Innovation Fellow Final Report

Project Title: Numerical simulation for high-rate compression moulding of SMC/prepreg

PI name: Connie Qian

Research staff/students (*include name and % of time they worked on project*): Connie Qian 100%

Partners (include support from industry): Toray AMCEU, Toray Engineering D Solutions

Institutional Support: (number of PhDs supported and value £): 1 PhD 50% for 6 months; £25,000 additional consumable budget

Start date: 22/01/2020

End date: 31/07/2022

Identify benefits to Industrial Partners:

The project helps material suppliers to better understand the processibility of their products and identify new methods for quality control. It also helps software developer to understand the capabilities and limitations of their existing process simulation products. Finally, it helps part manufacturers and OEMs to better engineer their designs, although this route has not been exploited to a great depth within this project.

Associated research grants awarded (title and value):

- EPSRC Metrology Hub feasibility study "Investigation of fibre content and fibre orientation distributions in compression moulded carbon fibre SMC", £50,000
- EPSRC Metrology Hub Innovation Fund "3D fibre orientation characterisation for carbon fibre composite structures with hybrid architecture using micro-CT scanning technique", £80,000
- Henry Royce Institute Summer Internship Programme "Compression moulding compound manufactured from reclaimed prepreg waste", £3,600

Publications:

1. C. C. Qian, H. Yuan, M. Jesri, M. A. Khan, K. N. Kendall, "Flow Behaviour of Carbon Fibre Sheet Moulding Compound", Key Engineering Materials, Vol. 926 (2022)
2. C. Qian, D. Norman, M. A. Williams, K. Kendall, "Experimental and Numerical Characterisation of Fibre Orientation Distributions in Compression Moulded Carbon Fibre SMC", Plastics, Rubber and Composites: Macromolecular Engineering, Accepted July 12th 2022.
3. N. Fereshteh-Saniee, N. Reynolds, D. Norman, C. Qian, D. Armstrong, P. Smith, R. Kupke, M. A. Williams, K. Kendall, "Quality Analysis of Weld-Lines in Carbon Fibre Sheet Moulding Compounds by Automated Eddy Current Scanning", Journal of Manufacturing and Materials Processing, Under review
4. H. Yuan, C. C. Qian, M. Khan, K. N. Kendall, "Process Characterisation for High-rate Compression Moulding of Hybrid-architecture Composites", Plastics, Rubber and Composites, In preparation

More journal papers in preparation based on conference paper 2,5, and 6.

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Conference papers:

1. H. Yuan, C. C. Qian, M. Khan, K. N. Kendall, "Process Characterisation for High-rate Compression Moulding of Hybrid-architecture Composites", abstract accepted for ICMAC 2022
2. C. C. Qian, H. Yuan, M. Khan, K. N. Kendall, "Squeeze Flow of Carbon Fibre Sheet Moulding Compound in Compression Moulding", 20th European Conference on Composite Materials (ECCM20), June 26-30, 2022, Lausanne, Switzerland
3. C. C. Qian, H. Yuan, M. Jesri, M. A. Khan, K. N. Kendall, "Flow Behaviour of Carbon Fibre Sheet Moulding Compound", 25th International Conference in Material Forming (ESAFORM 2022), April 27-29, 2022 Braga, Portugal.
4. C. Qian, D. Norman, M. A. Williams, K. Kendall, "Numerical and experimental study of fibre content and fibre orientation distributions in compression moulded Sheet Moulding Compound", International Conference on Manufacturing of Advanced Composites 2021 (ICMAC 2021), October 2021, Online
5. C. Qian, A. Deshpande, M. Jesri, R. Grove, N. Reynolds, K. Kendall, "A Comprehensive Review of Commercial Process Simulation Software for Sheet Moulding Compound", 24th International Conference on Material Forming (ESAFORM 2021), April 14-16, 2021, Liege, Belgium
6. C. Qian, K. Kendall, "A digital twin for compression moulding of sheet moulding compound", SAMPE Europe Conference 2020 (SAMPE Europe 20), September 30 – October 1, 2020, Amsterdam, Netherland

Have you engaged/or will engage with HVMCs and/industry:

The PI is based at WMG which is also an HVMC. The PI has been working closely with her colleagues at WMG and has been engaged in the following industrial research projects:

- Interaction with Project CHAMELEON (APC 6) and TUCANA (APC 10),
- Collaboration with DowAksa (direct funded research) and Toray (in-kind contribution)

Have you sought further funding from EPSRC, Innovate UK or other funding body?

- Innovate UK - NATEP helping SMEs innovate in aerospace: Spring 2022 "FEA-SMC: Enabling short fibre composites in high-performance aerospace applications through robust simulation technology", £300,000 (successful)
- EPSRC Future Composites Manufacturing Hub Synergy Promotion Fund "Zero-waste manufacturing of highly optimised composites with hybrid architectures" £200,000 (successful)
- See "Associated research grants" section for other successful awards totalling £133,600
- EPSRC New Investigator Award on 3D flow characterisation and simulation, est £300,000 (in preparation)
- EPSRC Future Composites Manufacturing Hub Feasibility Study "3D flow characterisations for compression moulding compound manufactured from reclaimed thermosetting prepreg" £50,000 (unsuccessful)
- EPSRC Future Composites Manufacturing Hub Synergy Promotion Fund "Integrated Additive Manufacturing-Compression Moulding for High-volume Production of Sustainable High-performance Composite Structures" £200,000 (unsuccessful)

CIMComp
EPSRC
Future Composites
Manufacturing Research Hub

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Executive Summary

This project aimed to develop novel process characterisation and process simulation techniques for high-rate compression moulding of SMC/prepreg. The project consisted of both experimental and simulation studies focusing on three main aspects including the processing behaviour of SMC or prepreg in a single-material compression moulding process, and the interaction between the two materials in a hybrid moulding process. The project fits the hub's key priority areas "high-rate deposition and rapid processing technologies" and "design for manufacture via validated simulation".

Background

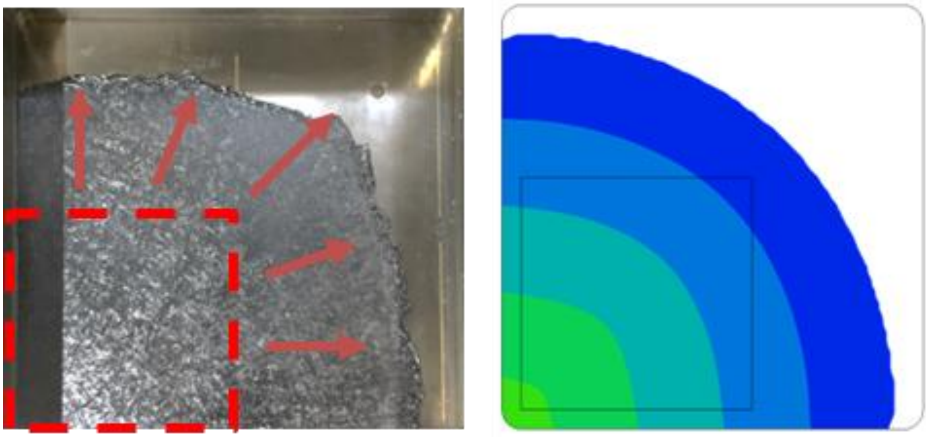
High-rate compression moulding of SMC/prepreg hybrid is an attractive solution for high-volume manufacturing of high-performance, lightweight structures. The process combines the superior specific properties of continuous fibre prepreg and the high design flexibility offered by SMC. However, such manufacturing process have not been widely adopted by industry because the material behaviour of SMC and prepreg and the interaction between the two materials during a hybrid moulding are poorly understood, and consequently there is no predictive process simulation models. It is very important to select appropriate experimental setups such that the material behaviour can be studied at typical hybrid moulding conditions (high pressure, high temperature and high strain-rate). These requirements create significant challenges for processes involving flows of SMC, as conventional rheometers cannot meet such testing condition requirements.

This project aims to address the gaps and challenges identified through the development of dedicated material and process characterisation methods and numerical simulation models. Hybrid moulding of SMC/prepreg has already attracted great interests in the automotive industry, and the development through this project will further promote the applications in automotive, driving the current non-structural applications of discontinuous fibre composites towards more structural applications, and potentially enable these materials and processes to be adopted in more demanding applications such as aerospace.

