RGC Ref.: N_CityU116/14 NSFC Ref. : 51461165101
(please insert ref. above)

The Research Grants Council of Hong Kong
NSFC/RGC Joint Research Scheme
Joint Completion Report

(Please attach a copy of the completion report submitted to the NSFC by the Mainland researcher)

Part A: The Project and Investigator(s)

1. Project Title

Design and Optimizing Laser-Based 3D Printing of Metallic Glass: A Systematic Study of the Joining and Crystallization Mechanisms of Amorphous Structures under Laser Irradiation

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

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof Yong YANG	Prof Wei Hua WANG
Post	Professor	Professor
Unit / Department / Institution	Mechanical Engineering/CityU	CAS
Contact Information		
Co-investigator(s) *(with title and institution)*	Prof T N TU (UCLA)	

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	1 Jan 2015		
Project Completion date	31 Dec 2018		
Duration *(in month)*	48		
Deadline for Submission of Completion Report			

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. Understand the laser interaction with MG powder layers
2. Understand the crystallization dynamics at extremely high heating/cooling rates and a small size scale.
3. Develop a laser 3D printing protocol and a MG alloy that fits each other for the production of 3D printed MG samples.
4. Develop a post-processing protocol that can improve the mechanical properties of the 3D printed MG samples.

5.2 Revised Objectives

Date of approval from the RGC: ____________________

Reasons for the change: ____

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1.
2.
3. ....

6. Research Outcome

Major findings and research outcome

(maximum 1 page; please make reference to Part C where necessary)

Some of the findings have already been briefly discussed in 5.3. Below are some more elaborations of our findings.

Through extensive molecular dynamics simulations, we found that, contrary to the previous beliefs, it is not local geometrical orderings extracted from instantaneous configurations but the intrinsic correlation between static configurations that captures the structural origin governing slow dynamics. More significantly, we demonstrated by scaling analyses that it is the static correlation length extracted from static configuration correlation rather than dynamic correlation lengths that is the key to determine the drastic slowdown of supercooled metallic liquids. The key role of the static configuration correlation could serve as the structural origin of the mysterious glass transition and provides an essential piece of the puzzle for the development of a universal theoretical understanding of glass transition in glasses, which then facilitate our understanding of 3D printing of metallic glasses.

There is a mild strength size effect when the MG sample size is reduced from the bulk scale to the micrometer scale. As the sample size is reduced further to the submicron scale, a transition from the size dependent to size independent yield strength occurs. This transition appears stochastic with strong data scattering in microcompression because of the interplay between the size-controlled shear band initiation mechanism and various extrinsic factors, which results in the randomness in the shear band initiation site. The data scattering becomes most significant around the transition length. It diminishes with the increasing sample size and levels off to a constant value with further size reduction. The critical length scale L^* could range from 0.2 μm to 2 μm for the above transition, which generally increases with the modulus of the BMGs. The achievable maximum strength σ_{max} in MGs generally varies with their chemical composition, the value of which depends on the shear band thickness t_{SB}, the elastic modulus E, the ratio of the bulk strength σ_0 to the elastic modulus E and the energy dissipated per unit area Γ during the formation of a shear band embryo.

In 3D printing, metallic glasses were usually heated up above their glass transition points to enable hot joining in additive manufacturing, which, however, usually causes crystallization and is hence compositional limited. Through the funded research, we develop a facile ultrasound based approach to synthesize bulk metallic glasses by fully activating their fast atomic dynamics within an ultrathin surface layer. As a result, formation of metallic bonding between surfaces of identical or drastically different compositions can be formed without bulk crystallization and within few seconds at a temperature far below the bulk glass transition points. In principle, our approach overcomes the compositional limitation facing the traditional methods, which opens up a window not only to synthesize bulk metallic glasses of extended compositions but also towards the discovery of multi-functional glass-glass composites which have never been reported before.

Potential for further development of the research and the proposed course of action *(maximum half a page)*

We propose the further development of cold printing technique for BMGs and other glasses as the one possible direction for the follow-up research. This has never been explored before and should be studied in a systematic manner.

