Modeling meteorite crater by impacting melted tin on sand

Hung-Yueh Huang[1] (黃弘岳), Ping-Rui Tsai[1] (蔡秉叡), Chang-Yi Lyu[1] (呂長益), Hong Hao[1] (郝鴻), Yi-Jui Wu[1] (吳翊睿), Zong-Ting Ling(凌宗廷), Yan-Liang Chen[2] (陳彥良), and Tzay-Ming Hong[1] (洪在明)

[1]Department of Physics, National Tsing Hua University, Hsinchu 30043, Taiwan, Republic of China
[2]Department of Mechanical Engineering, National Taiwan University, Taipei 10617, Taiwan, Republic of China

ABSTRACT

By impacting a granular bed by steel balls and liquid drops, previous researchers focused mainly on the morphology of impact craters. [1-2] To mimic the heated exterior of a meteorite, we adopt the melted tin. A high-speed camera allows us to follow step by step the fiery interaction between melted tin and sand, as manifested in PIV and CNN, and monitor their deformation. Kinetic energy, temperature and diameter of the projectile are used to build phase diagrams for the morphology of both players. We are able to reproduce simple and complex craters based on the morphology. By employing the feature detection with deep learning, we can further verify that the mechanism for generating a central peak in our pearl crater is indeed similar to that in complex craters. How the width and depth of crater are correlated and separately vary with kinetic energy are shown to change with the granular size. For our finest sand, the pearl and cookie craters share the same relationship for a simple crater, while the snowflake crater behaves more like a complex one. Geological compilations of crater data are clearly mixed with different meteorite energy and temperature. Thus, our work is not confined to reproducing real observations, but has the potential of debunking artifacts.

