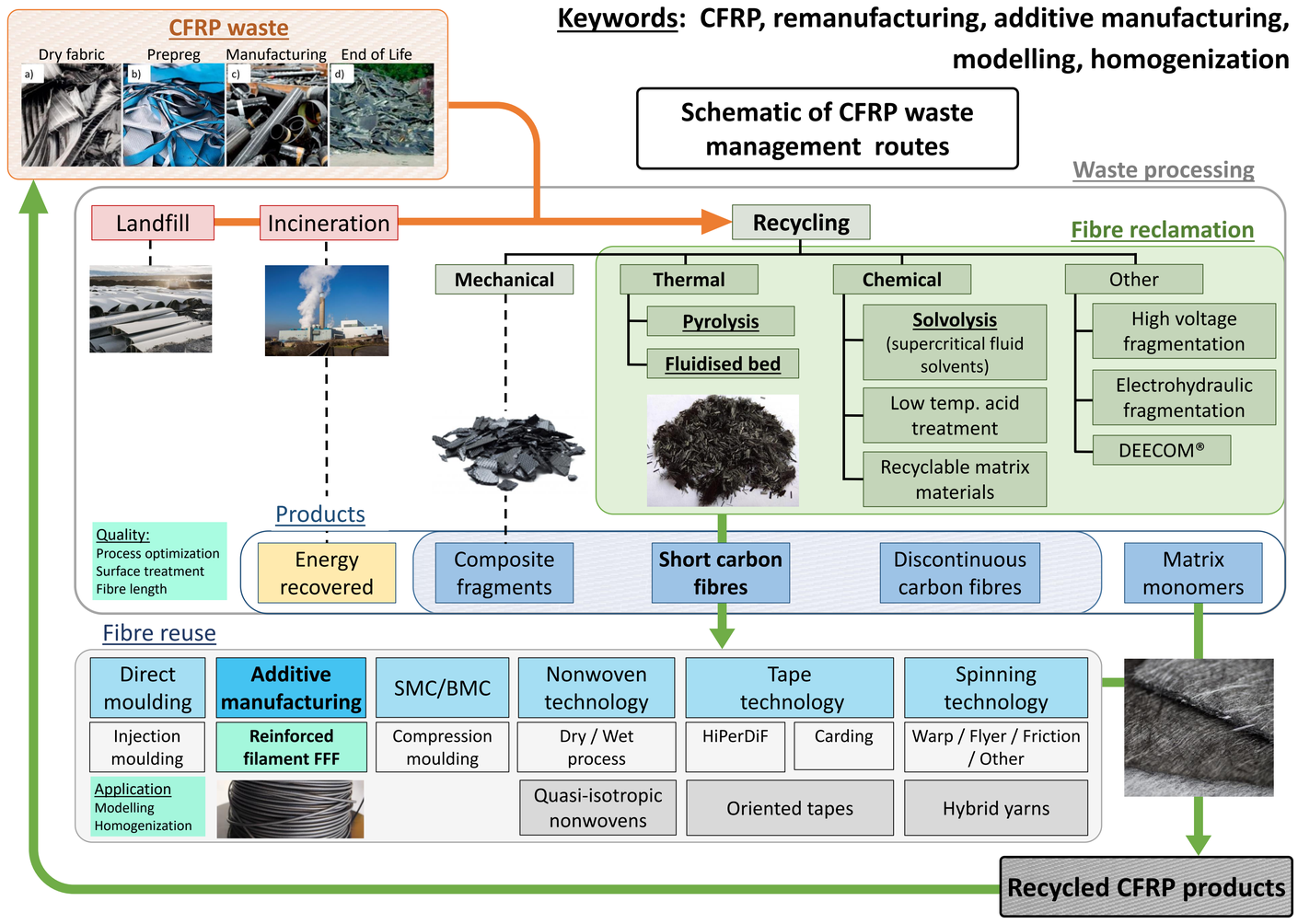
Scope – Recycling

One of the challenges of carbon fibre-reinforced composites (CFRP) recycling is reprocessing recovered fibres to make the material stream more circular. This is a complex issue, as composite waste can contain a mixture of carbon fibres of different qualities (diameter, modulus, surface treatment) and other additional materials. While conventional composite materials contain continuous filaments, recycled fibres lose their continuity and are considered short fibres, with their distinct length varying over a wide range. These short fibres can be repurposed by several technologies listed in the schematic of CFRP waste management routs.