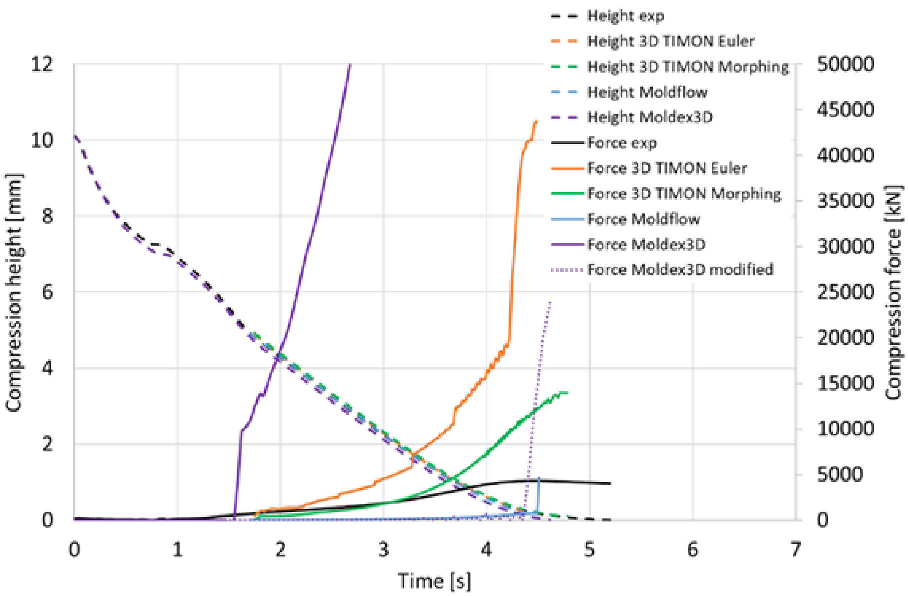
Results/Deliverables/Outcomes

<u>Assessment of existing SMC process simulation models</u>

The original plan was to develop an SMC process simulation model in ABAQUS based on an existing commercial model. A comprehensive benchmark study was performed to assess the predictive validity of three commercial software: Moldex3D, 3D TIMON and Moldflow, where the constitutive models employed in all three software are based on the shear viscosities of the material. Various case studies were performed including flat plaque geometry moulded with in-plane 2D flow regimes, and 3D geometry with ribs moulded with combined in-plane and out-of-plane flow regimes. For all cases investigated, all simulation software failed to correctly predict the filling pattern as well as the compression forces and pressures (See example case study in Figure 1). It was therefore concluded that shear viscosity based material models were unsuitable for SMC compression moulding, and a new dedicated material model needed to be developed in this project.



(a)



(b)

Figure 1: Case study for SMC compression moulding for a flat plaque geometry. (a) comparison of filling patterns between experiment and simulation using Moldex3D. (b) Comparison of compression forces predicted by various commercial process simulation software against the experimental data.

Development of the compression testing rig

A compression testing rig was required in this project for characterising the flow behaviour of SMC, the compaction behaviour of prepreg, and the interfacial behaviour between SMC and prepreg. An existing heated compression rig (Figure 2) at WMG was originally chosen for this project (referred as the old rig hereafter). The rig was commissioned onto a 250kN servo-hydraulic testing machine. Several limitations with the old rig were identified through preliminary SMC squeeze flow tests. Firstly, the rig had a testing area of 160mm x 160mm, restricting the sample size to 50mm diameter, and a representative sample size could not be achieved for typical SMC materials where the fibre length is typically 25mm. The small testing area also restricted the number of pressure transducers that can be installed. Furthermore, the heating distribution on the testing surface lacked uniformity due to the use of fewer, larger heating elements. Issues were also identified with the testing machine itself. Firstly, the testing machine did not have input channel, meaning no extensometer or LVDT could be used for displacement measurement, such that the sample deformation could only be measured from the crosshead displacement. Due to the compliance of the machine, softening was observed from the compressive stress-strain curves (Figure 3). The softening phenomenon was considered unrealistic because the resistance in compacting the fibre network in SMC was expected to increase significantly with compressive strain. The data acquisition system was also faulty such that data recording terminated sooner at higher testing speed (see Figure 3)

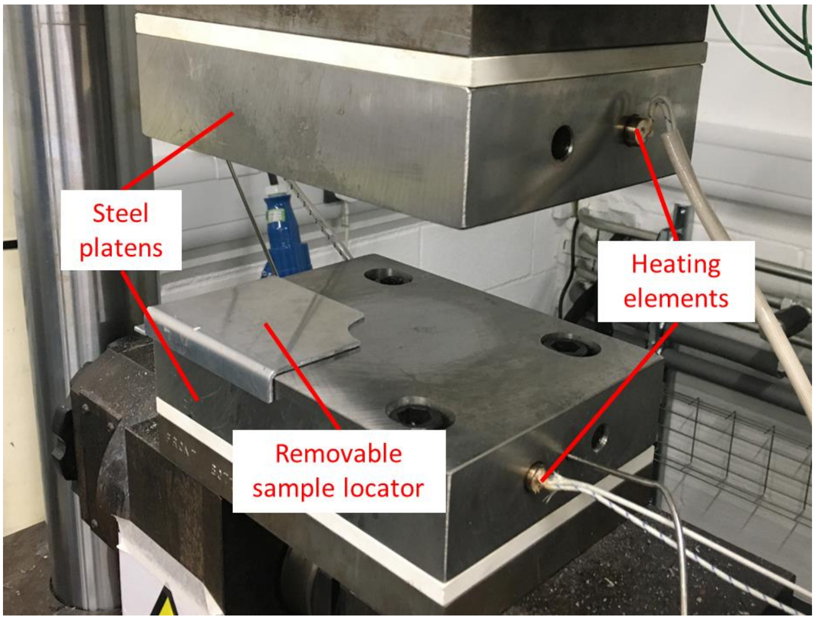


Figure 2: The old compression testing rig.

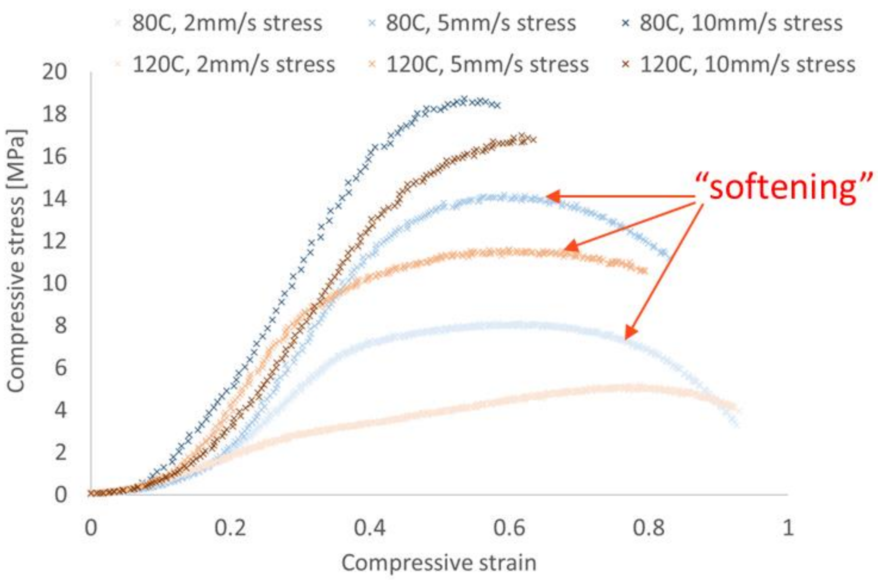


Figure 3: Typical compressive stress-strain curves from SMC squeeze flow tests using the old compression testing rig (see Figure 2)

A new compression testing rig (Figure 4) was therefore designed and manufactured in this project to address the limitations with the old rig. The testing frame and the software was also upgraded with the financial support from WMG. The new rig consisted of a pair of heated platens with 350mm x 350mm testing area, four guide columns to ensure parallelism between the platens an extensometer for accurate displacement measurement, and five 1000bar pressure transducers. Due to the large testing surface area and the limited heating power available, a finite element based thermal analysis was performed to ensure uniform temperature distribution could be achieved. Figure 5 presented the optimised heating plan determined through the thermal analysis.

