RGC Ref. No.:
UGC/FDS16/E05/19
(please insert ref. above)

RESEARCH GRANTS COUNCIL
COMPETITIVE RESEARCH FUNDING SCHEMES FOR
THE LOCAL SELF-FINANCING DEGREE SECTOR

FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report
(for completed projects only)

Submission Deadlines:
1. *Auditor's report with unspent balance, if any: within **six** months of the approved project completion date.*
2. *Completion report: within **12** months of the approved project completion date.*

Part A: The Project and Investigator(s)

1. Project Title

The modelling and development of Twin-screw type extrusion system for making recycled filament materials in additive manufacturing

2. Investigator(s) and Academic Department(s) / Unit(s) Involved

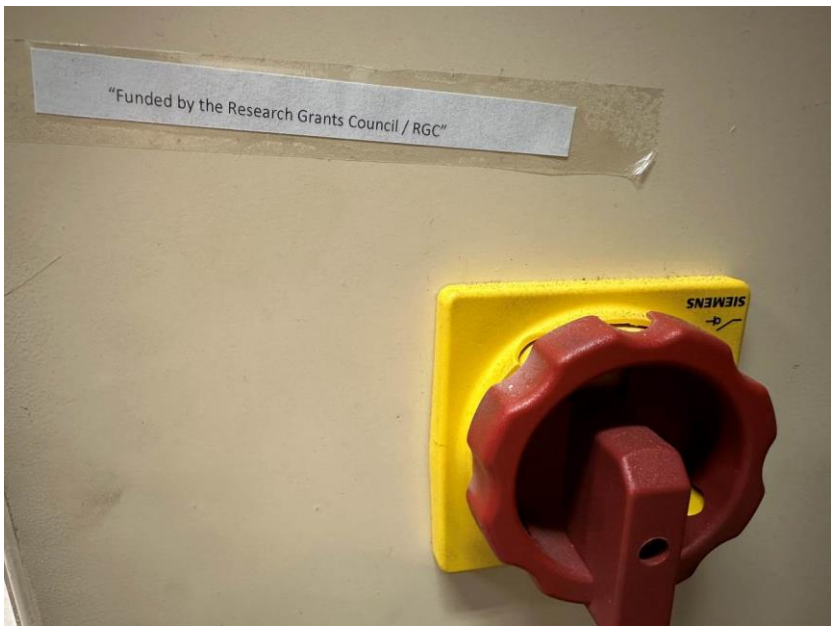
Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Ir Dr LI Jimmy Chi-ho / Assistant Professor	Department of Construction and Quality Management, School of Science and Technology, Hong Kong Metropolitan University
Co-Investigator	Ir Dr TANG Fanny Wai-fan / Assistant Professor	Department of Construction and Quality Management, School of Science and Technology, Hong Kong Metropolitan University
Co-Investigator	Ir Dr MAK Shu-lun / Principal Lecturer	Youth College (Kwai Chung), Vocational Training Council

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval *(must be quoted)*
Project Start Date	1 January 2020	1 January 2020	
Project Completion Date	30 June 2022	30 June 2023	18 May 2022
Duration *(in month)*	30	42	18 May 2022
Deadline for Submission of Completion Report	30 June 2023	30 June 2024	18 May 2022

4.3 Please attach photo(s) of acknowledgement of RGC-funded facilities / equipment.

Desktop twin screw electrical driven extruder



Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. **Analyse** the distribution and physical properties of common polymeric materials of waste plastic bottles in Hong Kong.

2. **Determine** the essential additives to improve the properties of waste plastics in order to suit the application of 3D printing.

3. **Design** and **develop** the twin-screw extruder to make the filaments.

4. **Evaluate** the maintainability and productivity of extrusion and 3D printing processes.

5. **Compare** and **analyse** the mechanical strength of printed products.