Keyword: meteorite, impact, deep learning

Experimental Setup and Phases

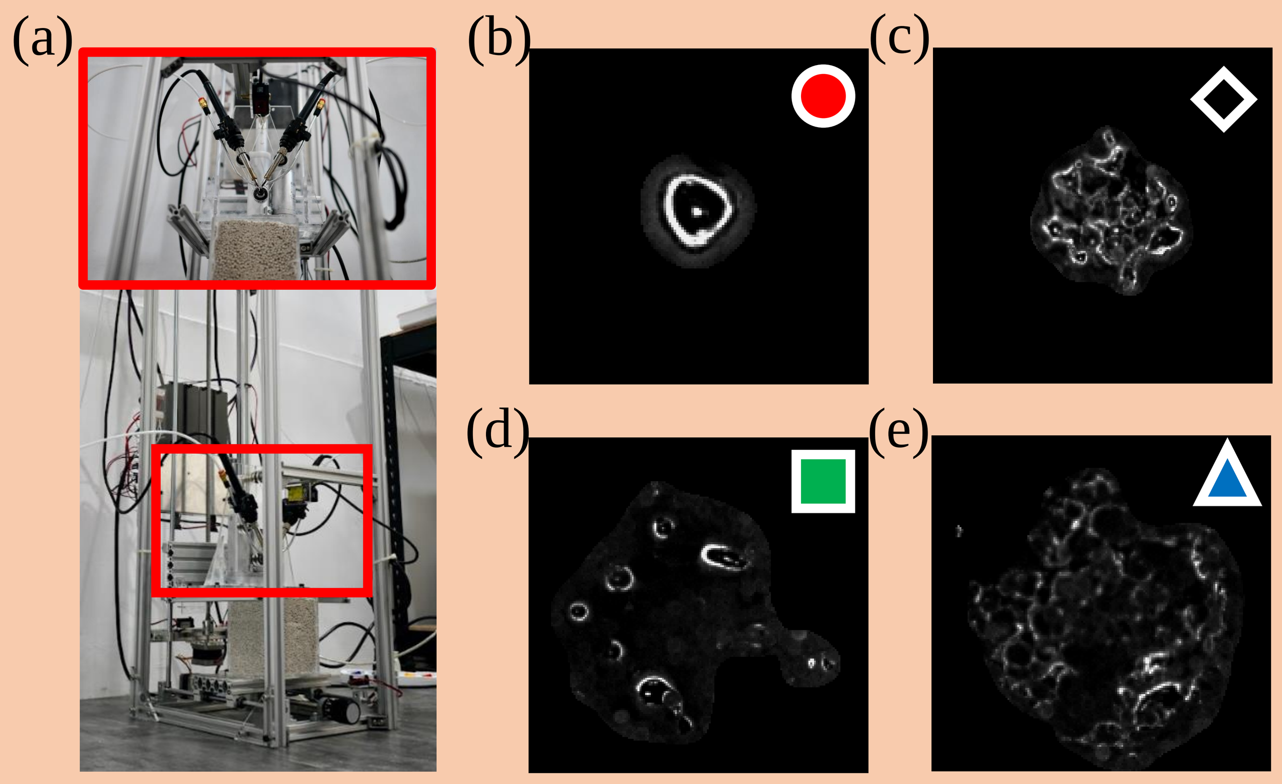

FIG. 1. (a) Impact experimental setup. There are four phases for tin remnant: (b) pearl, (c) cookie, (d) shotgun, and (e) snowflake.