It should be noted that significant delay was caused to the manufacturing and commissioning of the new rig due to the material supply issue during and post covid lock, and the challenges with obtaining health and safety approval for the electrical wiring system due to the lack of experience of the PI and the supporting technicians.

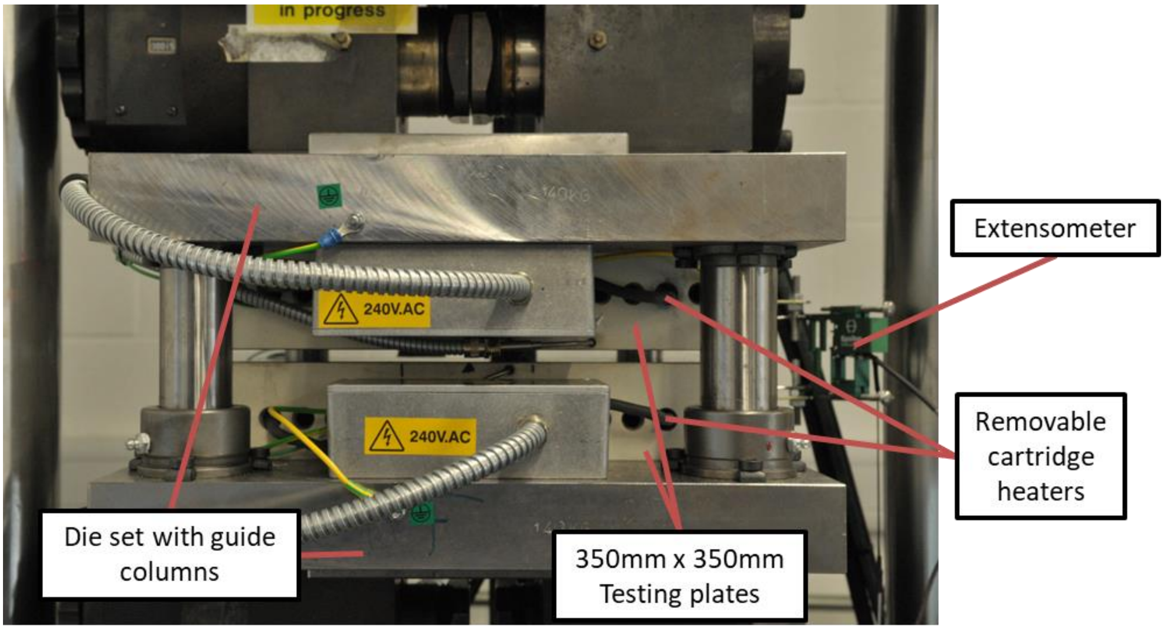


Figure 4: The new compression testing rig delivered through the project.

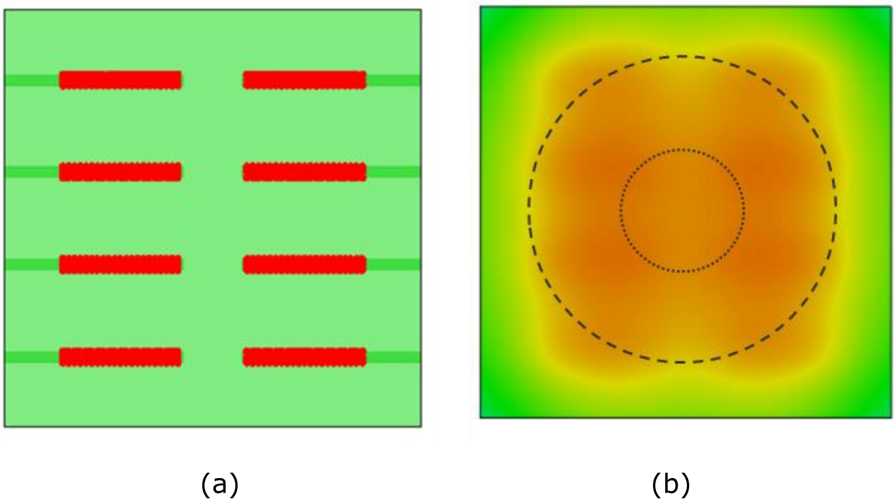


Figure 5: Optimised heating plan (a) cartridge heater layout (b) effective temperature distribution.

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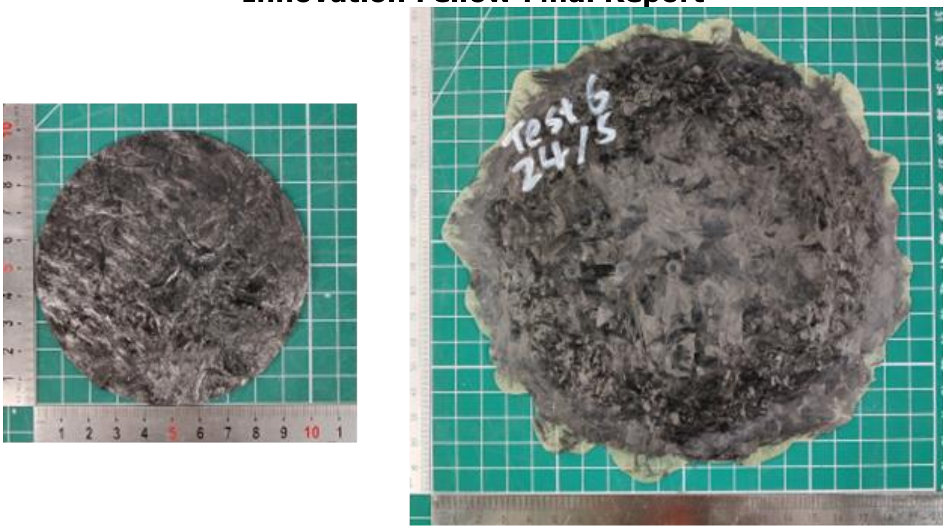
Experimental material/process characterisation

Table 1 summarises the experimental material/process characterisation performed in this project with information on the sample geometry and testing conditions.

Table 1: Summary of experimental material/process characterisation performed on the new compression testing rig

	SMC squeeze flow	**Prepreg compaction**	**Hybrid compaction**
Layup	1 ply SMC only	1 ply prepreg only	1 ply SMC + 1 ply prepreg
Shape	Circular with 100mm diameter	Square with 100mm edge length	SMC - Circular with 100mm diameter Prepreg - Square with 200mm edge length
Testing conditions	100°C, 1mm/s, 3mm/s, 5mm/s	100°C, 1mm/s	100°C, 1mm/s
	Tested at constant crosshead speeds up to ~200kN compression force Specimens held at a constant cavity height for 20 minutes to cure		

The flow behaviour of SMC was characterised using a squeeze flow testing method, where a single-ply circular sample was positioned in the centre of the testing surface, and flowed out radially as the two testing surfaced approaching each other (Figure 6). Various types of SMC materials supplied by different material manufacturers were studied in this project, where all materials were tested at three different closing speeds of 1mm/s, 5mm/s and 10mm/s, and temperature of 100°C. Although the effects of temperature were also considered, it was noticed that there were much higher variabilities in the testing results at temperature greater than 120°C, possibly because the material’s curing rate increased significantly at such high temperature, causing the degree of cure in the material largely affected by the sample loading time, which could not be very well controlled using the current testing procedure. There, data collected at higher temperatures were not analysed further in this project.



(a) (b)

Figure 6: Comparison of an SMC squeeze flow sample (VE based, 25mm fibre length, 37%vf) (a) before test and (b) after test. The test was performed at 1mm/s closing speed and 100°C.