5.2 Realisation of the objectives

1. Analyse the distribution and physical properties of common polymeric materials of waste plastic bottles in Hong Kong:
   The analysis of the plastic waste and specifically the types of materials from waste bottle containers are carried out, and polyethylene terephthalate (PET) is chosen as the recycled material for the project.
2. Determine the essential additives to improve the properties of waste plastics in order to suit the application of 3D printing:
   The additive of talc/talcum powder is explored in improving the properties of plastic, and the features of the quantity and portion of the additive are explored in finding the preferred mixture ratio for turning recycled plastic into suitable material for 3D printing filaments.
3. Design and develop the twin-screw extruder to make the filaments:
   The twin-screw extruder is explored for making 3D printing filaments, and compared to the more traditional single-screw method, as well as the challenges that were encountered during the development process are discussed.
4. Evaluate the maintainability and productivity of extrusion and 3D printing processes:
   The twin-screw extruder exploration provided insights into the optimal conditions for plastic filament production, and the material properties investigation provided information on the recycled PET plastics for the 3D printer process, with the speed and quality of printing on par with an existing solution of PLA.
5. Compare and analyse the mechanical strength of printed product:
   The study compared and analysed the mechanical properties of printed products using plastic filaments made from waste plastic bottles. The tensile strength, compressive strength, flexural strength, and impact strength of the printed products are explored, providing details and properties for this potential new feedstock for 3D printers.

5.3 Summary of objectives addressed to date

Objectives *(as per 5.1/5.2 above)*	**Addressed** *(please tick)*	**Percentage Achieved** *(please estimate)*
Analyse the distribution and physical properties of common polymeric materials of waste plastic bottles in Hong Kong.	✓	100%
Determine the essential additives to improve the properties of waste plastics in order to suit the application of 3D printing.	✓	100%
Design and **develop** the twin-screw extruder to make the filaments.	✓	100%
Evaluate the maintainability and productivity of extrusion and 3D printing processes.	✓	100%
Compare and **analyse** the mechanical strength of printed products.	✓	100%

6. Research Outcome

6.1 Major findings and research outcome

This study found that talc powder can improve stiffness, crystallization, and thermal stability, and modify the viscosity behavior of different polymers. However, high talc content may reduce impact strength and strain at break. Also, pyrolysis can convert plastic waste into valuable products such as oil, gas, and carbon black. However, the efficiency of the process depends on the type of plastic waste and pyrolysis conditions.

The study also found that recycled PET waste can be used to make high-quality 3D printing filaments using the extrusion method. However, the mechanical properties of the filaments depend on the extrusion conditions and the quality of the recycled PET waste, which needs processing to be presentable in a usable state for processing into 3D printing filaments.

The study also explored the use of bio-oil extracted from food waste as an alternative additive for recycled 3D printing filaments and found that bio-oil can improve the mechanical properties of recycled 3D printing filaments. However, the compatibility of bio-oil with different polymers and the optimal ratio of bio-oil to polymer still needs to be further investigated.

The use of a twin-screw extruder for thermoplastic materials such as waste PET is also discussed. The study found that twin-screw extruder has significant advantages over single-screw extruders in terms of the quality and productivity of 3D printing filaments. However, the cost of a twin-screw extruder is higher than the single screw extruder and might hamper the economic viability of the project in producing competing products to existing solutions.

6.2 Potential for further development of the research and the proposed course of action

The potential for the further development of this project is quite significant, with the demand for 3D printing materials expected to grow in recent years. Finding ways to reuse the waste plastics and provide decent material for 3D printing, would put the plastics to the landfill back into utility, and address issues of environmental impacts from plastic wastes through the reduction, as well as reducing the need for new virgin plastic.

One possible course of action for further development of this project is to focus on optimizing the twin-screw extrusion system for processing more different types of thermoplastics such as high-density polyethylene (HDPE) or polypropylene (PP). This could involve experimenting with different additives and processing conditions to improve the quality and consistency of the resulting 3D printing filament, as well as alternate ways of alternating properties of the materials, such as dyeing and reinforcements if needed.

Another potential avenue for further development is to explore partnerships with industry or educational institutions to implement the twin-screw extrusion system in real-world settings. This could involve working with schools or community organizations to establish recycling programs for waste plastic bottles and providing them with the necessary equipment and training to produce their 3D printing filament. Such partnerships could help to promote sustainable practices and reduce waste in local communities.