Morphology of Craters

(I) Temperature Effect

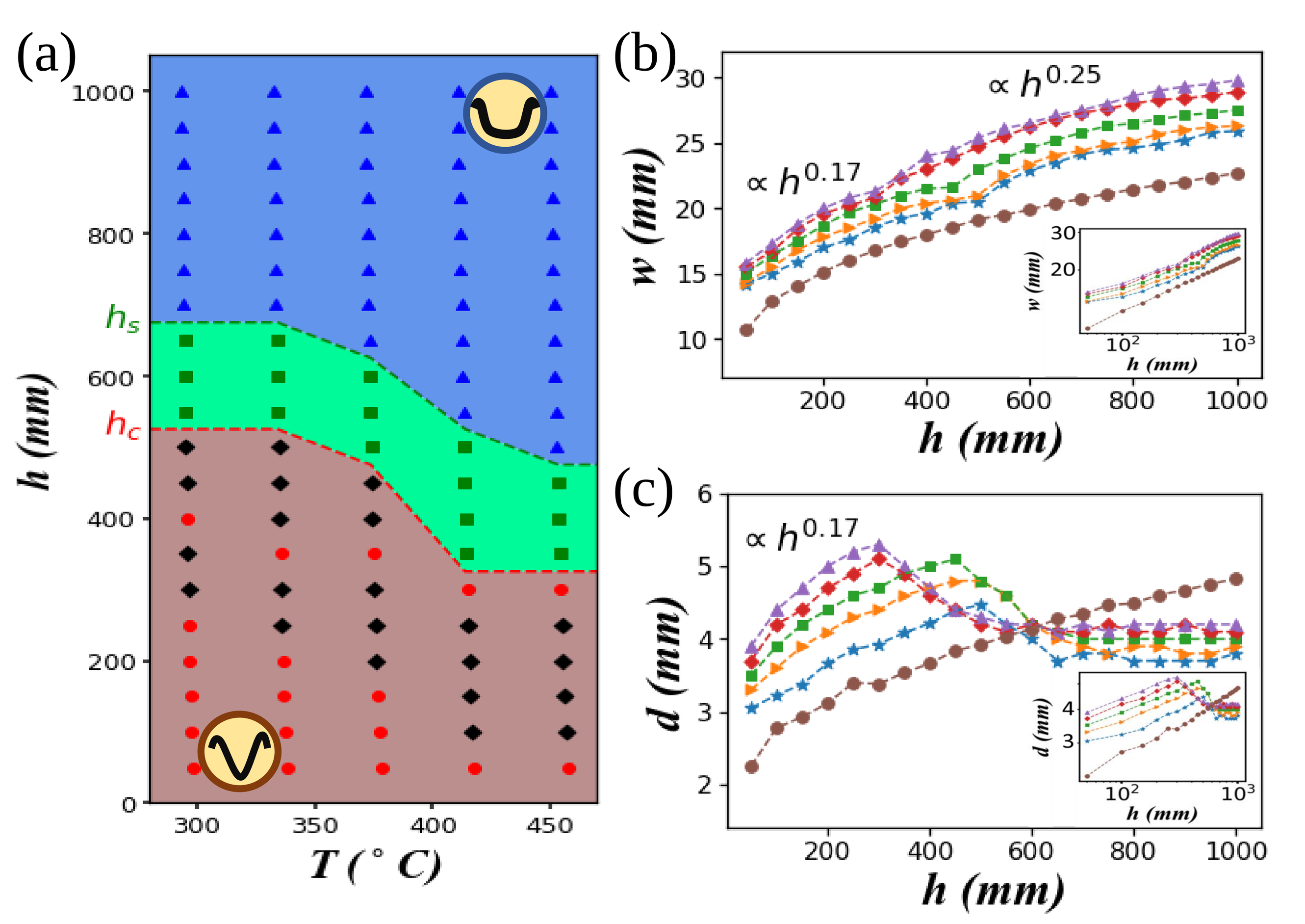

FIG. 2. Morphology of impact craters includes U- and V-shapes by 6.36-mm liquid tin drops: (a) Phase diagram for height h vs temperature T where the symbols are defined in Fig. 1. (b) Crater width w vs h for steel balls (brown spot) and liquid tin drops with 300, 340, 380, 420, 460 ℃ (blue star, orange triangle, green square, red rhombus, purple triangle). (c) Crater depth d vs h with the same symbols as (b). The insets in (b, c) are full-log plots.