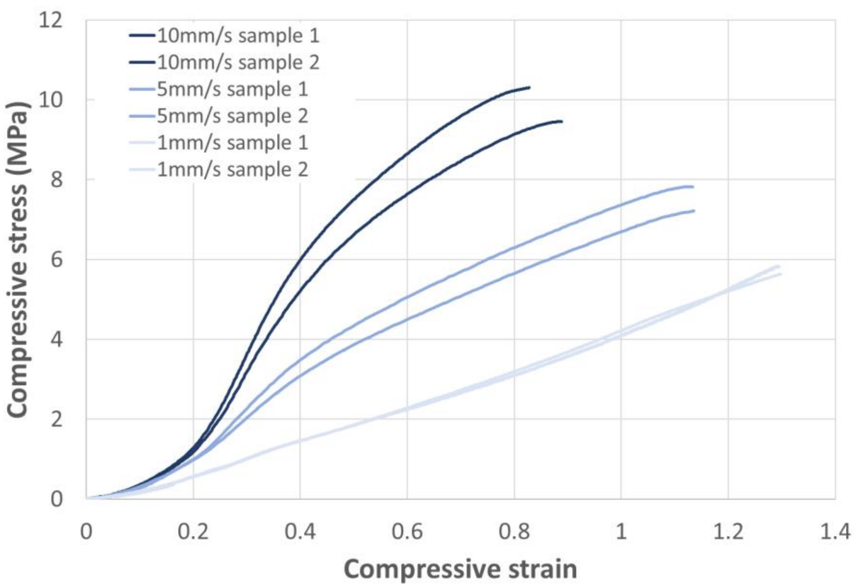


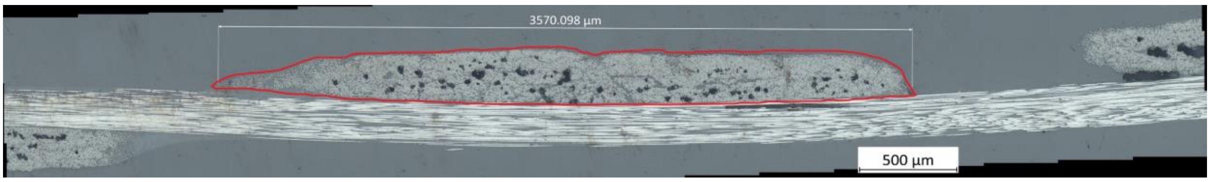
Figure 7: Compressive stress-strain curves for an example SMC material (VE based, 25mm fibre length, 37%vf) at different testing speeds and a constant testing temperature of 100°C. All samples were terminated at a 200kN force.

A compressive stress-strain based constitutive relationship was derived from the force-displacement data for each sample tested. It should be noted that due to the large deformation of the samples, true stresses and true strains were calculated using the momentary area and thickness of the sample at each data point. In addition, it was observed that all SMC materials studied in this project had apparent ~20% reduction in volume because the material not de-bulked prior to moulding, which has also been taken into account during the strain and strain calculations. Results suggested that all SMC materials studied experienced strong rate dependency, where not only the magnitude of compressive stresses increased with increasing testing speed, but also the stress-strain curves showed higher level of non-linearity at higher speed. Figure 7 presents a set of compression stress-strain curves for an example SMC material consisting of vinlyester (VE) resin and carbon fibre with 25mm fibre length and 37%vf.

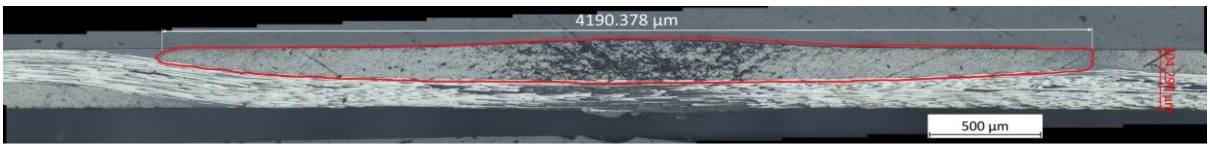
Prepreg compaction behaviour was characterised using a similar approach as the SMC squeeze flow tests, except the initial sample was square shaped. Only one type of prepreg material was studied in this project, which was a carbon fibre/epoxy prepreg with 12K 2x2 twill weave and 55%vf. Due to the time constraint of the project, only one set of testing parameters was used (Table 1). It was observed that the prepreg samples experienced little overall in-plane expansion after the compaction test, although resin bleeding and fibre wash were observed around the sample edges, which occurred while awaiting the sample to cure after the test instead of during the compaction process. However, the micrographs in Figure 9 suggests that individual fibre tows experiences large deformation after compaction, where the average width of the tow increased by up to 20%.

(a) (b)

Figure 8: Comparison of prepreg compaction sample (a) before test and (b) after test.



(a)



(b)

Figure 9: Micrographs showing typical cross-sectional dimensions of prepreg tows (a) before compaction and (b) after compaction.

The compressive stress-strain curve from prepreg compaction test (Figure 10, averaged from seven repeats) shows a typical bi-linear shape. It is considered that the first stage indicates the compaction of the fibre network where the spatial packing of fibre tows changes under pressure, where the second stage indicates the compaction of individual tows where the spatial packing of fibre filaments changes under pressure (Figure 9). Such deformation mechanism is very important in a prepreg only compression moulding or stamp forming process.

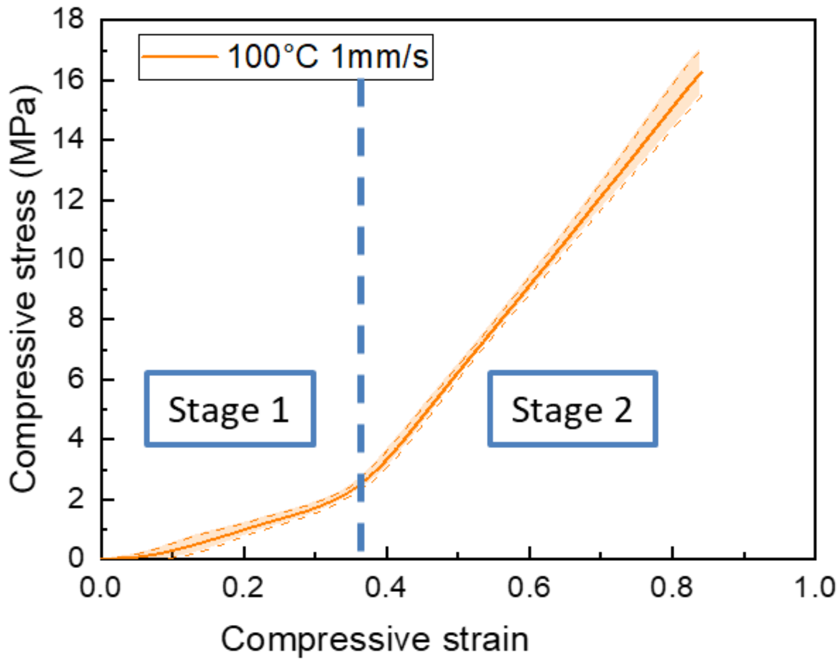
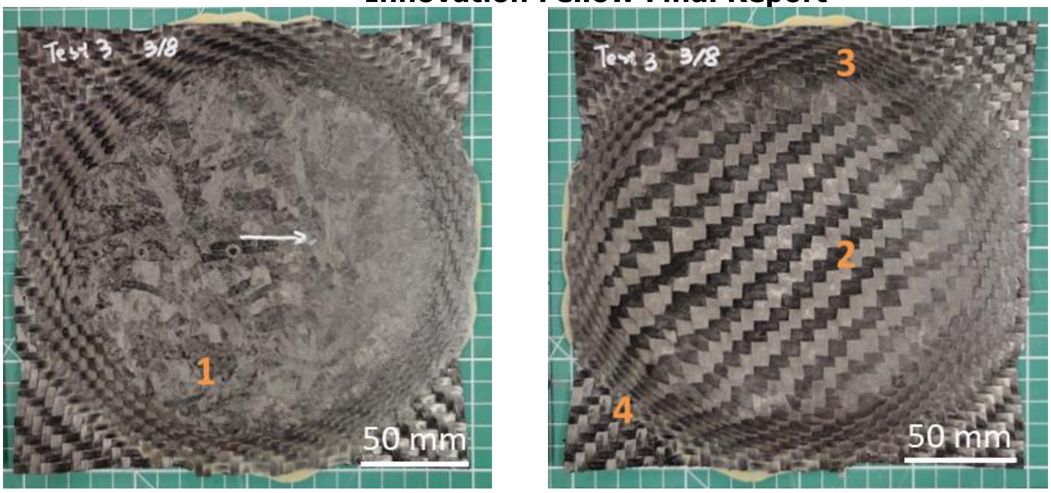


Figure 10: Compressive stress-strain curve from prepreg compaction test. The area bounded by the dashed curved indicate the variability range from seven repeat tests.