7. Layman's Summary

3D printing is a rapidly growing technology used for the more flexible side of manufacturing, and such additive manufacturing would also mean a significant need for plastics. The widespread use of 3D printers for various projects means an increased demand for plastic, such as polylactic acid (PLA), a popular choice of thermoplastic material derived from biological agents. The availability of recycled 3D printing materials would help reduce the impact of using 3D printers, as well as reduce the overall demand for new thermoplastics, and address the plastic waste issues from disposable plastic products as the proposed research project would turn the wastes, particularly from waste plastic bottles, into material that can be used for 3D printing.

The research project aims to discover the properties of waste bottle plastics and find methods and additives to suit the material for 3D printing, using a twin-screw extrusion system that can ultimately be applied in domestic and educational settings, reducing the waste generated by disposed plastic drink bottles of the type of plastic of polyethylene terephthalate (PET) as finalized in this project.

Part C: Research Output

8. Peer-Reviewed Journal Publication(s) Arising Directly From This Research Project

The Latest Status of Publications				Author(s) *(denote the corresponding author with an asterisk*)*	Title and Journal / Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this Report *(Yes or No)*	Acknowledged the Support of RGC *(Yes or No)*	Accessible from the Institutional Repository *(Yes or No)*
Year of Publication	**Year of Acceptance** *(For paper accepted but not yet published)*	**Under Review**	**Under Preparation** *(optional)*						
2021				M. Y. Wu, Shulun Mak, Fanny Tang and Chi-ho Li	A Study on Twin-screw Extruder for Thermoplastic Materials / 2021 *Annual Journal of HKIE CAD, HKIE, 2020, ISBN 9-789627-619741*	No	Yes [Attachment 1]	Yes	Yes
2022				M. Y. Wu, Shu-lun Mak, Fanny Tang, Chi-ho Li and Chi-wing Lai	A Review on Melt Flow Index Characteristics of Polylactide (PLA) for Recycle Use in 3-D Printing/ *Journal of Testing and Evaluation*	2022	Yes [Attachment 2]	Yes	Yes
2022				S. L. Mak, W. F. Tang, C. H.Li, C. C. Lee, M. Y. Wu, W. Y, Chak and W. K. Kwong	Recycling polyethylene terephthalate (PET) to make the 3D printing filaments, Chapter 8 3D Printing Revolution and Sustainable Product Development, Taylor and Francis, USA	No	Yes [Attachment 3]	Yes	Yes

9. Recognized International Conference(s) In Which Paper(s) Related To This Research Project Was / Were Delivered

Month / Year / Place	**Title**	**Conference Name**	**Submitted to RGC** *(indicate the year ending of the relevant progress report)*	**Attached to this Report** *(Yes or No)*	**Acknowledged the Support of RGC** *(Yes or No)*	**Accessible from the Institutional Repository** *(Yes or No)*
2 – 3 Feb 2021/ Changsha, China	A Review on Utilization of Plastic Wastes in Making Construction Bricks	2021 6th International Conference on Green Materials and Environmental Engineering (GMEE2021)	2021	No	Yes	Yes
28 Dec 2021/ Taipei	A Review on Mechanical Properties Modification of Polymer with Talc Powder	2021 IEEE International Symposium on Product Compliance Engineering - Asia (ISPCEASIA)	2022	No	Yes	Yes

10. Whether Research Experience And New Knowledge Has Been Transferred / Has Contributed To Teaching And Learning
(Please elaborate)

Nil

11. Student(s) Trained
(Please attach a copy of the title page of the thesis)

Name	**Degree Registered for**	**Date of Registration**	**Date of Thesis Submission / Graduation**
Nil			

12. Other Impact

(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, teaching enhancement, etc.)

The research received the short-term patent (eight years commencing on 29 June 2023) for the invention (title: Brick and method of forming same) and patent number is HK30091805 in Hong Kong.

13. Statistics on Research Outputs

	Peer-reviewed Journal Publications	Conference Papers	Scholarly Books, Monographs and Chapters	Patents Awarded	Other Research Outputs (please specify)	
No. of outputs arising directly from this research project	2	2	1	1	Type	No.

14. Public Access Of Completion Report

(Please specify the information, if any, that cannot be provided for public access and give the reasons.)

Information that Cannot Be Provided for Public Access	Reasons
Nil	