(II) Mass Effect

V-shape U-shape

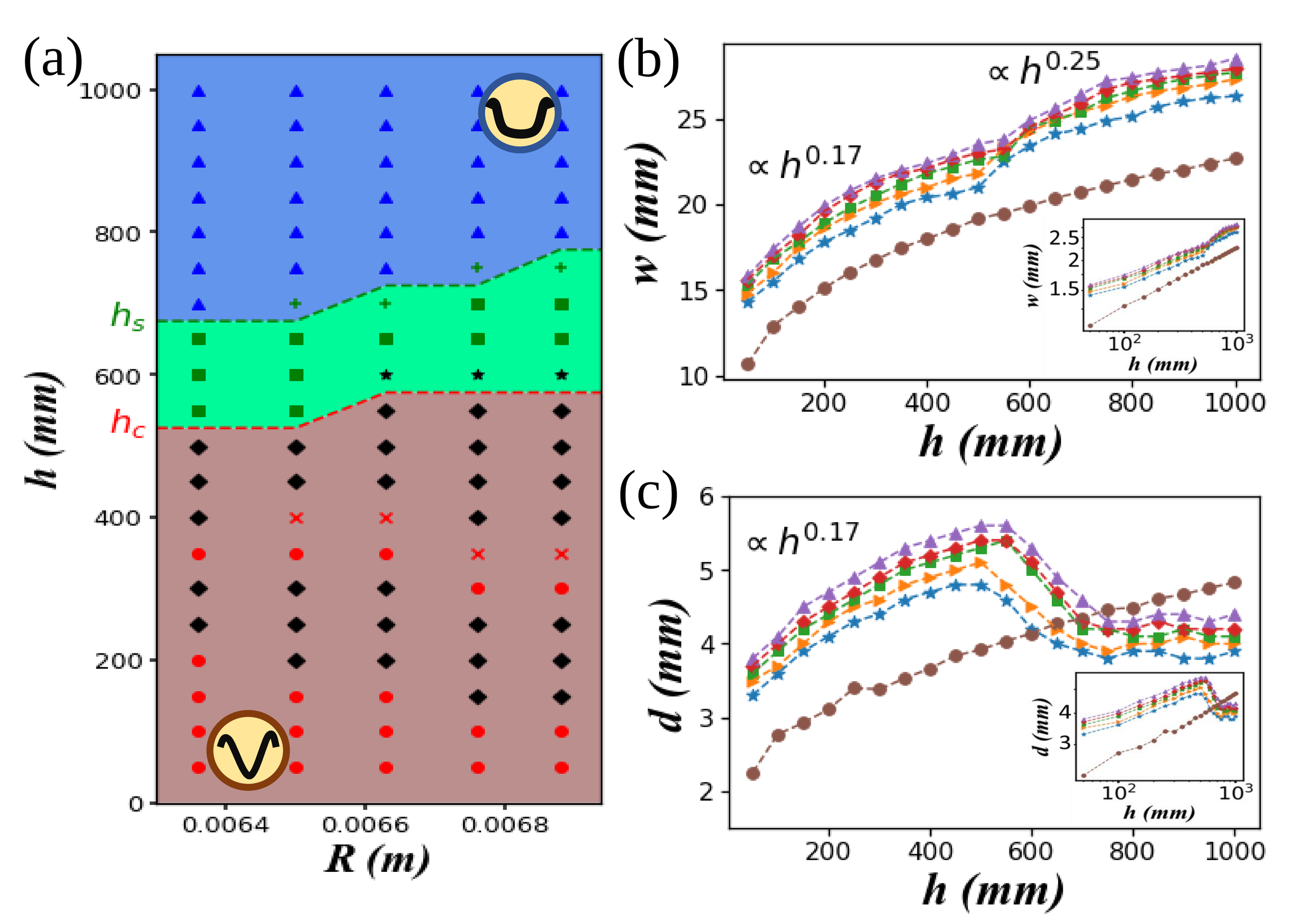

FIG. 3. Impact craters from 340 ℃ liquid tin drops. (a) Phase diagram h vs drop diameter R where the symbols are the same as Fig. 1. (b) w vs h for steel balls (brown spot) and liquid tin drops with 6.36, 6.5, 6.63, 6.76, 6.88 mm (blue star, orange triangle, green square, red rhombus, purple triangle) (c) d vs h with the same symbols as (b). The insets in (b, c) are full-log plots.

