Studentship Project: Annual Progress Report Oct/2021 to Oct/2022

Student Name:	Philip Johnson	AHDB Project Number:	SF/TF 170/a
Project Title:	Design and Control of a novel low-cost soft robotic gripper for soft fruit harvesting		
Lead Partner:			
Supervisor:	Dr Marcello Calisti		
Start Date:	01/10/20	End Date:	01/10/24

1. Project aims and objectives

- Design a soft robotic end effector for soft fruit picking
- Develop novel soft robotic technology for use in the end effector
- Fabricate the end effector
- Control and test the end effector

2. Key messages emerging from the project

- Shear thickening fluids (STFs) can be a used to create effective variable stiffening mechanisms in soft robotics
- STF joints can achieve upwards of 6x stiffness variation, based on the speed of actuation.

3. Summary of results from the reporting year

Following the transfer viva at the end of the first year of study, the main suggestion was the narrowing of the project scope to focus on the novel end-effector design rather than control and implementing of a whole harvesting arm. Therefore, since the start of this year (2022), and after a change of Director of studies, work has centred around design and prototyping of the end-effector and novel elements which may be included in its final configuration. My new supervisor Dr Calisti has contributed several ideas on exploitable gaps in the Soft robotic literature, one of which, is for passive variable stiffness in a robotic joint using shear-thickening fluids (STFs). The STF project activities have taken up the majority of this year's research efforts so far, starting with a literature survey of non-Newtonian fluids, their behaviour and their usage in research and current technology. We then moved on to creating proof-of-concept prototypes by 3D printing multi-part silicone moulds (Figure 3) and casting silicone joints, before filling them with STFs. At this stage, a number of other avenues were explored including directly 3D printing joints in elastic resin. This also required work to determine the optimum mixture of corn-starch and water to be used as a test STF. These successful proof-of-concepts led to the design of standardised test joints as well as a series of experiments (Figure 4) to evaluate and characterise their behaviour. The experiments required a number of 3D printed components such as brackets and fixtures to create a custom test rig for compression and expansion testing (Figure 4). The data collected in the experiments will is being used to evaluate this technology on a fundament level before using it in the design of a soft gripper for fruit. We already have a rough plan for how to integrate the STF in to gripper protoypes.

Delay: Unfortunately, due to covid and some health complications requiring surgery, I had to delay the project timeline by around a month and a half during the months of June and July.

Additionally, this year I have also been involved in the writing of a review paper on soft robotics in agriculture and food industries to be included in the IOP Science journal: Bioinspiration and Biomimetics. This will allow me to revisit the literature on soft robotics in agriculture and build on my existing literature review section. The paper is an international collaboration with academics from institutions such as Khalifa University and EPFL Switzerland. My NIAB supervisor Dr Charles Whitfield has also been invited to contribute.

The STF work was presented at the College of Science research showcase as well as featured in a LAR mini-conference presentation. The first scientific outcome of this work, from the data collected, is a conference paper recently submitted to the IEEE Robosoft conference entitled ‘Fabrication and Characterization of a Passive Variable Stiffness Joint’

Examples from the main data set collected:

Figure 1 gives a broad overview of the patterns which emerged across the experiments conducted. The maximum values of force for the STF joint in compression and bending experiments is dependent on the speed at which we actuate the joint. The STF joint behaves similarly to a water-filled joint at slow speeds but like solid silicone object at fast speeds. The effect is also observable in the images of the experiments shown in figure 2.