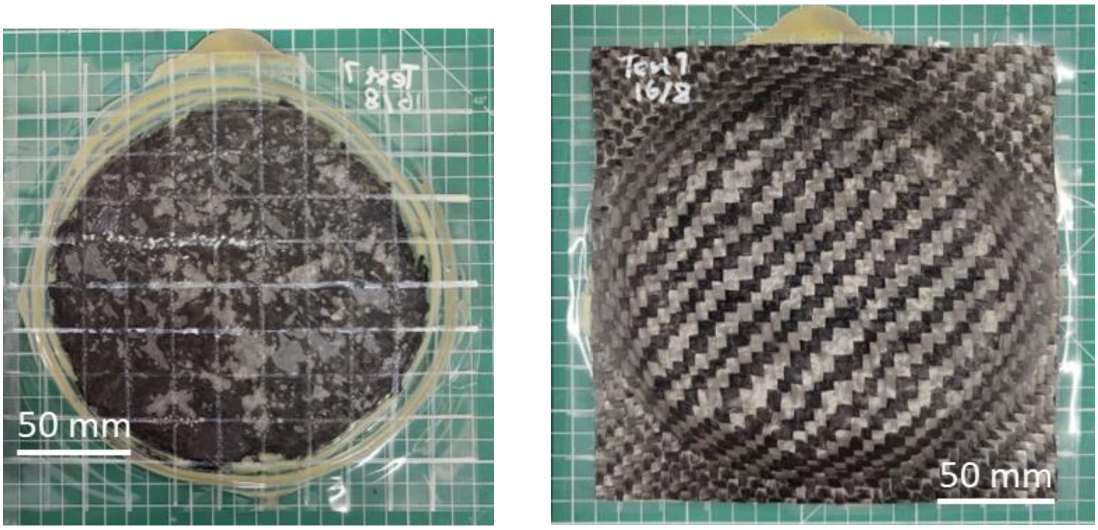
Process characterisation for SMC and prepreg hybrid moulding was performed under the same conditions as the prepreg compaction tests (Table 1). The same material in the prepreg compaction test was used in this study while the SMC was a chopped UD carbon fibre/epoxy prepreg based material with 27mm – 54mm fibre length and 53%vf, which had the same resin system with the woven prepreg. The hybrid sample after the compaction test is presented in Figure 11, where the numbers indicate critical material deformation mechanisms: 1. Squeeze flow of SMC; 2. Tow spreading in prepreg caused by in-plane tension and out-of-plane compaction; 3. Tow compaction in prepreg caused by in-plane compaction and 4. Fibre misalignment caused by in-plane shear. Furthermore, the in-plane compaction of prepreg led to fibre locking in the region just outside the SMC flow front (region 3 in Figure 11), which restricted the flow distance in SMC compared to an SMC only test (~17% reduction in final SMC coverage).



(a) (b)

Figure 11: Hybrid sample after compaction test (a) SMC side, (b) prepreg side. The numbers indicate important deformation mechanisms in a hybrid moulding process: 1. SMC squeeze flow; 2. Prepreg in-plane tension and out-of-plane compaction (tow spreading); 3. Prepreg in-plane compaction (tow locking) and 4, Prepreg in-plane shear (misalignment).

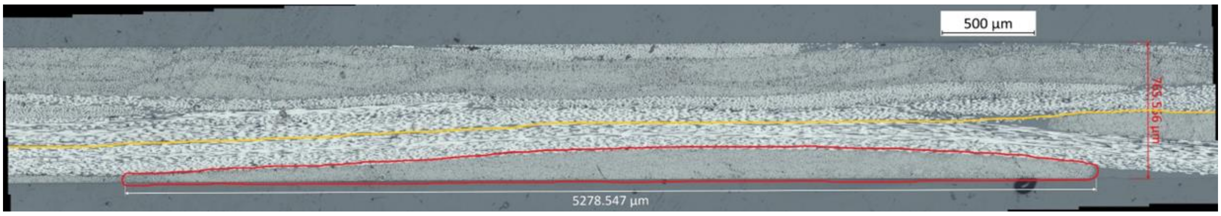
A variation of the hybrid compaction test was performed to study the interaction mechanisms between the SMC and the prepreg. Two layers of biaxially orientated plastic films with pre-drawn grid lined were inserted between the SMC and the prepreg. After the compaction test, the sample was separated through the film-film interface and no noticeable distortion in the grid lines was observed (Figure 12a), indicating no friction (no sliding) acted on the prepreg surface. The deformation in the prepreg with the film (Figure 12b) was almost identical to that without the film (Figure 11b). Therefore, it was concluded that the interaction between SMC and prepreg was dominated by the normal stress transfer between the two materials, and the effects of friction was negligible.



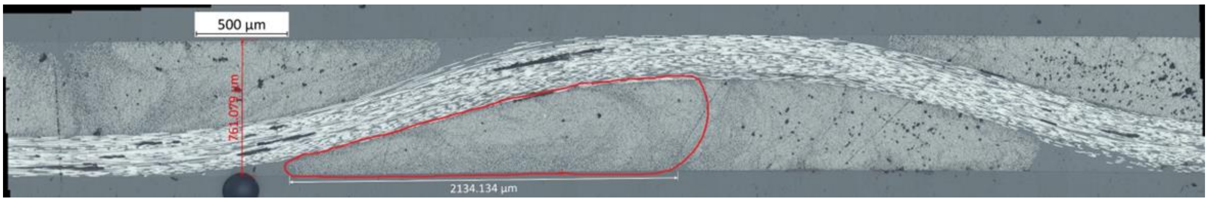
(a) (b)

Figure 12: Hybrid sample after compaction test (a) SMC side showing the grid lines on the film and (b) prepreg side.

Figure 13 compares the micrographs taken from region 2 and region 3 in Figure 11, showing the change in cross-sectional dimensions of the tow as a result of tow spreading and tow compaction respectively. Typical fibre tows in tow spreading region has ~50% increase in tow width, where typical fibre tows in tow compaction region has ~40% reduction in tow width. An image processing based method is currently being developed for quantifying the tow-width distribution in prepreg samples, which can be utilised for assessing the uniformity of tow spreading/tow compaction in hybrid samples. It should be noted that the tow spreading/compaction phenomenon is only observed in hybrid samples.



(a)



(b)

Figure 13: Micrographs showing typical cross-sectional dimensions of prepreg tows (a) in tow spreading region (region 2 in Figure 11) and (b) in tow compaction region (region 3 in Figure 11).

Process simulation

The covid pandemic caused significant delay in the delivery of the new testing rig and the experimental characterisation work. Consequently, only an SMC process simulation model was delivered in this project.

The constitutive material model for SMC compression moulding was developed based on the compression stress-strain curves presented in Figure 7. The model was implemented in ABAQUS/Explicit as a plasticity model and ALE adaptive mesh was used to prevent excessively distorted elements in large deformation. The current material model was isotropic and homogeneous, and rate dependency was not incorporated (i.e. different material models need to be created for different testing speed). The constitutive material model was validated via simulation of the squeeze flow test. Results presented in Figure 14 compares the force-displacement curves predicted using various simulation models against the experimental data. The proposed new model shows significant improvement in force prediction compared to commercial software Moldex3D and 3D TIMON in terms of both the magnitude of the compression forces and the characteristic shape of the curve. With the proposed new model, the errors in force prediction increase with the displacement, possibly due to the existence of friction at the sample/tool interfaces and the inaccuracy of the compressibility model.