Compare with Real Craters

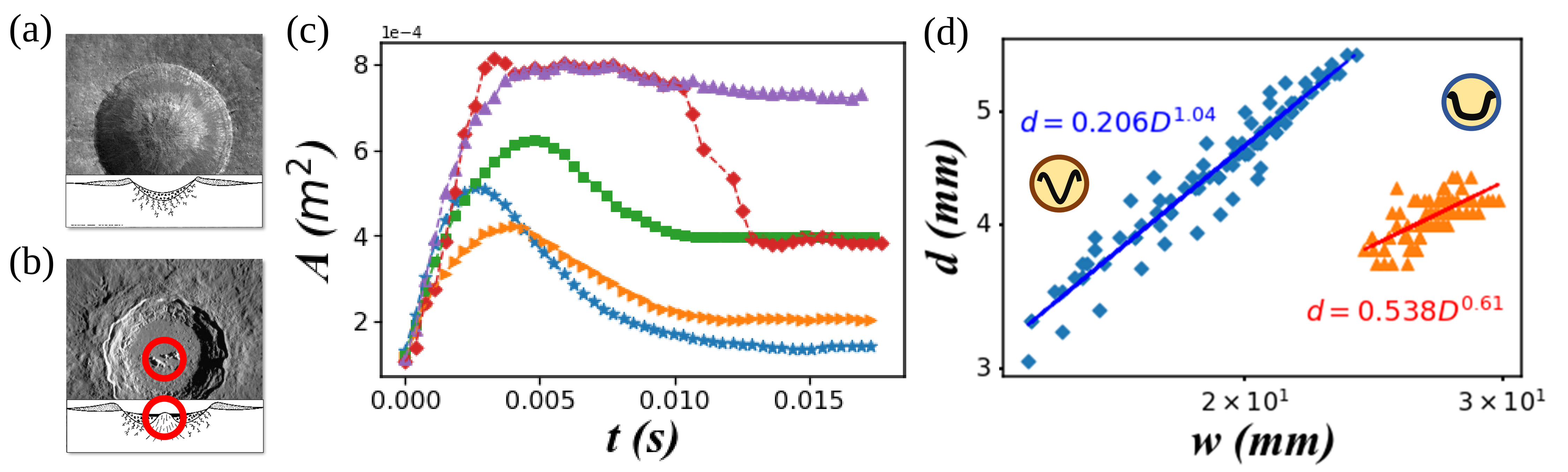

FIG. 4. (a, b) simple and complex craters. (c) The area A of tin remnant expands with time t in phases pearl, special pearl, cookie, shotgun, and snowflake (blue star, orange triangle, green square, red rhombus, purple triangle) (d) d vs w for granular size 270μm: V-shape craters (blue rhombus) and U-shape craters (orange triangle).