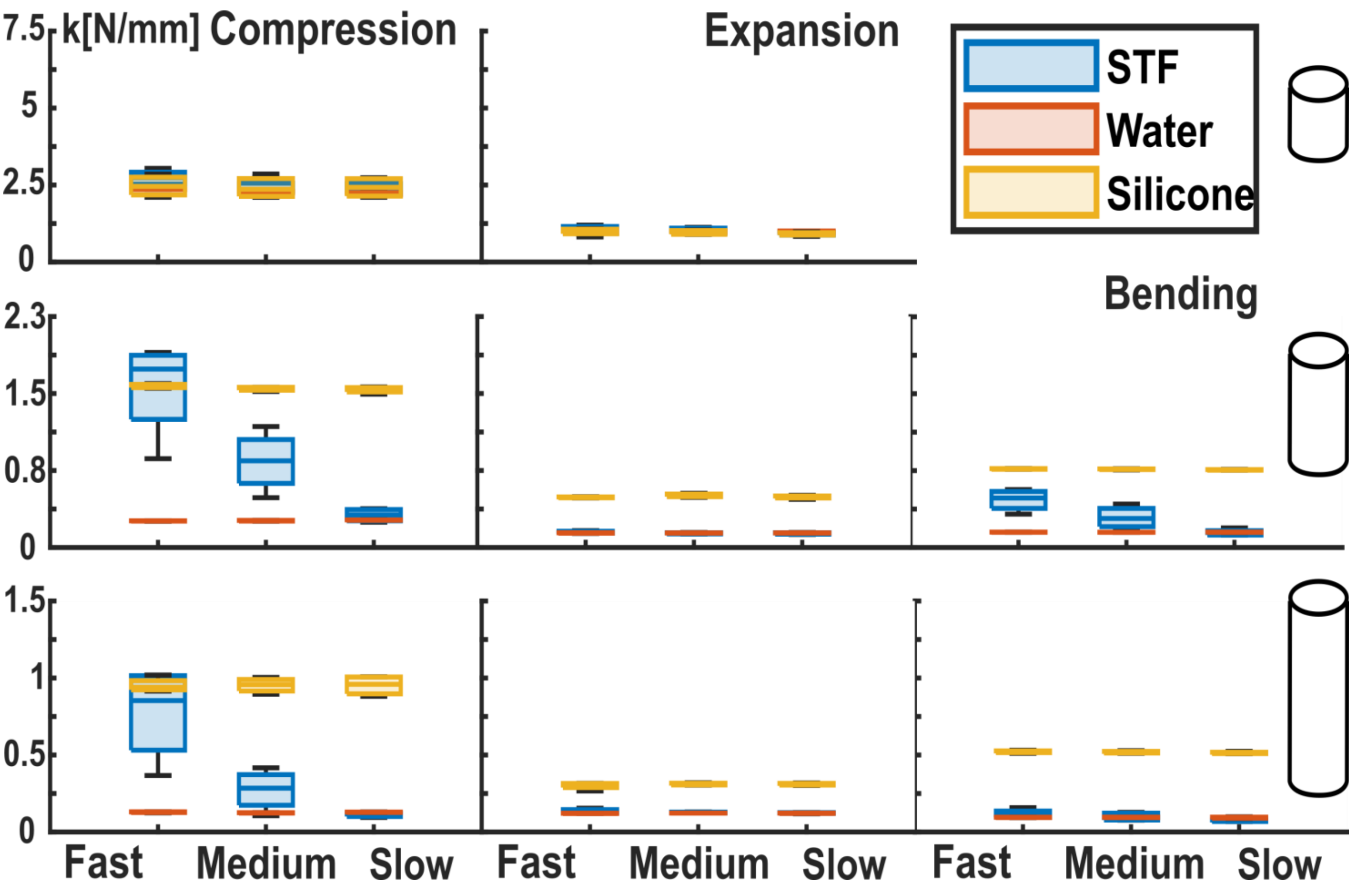

Figure 1: Box plots for the max values of force (Fz) across all STF experiments.Top row: 20mm joints, middle row: 40mm joints bottom row: 60mm joints