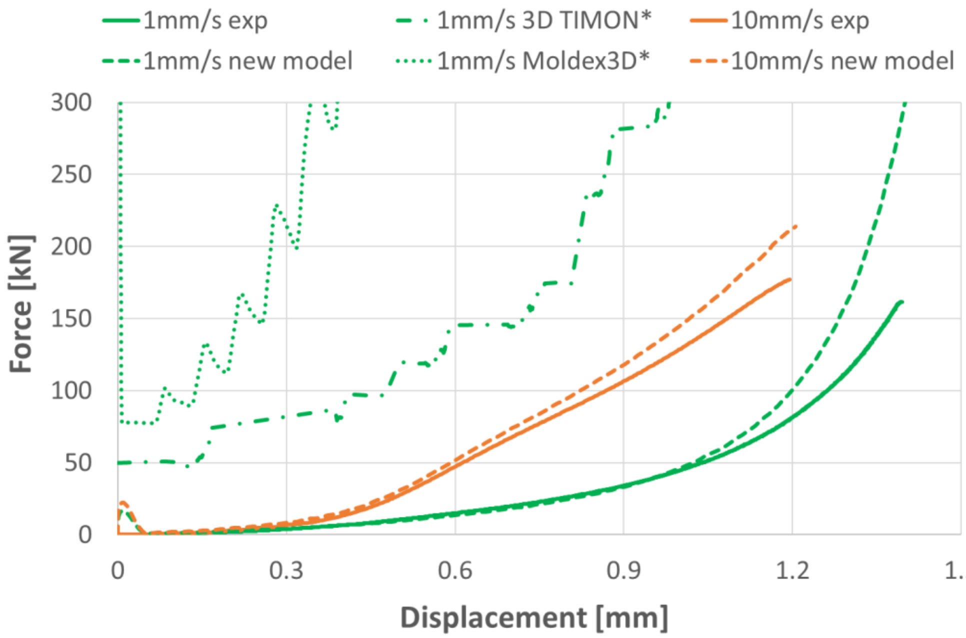
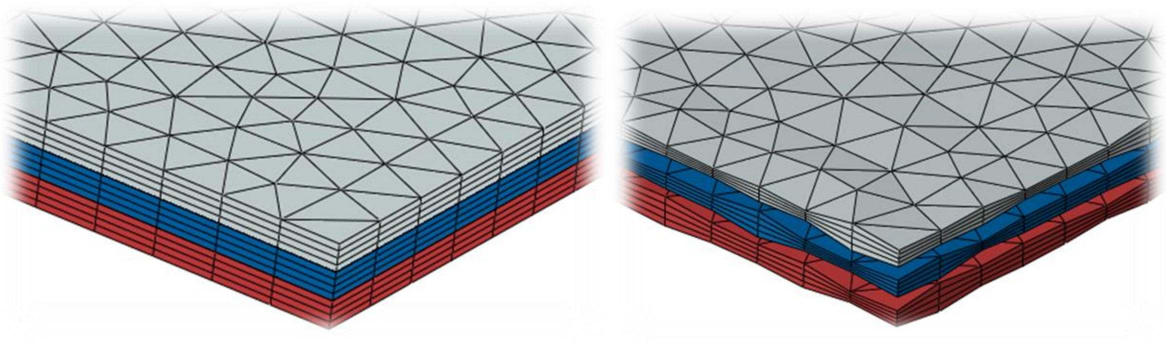


Figure 14: Comparison of force-displacement curves from the squeeze flow tests between the proposed new constitutive model, selected commercial software and the experimental data.

Compression moulding process simulation was performed using a square flat plaque geometry with a centrally located square charge of 60% initial coverage. The initial charge consisted of 3 plies of SMC, which was individually modelled in the process simulation. Two different approaches were used for modelling the geometry of the initial charge including a regular thickness approach and an irregular thickness approach (Figure 15) The irregular thickness approach can capture the lofting between plies commonly seen in SMC materials due to the uneven ply thickness, which affects the overall thickness of the initial charge.

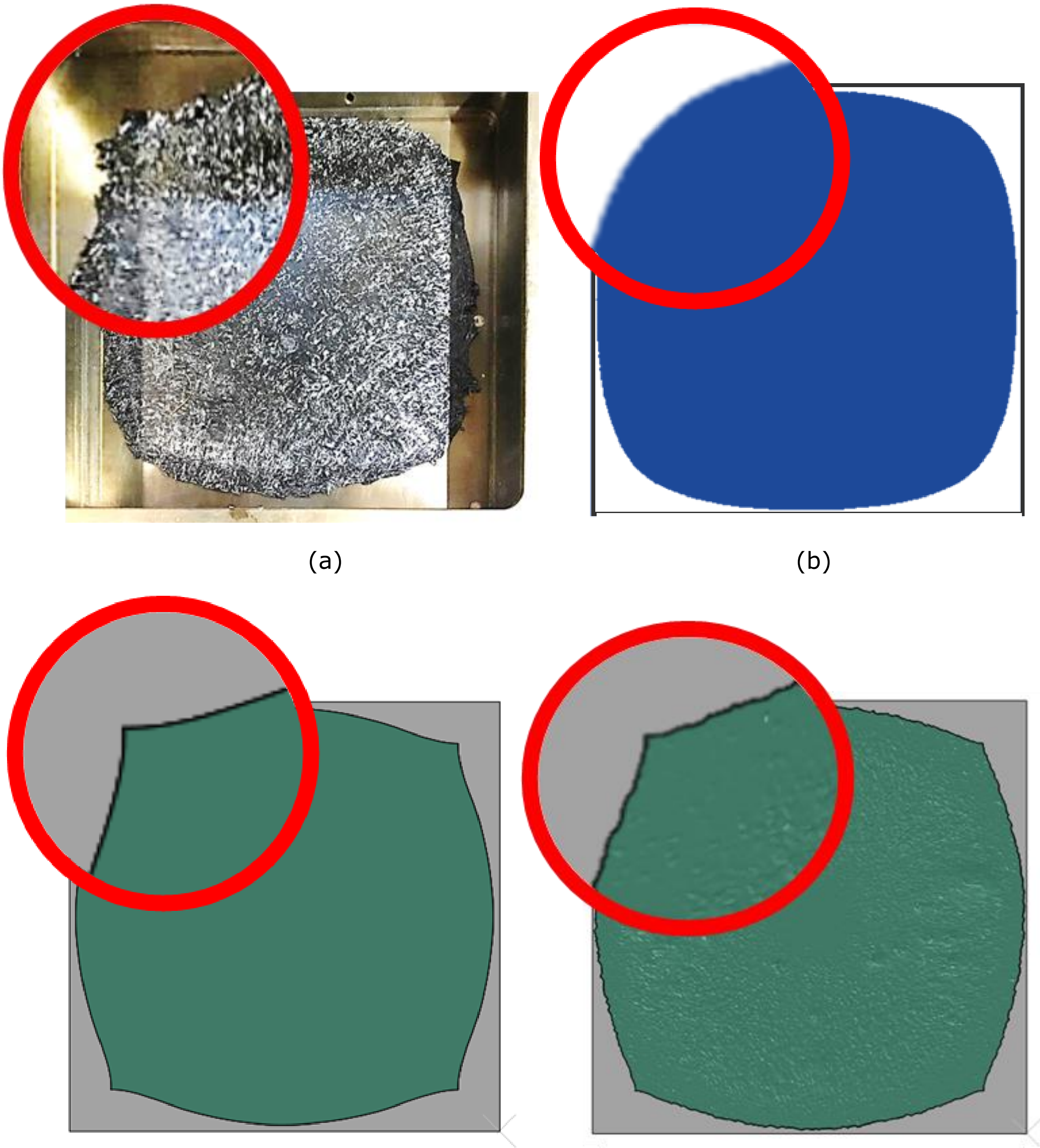


(a) (b)

Figure 15: Initial charge modelled using (a) regular thickness approach and (b) irregular thickness approach

Figure 16 compares the filling patterns predicted using different process simulation models against the filling pattern taken from an experimental partial closure. It can be observed from Figure 16a that the SMC experienced solid-like deformation, such that the corners on the original charge still presented. However, the filling pattern predicted by Moldex3D showed a more rounded shape, similar to that's commonly seen in liquid moulding process.

The filling patterns predicted using the proposed new model showed much better agreement with the experimental filling pattern. The filling pattern predicted using the irregular thickness approach was more realistic as it could capture the irregular flow front seen in the experimental filling pattern.



(a) (b) (c) (d)

Figure 16: Filling pattern comparison for the flat plaque geometry. (a) Experimental. (b) Moldex3D. (c) Proposed new model with regular charge thickness. (d) proposed new model with irregular charge thickness.

Fibre prediction model

Investigation of fibre prediction was not in the original project plan, but added to the project during covid lockdown as the work was primarily simulation focused and did not heavily rely on experimental activities. The model investigated in this project was a Direct Fibre Simulation (DFS) model developed by one of the industrial partners, Toray Engineering D Solutions, and available through commercial process simulation software 3D TIMON. Toray's DFS model can capture the movement and deformation of individual fibre tows by modelling each tow as a chain of truss elements. The aim of this work package was to understand the predictive validity of Toray's DFS model for SMC compression process simulation. 1D flow regimes were used in all cases for this work in order to eliminate incorrect fibre predictions caused by incorrect filling pattern predictions, as for the majority of fibre prediction models, the fibre orientations were calculated from the flow velocities.