Since the material properties of recycled fibres differ from virgin CFs, highly oriented short fibre intermediates lead to value-added recycling. When thermoplastic matrix materials are considered, the possibility of additive manufacturing arises. In recent years, 3D-printed CFRP has become the subject of intensive research and industrial development. Fibre-reinforced additive technologies offer the best means to exploit composites' anisotropy, enabling topological optimisation and enhancing product design and manufacturing efficiency. Since 3D-printed CFRP products containing short or long fibres are mainly used for tooling, functional prototypes and replacement components, they are typically combined with technical grades thermoplastic matrix materials such as ABS, PEEK, PEAK, and PA [1]. To promote the application of such novel materials, modelling the 3D printed structures and involvement in the finite element simulation is necessary. Few studies applied homogenisation methods on these emerging composite materials, predicting their elastic properties.

Schematic of CFRP waste management routes

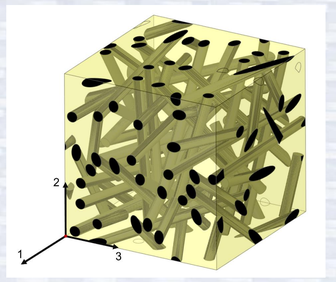


Concept

- Filament production via extrusion (Teluran© GP35 ABS + rCF)
- Specien production: Additive manufacturing via FDM printing
- Comprehensive mechanical characterisation – **Elastic Properties**
- Fibre orientation measurements - FOD
- Morphology characteisation – Optical microscopy and SEM (single fibres, fracture surface, voids, porosity)
- Parameter optimization

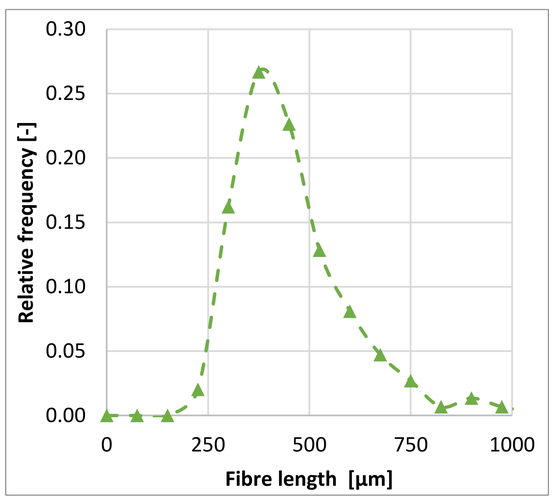
Determination of mechanical and microstuctural inputs for modelling
Modelling and validation (CLT)
Implementation into simulation

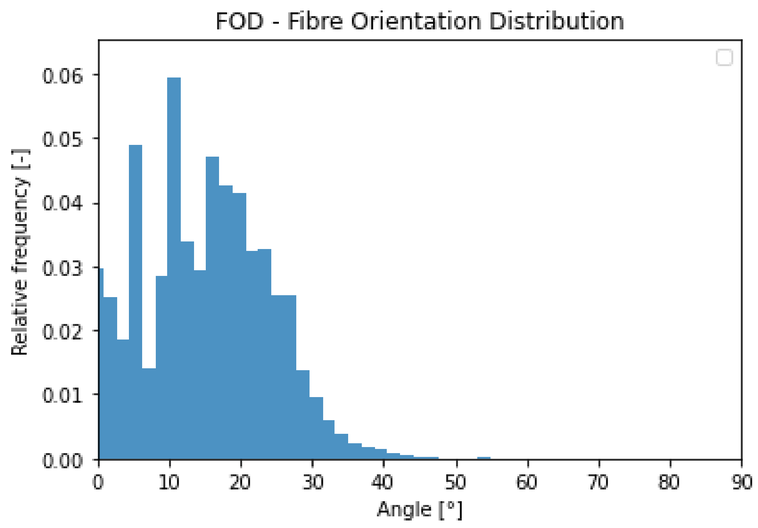
Modelling



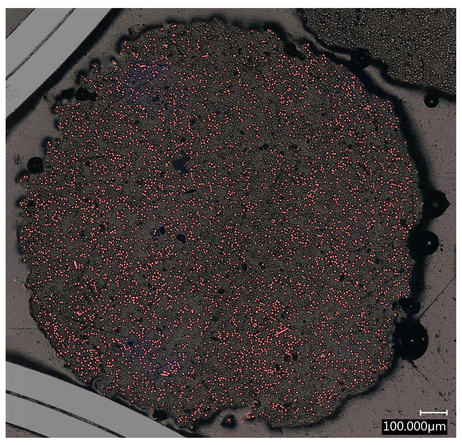
The effective elastic properties could be predicted based on the microstructure and the constituents of a composite prepared by additive manufacturing. These methods have already been used for materials processed by other technologies (hand layup, compression and injection moulding) but only recently applied for printed structures. These studies focused on the microstructure characterisation of composites where the orientation and length of carbon fibre are not homogeneously distributed in the matrix.
The **Mori-Tanaka homogenisation model** is proposed in several studies [6], which incorporates explicit orientation averaging to account for the contributions of each reinforcement (termed inclusions) with arbitrary orientations. Research has demonstrated that when applied to such materials, the Mori-Tanaka model accurately predicts effective properties that align with the lower bound specified by the Hashin-Shtrikman criterion for aligned continuous inclusions. Moreover, the model yields even lower estimates for effective properties when inclusions possess orientations and aspect ratio distributions different from the aligned case. It is important to note that such predictive models are limited, do not take manufacturing defects (voids), and idealise fibre-matrix bonding.