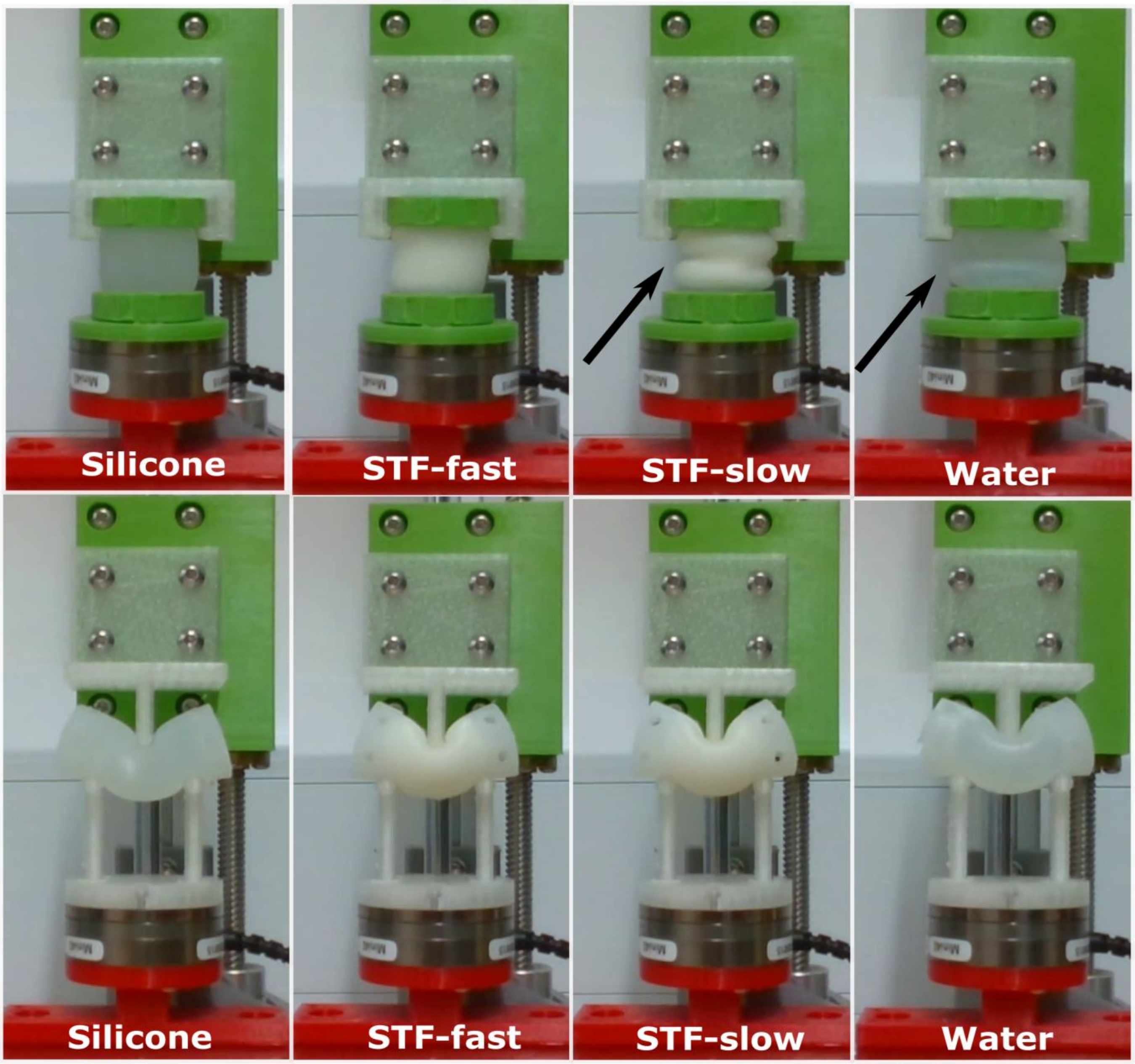

Figure 2: Visual record of the joint behavior in different experiments. Arrows highlight the buckling behavior at slow speeds which is not present in the STF when compessed at faster speeds

Examples of Fabrication process and Joints:

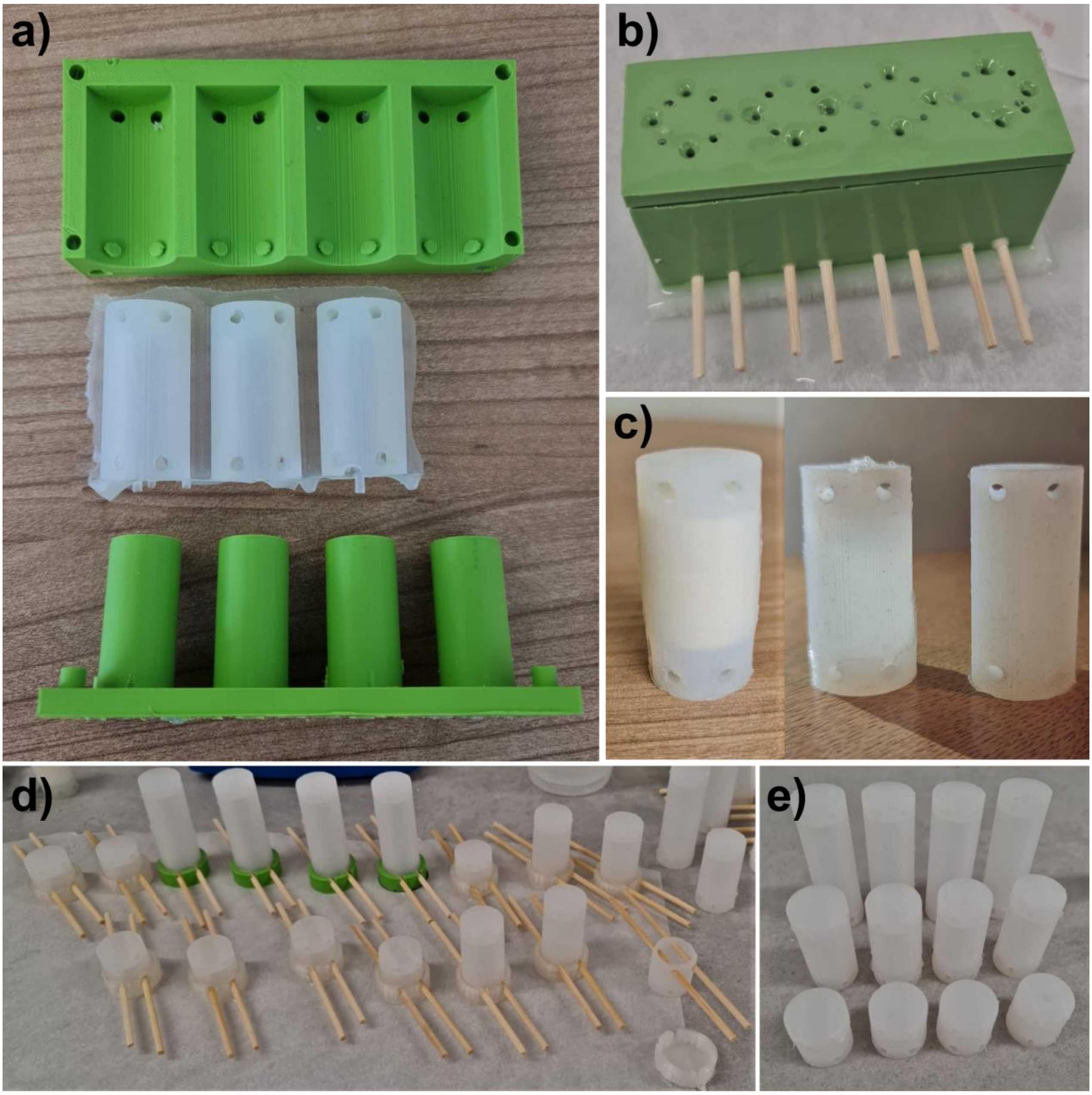

Figure 3: a) Custom 3d printed mould (open) b)Closed mould c)Joints left-right: STF, Water, Silicone d)End-capping e)Three joint sizes (60/40/20mm)