Two studies were conducted in this work package, including indirect validation and direct validation. The indirect validation was achieved be predicting the mechanical properties of moulded SMC based on the outputs from process simulation, and comparing the predicted mechanical properties against experimental data. Meso-scale virtual tensile testing coupons (Figure 17) were created in ABAQUS based on the fibre architecture outputs from 3D TIMON, and the analysis was performed using the standard solver.

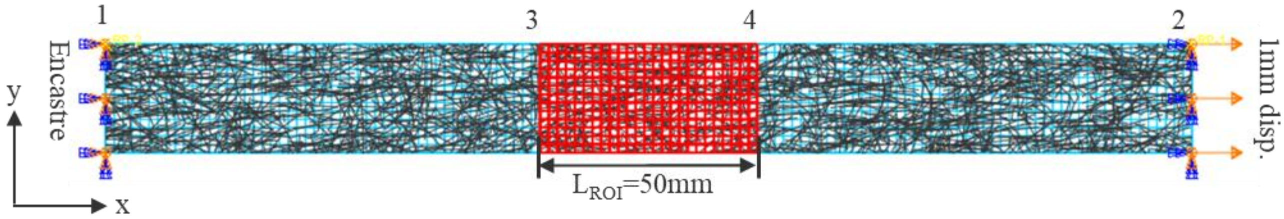


Figure 17: Example meso-scale virtual tensile testing coupon generated in ABAQUS/standard.

Figure 18 illustrates the different initial charge locations investigated in this study and the tensile testing sample layout. The simulation results are presented in Figure 19 and compared with the experimental data. In general, there was good agreement between the simulation and the experimental data. The simulation under-predicted the tensile modulus by to 20%, possibly caused by the difference in fibre tow counts between the experimental samples and the simulation models, as well as the incorrect fibre cross-section used in the simulation. In addition, the coefficients of variation were found to be higher in experimental data. A damage model will be developed to enable failure prediction for compression moulded SMC.

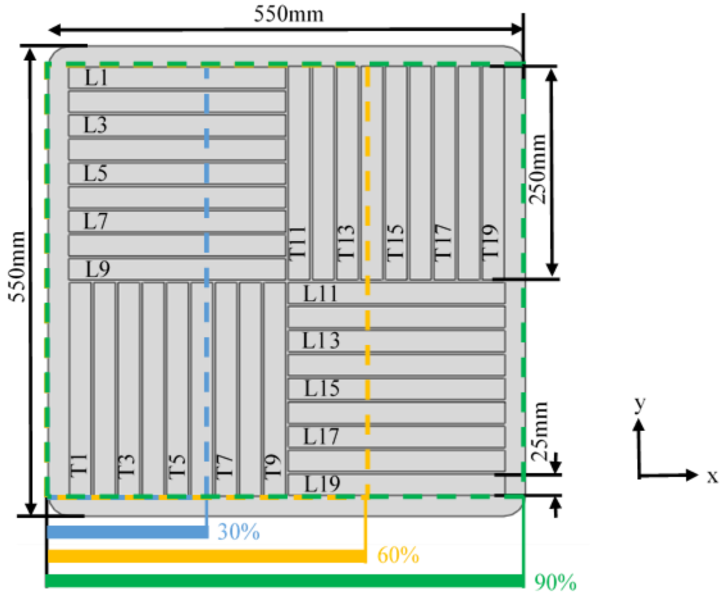


Figure 18: Schematic of the initial charge locations and tensile testing sample layout for the indirect validation study. L1-L9 are referred to as longitudinal, low flow. T1-T9 are referred to as transverse, low flow. L11-L19 are referred to as longitudinal, high flow. T11-T19 are referred to as transverse, high flow.

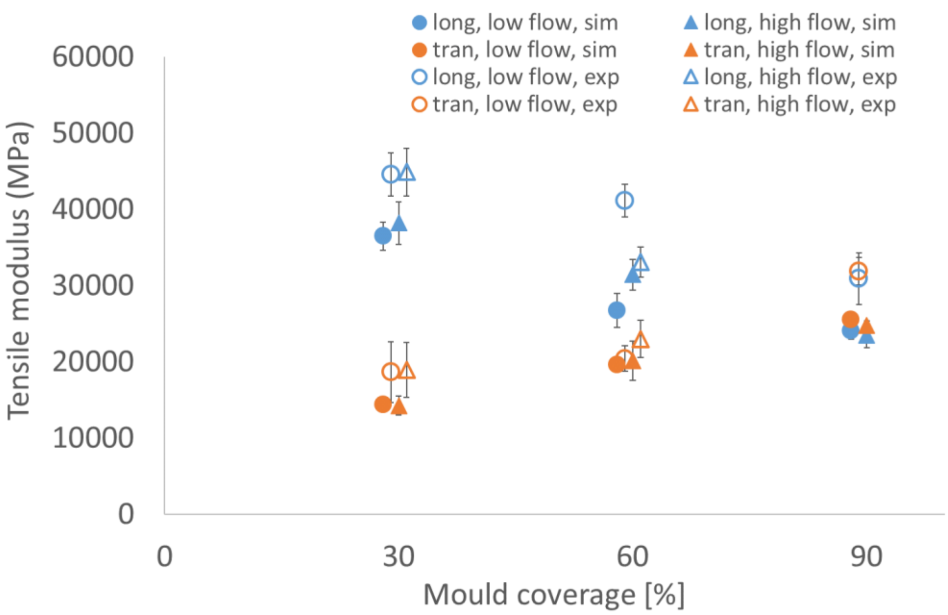


Figure 19: Comparison of tensile modulus predicted from simulation against experimental. The sample configurations are be found in Figure 18.

The direct validation study was performed using µCT scan data delivered through the EPSRC Metrology Hub Feasibility Study. The same flat plaque geometry was chosen in this study. Figure 20 presents the location of the µCT sample in relation to the flat plaque and the initial charge. Fibre orientation results predicted using the DFS model were plotted as distributions of each orientation tensor along the length of the sample, and compared the with the experimental data and the results predicted using the conventional Folgar-Tucker model (available in commercial software Moldex3D).

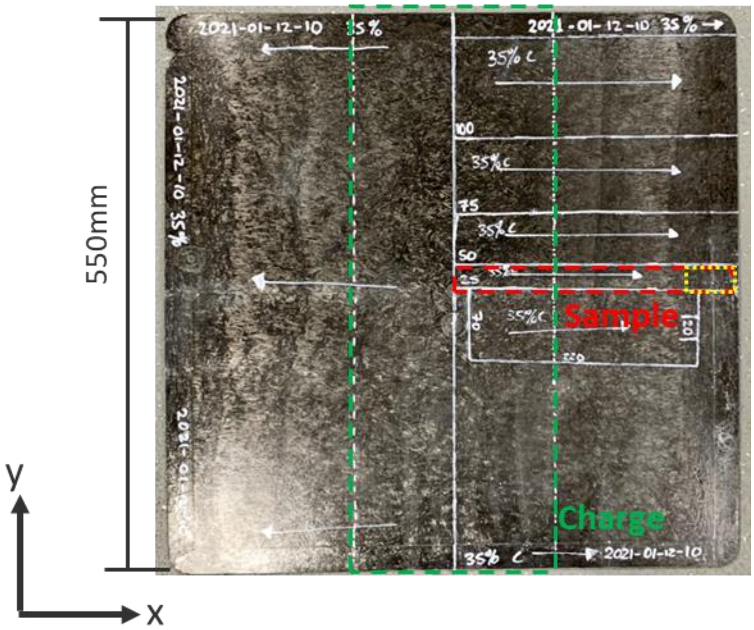


Figure 20: Schematic of the µCT sample location, initial charge location in relation to the flat plaque.