Preliminary Results

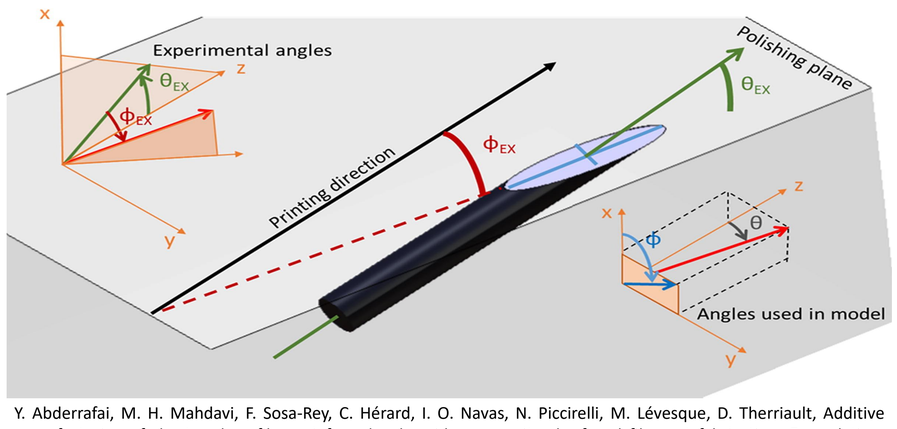




	Experimental				Present study
	Li et al. [2]	Rodriguez et al. [3]	Casavola et al. [4]	Zhang et al. [5]	
Materials Elastic prop.	ABS – P400	ABS – P400	ABS	ABS – CF 15wt%	**ABS + rCF 20wt%**
E_{11}, MPa	2030.9	1972	1790	5899	**5205.6**
E_{22}, MPa	1251.6	1762	1150	2193	**2415.8**
ν_{12}	0.34	0.37	0.34	0.37	**0.37**
G_{12}, MPa	410	676	808.5	964	**904**
UTS, MPa	-	24.41	26.11	39.05	**58.79**



Optical micrograph of polished printing filament surface at 200x magninification for FOD measurement



Y. Abderrafai, M. H. Mahdavi, F. Sosa-Rey, C. Hérard, I. O. Navas, N. Piccirelli, M. Lévesque, D. Therriault, Additive manufacturing of short carbon fiber-reinforced polyamide composites by fused filament fabrication: Formulation, manufacturing and characterization, *Materials & Design*, **214**, 2022, 110358

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References

[1] N. van de Werken, H. Tekinalp, P. Khanbolouki, S. Ozcan, A. Williams, and M. Tehrani, Additively manufactured carbon fiber-reinforced composites: State of the art and perspective, *Additive Manufacturing*, **31**, 2020, pp. 100962
[2] L. Li, Q. Sun, C. Bellehumeur, P. Gu, Composite modeling and analysis for fabrication of FDM prototypes with locally controlled properties, *J. Manuf. Process.*, **4**, 2002, pp. 129–141.
[3] J.F. Rodríguez, J.P. Thomas, J.E. Renaud, Mechanical behavior of acrylonitrile butadiene styrene (ABS) fused deposition materials. Experimental investigation, *Rapid Prototyp. J., **7**,* 2001, pp. 148–158.
[4] C. Casavola, A. Cazzato, V. Moramarco, C. Pappalettere, Orthotropic mechanical properties of fused deposition modelling parts described by classical laminate theory, *Mater. Des*., **90**, 2016, pp. 453–458
[5] W. Zhang, C. Cotton, J. Sun, D. Heider, B. Gu, B. Sun, T.-W. Chou, Interfacial bonding strength of short carbon fiber/acrylonitrile-butadiene-styrene composites fabricated by fused deposition modeling, *Composites Part B: Engineering*, **137**, 2018, pp. 51–59.
[6] Benveniste Y., A new approach to the application of Mori-Tanaka's theory in composite materials, *Mech. Mater.* **6,** 1987, pp. 147–157.