Feature Detection with Deep Learning

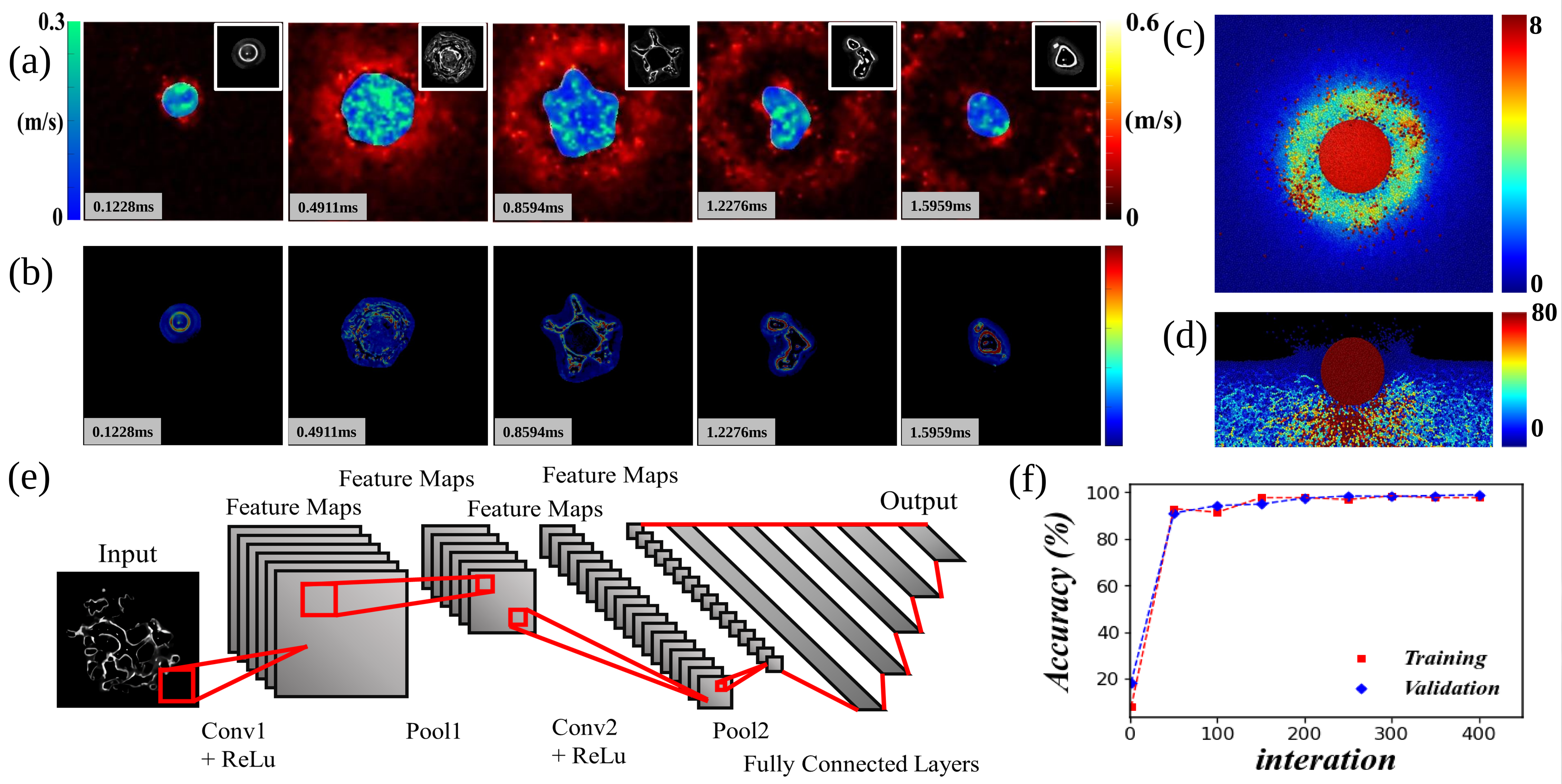

FIG. 5. (a) PIV analysis with colorbars for sand (right) and tin (left). (b) Gradcam analysis for tin. (c, d) Simulation of impact processes by Lammps. (e) Convolutional neural network structure. (f) Training and Validation accurancy.

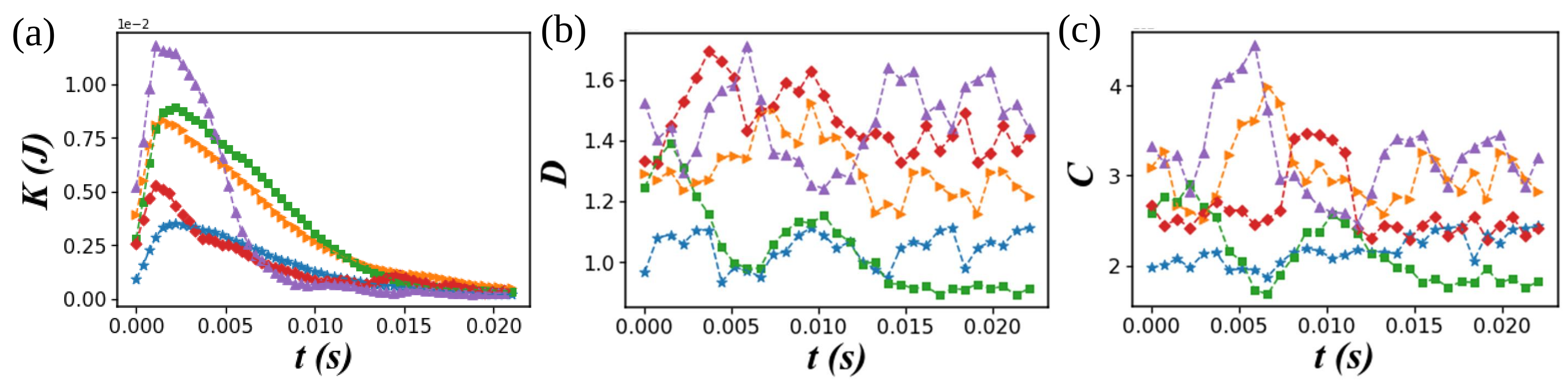

FIG. 6. (a) K vs t where K denotes the average kinetic energy of tin in Pearl, special Pearl, cookie, shotgun, and snowflake. (b) D vs t where D is the density of feature points made by Gradcam score Top 10%. (c) The centrality of feature points C vs t. The symbols are the same as (a).

Conclusion & Discussions

Meteorite impact events are extremely complicated which combine hydrodynamics, granular flows and even heat transfer. However, our simple experiment manages to capture several features:

(i) Formation mechanism of complex crater by our pearl crater
(ii) Crater depth is not a monotonically increasing function of impact energy
(iii)Debunk possible artifacts for crater width vs depth that includes data from different impact energy and size.

Future work: How does the granular size affect the results in our work? What is the distribution of sand density during impact processes? And how does the granular temperature affect the morphology of impact crater?

Reference

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