Figure 21 compares the orientation tensor Axx distributions between the experimental data and the results from the two fibre prediction models. In general, the DFS results better represented the high level of variabilities of the material, and also provided better prediction results compared to the Folgar-Tucker model. Both models failed to predict some of the important meso-scale features in the material. For instance, the moulded plaque in Figure 20 had vertical lines visible from the plaque surface, which was cause by the difference in flow distance in each SMC ply, where the vertical lines were the edges of SMC plies. Such phenomenon could not be captured by the commercial simulation software because the initial charge was always modelled as a single block of material. Consequently, the fibre prediction model could not correctly predict the fibre orientation at ply edges. The simulation models also failed to predict the fibre orientation near the edge of the mould. Figure 22 compares the meso-scale fibre architecture obtained from the µCT scan and the DFS model. The fibres in the µCT scan shows a much higher level of fibre waviness, as well a larger affected area, where the fibres in the simulation shows low level, and very localised fibre waviness. This is because the DFs model does not consider the interaction between fibres, and also the truss element approach increases the overall stiffness of fibre tows.

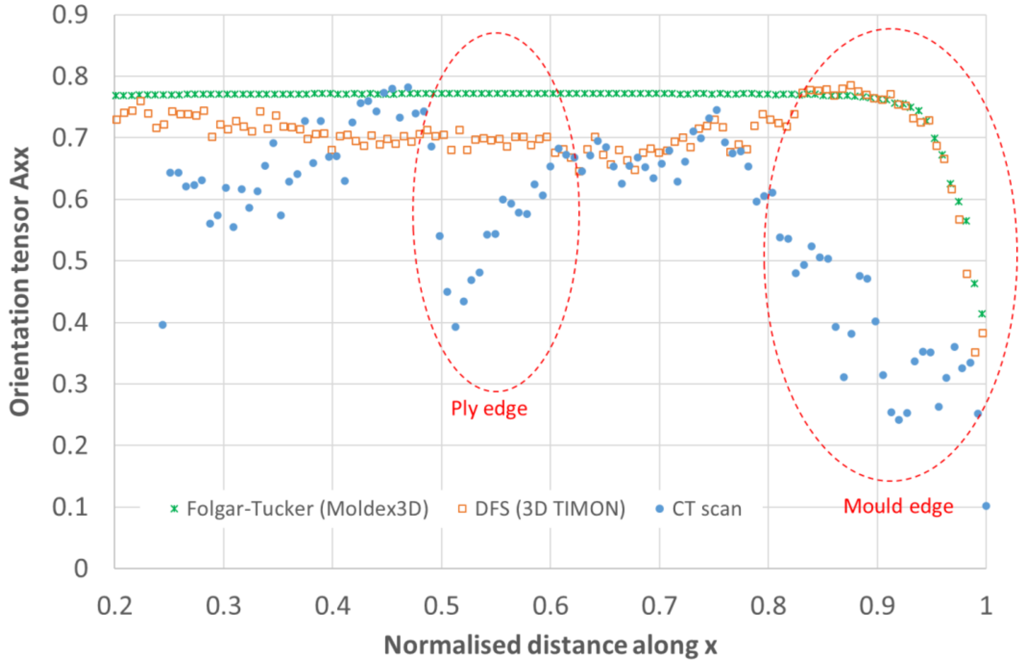


Figure 21: Comparison of fibre orientation tensor Axx distributions along the sample length between the Folgar Tucker model, the DFS model and the µCT data.

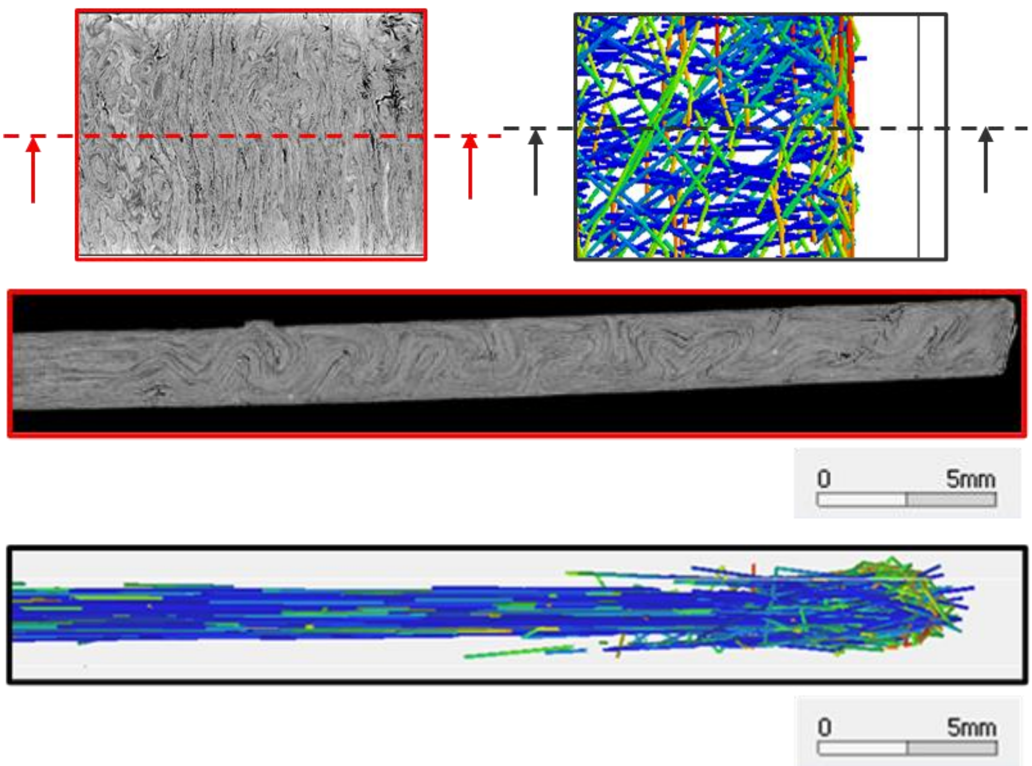


Figure 22: Meso-scale fibre architecture comparison between µCT scan and DFS results. The sample was indicated by the yellow box in Figure 20

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Future Direction/Impact

The experimental material/process characterisation methods are ready to be implemented in higher TRL (4-6) projects. An Innovate UK project has been secured where WMG's role is to provide material input data for commercial simulation software developers. Furthermore, the presentation at ECCM 20 conference attracted good level of interests from other academic institutions. An international benchmark exercise is currently being organised, aiming to develop a standard for the SMC squeeze flow tests.

The process simulation technology is still within low TRL and requires future development before industry exploitation. A PhD student will continue to develop the current SMC process simulation model, and develop new constitutive models for prepreg. The PI will apply for a follow-on EPSRC project, possibly through the New Investigator Aware to develop material characterisation and simulation methods for SMC out-of-plane flow, as SMC is typically adopted for manufacturing complicated features such as ribs and bosses, where out-of-plane plays an important role.

A new collaborative project, led by WMG and École Centrale de Nantes is currently being organised, aim to investigate the effect of rig design and testing procedure on the testing results of the SMC squeeze flow tests.

The potential impact of this project is mainly in two areas:

1. Sustainability. Processing of discontinuous fibre composites is an important solution to sustainable composites manufacturing, particularly in the areas of recycling and reuse, as the waste materials typically have infinite fibre lengths, meaning that they can no longer be processed using conventional forming processes.
2. Promote the application of discontinuous fibre in other industries. The application of SMC has been limited to the automotive industry for decades, and primarily for non-structural applications, due to the poor understanding in the processing behaviour and mechanical properties of the material. The methodology developed in this project and the outcomes will provide better understanding in the material, and facilitate the development of robust and reliable design tools, enabling SMC to be adopted in other applications where the design requirements are more demanding. The new Innovate UK – NATEP project aims to introduce SMC compression moulding to the aerospace industry.

Synergy with other Hub projects

2 proposals were submitted for hub synergy funds and 1 was successful. The successful project was based on the current innovation fellowship project and the former core project "Compression moulding of hybrid architecture composites"

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Metrics Summary

Please complete the following table:

		Target	
	Project duration (yrs)	2	2.5
	Project Value	£ 220,000	£220,000
Project Metrics	**PhD students**	0	0.5
	PDRAs (FTE per year)	1	1
	Person years	2	2
	Project based partners	2	2
	Institutional support	£ -	£30,000
	Industry support (Letters of Support)	£ 50,000	£50,000
	Additional leveraged grant income	£ 400,000	£633,600
	Additional industry leveraged income	£ 200,000	0
	Journal publications	3	2 accepted + more in preparation
	Conference papers	4	6
	Patent applications	1	0
	New collaborative research activity	0	1

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