7. The Layman's Summary

(describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

In the human history, glass has been playing critical roles both in scientific research and technologic development. Nowadays, many kinds of natural or man-made glasses find extensive applications in optics, biotechnology, medicine, and electronics, among which bulk metallic glasses (BMGs) were considered as a candidate material for both structural and functional applications and therefore have gained a great deal of attention ever since being discovered. However, the glass forming ability (GFA) of metallic glass-forming liquids is limited and compositional sensitive. To overcome this limitation, 3D printing of BMGs is considered as a flexible and promising route by joining micro-sized powders into bulk, which enables the fabrication of complex shapes. In this project, we studied the fundamental issues related to 3D printing of BMGs, such as the physical origin of glass transition and the combined effects of pressure, surface, mechanical constraints and sample dimension on the physical/mechanical properties of BMGs. Based on the outcome of our research, we also propose solutions to mitigate the issues people are facing in 3D printing of BMGs.

Part C: Research Output

8. Peer-reviewed journal publication(s) arising directly from this research project

(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s) (*bold the authors belonging to the project teams and 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 this Joint Research Scheme (*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*)						
2017				**Y.C. Hu**, P.F. Guan*, Q. Wang, **Y. Yang***, H.Y. Bai, **W.H. Wang***	Pressure effects on structure and dynamics of metallic glass forming liquid, *J. Chem. Phys.*, 146, 024507, 2017.	31 Dec 2016	Yes	Yes	No
2016				Y.C. Hu, B. Shang, P.F. Guan*, **Y. Yang*** H.Y. Bai, **W.H. Wang***	Thermodynamic scaling of glassy dynamics and dynamic heterogeneities in metallic glass-forming liquid, *J. Chem. Phys.*, 145(10), 104503, 2016.	31 Dec 2016	Yes	Yes	No

2016				**Y.C. Hu**, Y.Z. Wang, R. Su, C.R. Cao, F. Li, C.W. Sun, **Y. Yang**, P.F. Guan*, D.W. Ding, Z.L. Wang, **W.H. Wang***	A highly efficient and self-stabilizing metallic glass catalyst for electrochemical hydrogen generation, ***Advanced Materials***, 28, 10293-10297, 2016.		Yes	Yes	No
2017				F.C. Li, S. Wang, Q.F. He, H. Zhang, B.A. Sun, Y. Lu, **Y. Yang***	The stochastic transition from size dependent to size independent yield strength in metallic glasses, ***Journal of the Mechanics and Physics of Solids***, 109, 200-216, 2017.		Yes	Yes	No
2018				**Y.C. Hu***, Y.W. Li, **Y. Yang**, P.F. Guan*, H.Y. Bai, **W.H. Wang**	Configuration correlation governs slow dynamics of supercooled metallic liquids, ***Proc. Natl. Acad. Sci. USA*** **(PNAS)**, 115(25), 6375-6380, 2018		Yes	Yes	No

9. Recognized international conference(s) in which paper(s) related to this research project was/were delivered *(Please attach a copy of each delivered paper. All listed papers must acknowledge RGC's funding support by quoting the specific grant reference.)*

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 this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
July/2017/Xiamen China	Universal Secondary Relaxation and Unusual Brittle-to-Ductile Transition in Metallic Glasses	Chinese Materials Conference	No	No	No	No
July/2018/Yinchuan China	金属玻璃强度的随机尺寸效应：从块体金属玻璃到金属纳米玻璃	Chinese Materials Conference	No	No	No	No
May/2018/Seoul Korea	Fast Secondary Relaxation and Plasticity Initiation in Metallic Glass	The 12th International Conference on Bulk Metallic Glasses	No	No	No	No

10. 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
LYU Yumiao	PhD (Joint supervision with UCAS)	Jan 2015	May 2017
HU Yuanchao	PhD (Join supervision with UCAS)	Sept 2015	May 2018
LIU Xiaodi	PhD	Aug 2015	Aug 2018

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

Collaboration with the research group of Prof K.N. Tu at UCLA on creep of advanced structural materials