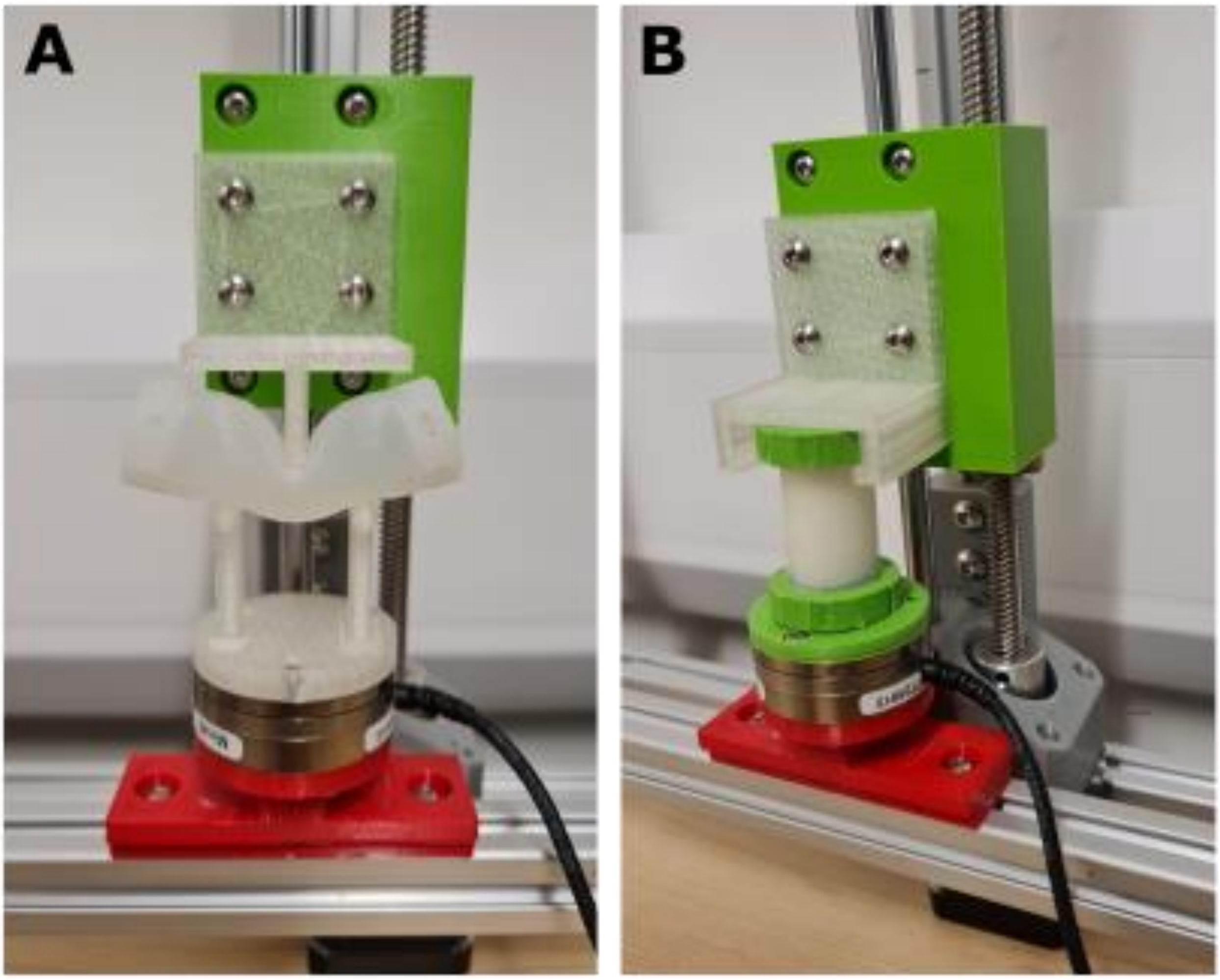

Figure 4: A- Bending test setup B-Compression/Expansion test setup

4. Key issues to be addressed in the next year

- We need to continue to develop work on the STF joints, building on the data gathered this year to produce higher quality experiments and more refined joint designs. Further data must be obtained to clarify the extent of the variation in stiffness that is possible.
- A model should be build and verified with experiments to predict the behaviour of STF joints at different scales.
- Other compositions of STF should also be investigated, we have already purchased the raw materials necessary to make more stable STFs.
- A prototype gripper should be made using the STF technology developed enough for manual testing at the start of the next growing season
- The functionality and cycle time achievable with the prototype must be evaluated in a lab setting with the UR3 robot arm

5. Outputs relating to the project

(events, press articles, conference posters or presentations, scientific papers):

Output	Detail
Conference Paper	Scientific paper submitted to the IEEE Robotsoft conference in October (currently under review).
Review Paper	Wrote a section for an invited review paper in Biomimicry and Bioinspiration (IOP Physics) called 'Soft robotics in agriculture'.
Presentation	Work presented at the University of Lincoln, Lincoln Agri Robotics mini-conference
Conference poster	Presented my work with a poster presentation at the East Midlands Robotic Network (University of Nottingham)
Presentation	Presented my work at the Harmston and Wragby YFC evening at Barclays Eagle Lab
Conference poster	Work presented at University of Lincoln College of Science research showcase.

6. Partners (if applicable)

Scientific partners	
Industry partners	Berry Gardens Ltd
Government sponsor	UKRI (BBSRC)