THREE-DIMENSIONAL MICROFORMING BY METAL JET

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1. Introduction

Various microprocesses have been developed to produce 3-dimensional micro models in recent years. Small sensors or micro parts can be produced by a silicon fabrication process. LIGA, a laser assisted etching and 3-dimensional photo fabrication processes have also been developed to produce various micro components. However, these processes are based on a patterning technique, so it is difficult to make 3-dimensional models. On the other hand, rapid prototyping techniques such as the sheet laminating method, laser sintering method and stereo lithography technique have been developed. These techniques, however, have serious limitations in forming micro 3-dimensional models i. e., the accuracy, quality and structure of products.

The authors have proposed a 3-dimensional microstructure generation process. In this technique, molten metal is jetted onto a plate to form an image. The most attractive feature of this method is its potential to form 3-D functional structures made of not only metals but also ceramics or plastics ejected out of multiple nozzles at the same time. In the first step, the basic principle and performance of this technique are described, and typical examples of 3-D models and structures are demonstrated.

2. Principle of forming and system

Figure 1 shows the forming principle, and the structure of the metal-jet head used in this research is shown in Fig. 2. The driving mechanism is similar to that in ink jet printing. The metal is melted in an electrically-heated tank mounted above the nozzle, and the molten metal is then supplied to the chamber by gravity. The chamber has a diaphragm which connects to the piezoelectric actuator. The volume of the chamber (filled with molten metal) is changed by applying voltage to this actuator, and the molten metal drops are then jetted out of the nozzle onto a plate. The temperature of molten metal is controlled by adjusting the electric current of the heater. The forming procedure is as follows. First, a 3-D CAD model is sliced into layers of 2-D images in the computer. Then, the 2-D image is formed on the base plate by scanning molten metal drops. Thin layers are piled up by repetition of this procedure so as to form 3-D models.

Figure 3 shows a flow chart of the forming system. This system consists of a CAD to make 3-D models and a CAM to control the X-Y-Z table and nozzle driving signal. In this study, Form Z is utilized as a 3-D rendering tool. This software has almost the same functions as in the software for a commercial rapid-prototyping system. The 3-D model is automatically divided into layers by a macro program as shown in Fig. 4 and 5. The layer thickness is determined the same as for a layer in metal printing. These layer data are then processed by image analyzer and the scanning data are prepared. Finally, nozzle actuating signal and X-Y-Z table are simultaneously controlled on the basis of the scanning data, and thus the 3-D model can be formed. Figure 6 is a photo of the experimental apparatus.

In this study, U alloy with a composition of Bi-44.7%, Pb-22.6%, In-19.1%, Sn-8.3% and Cd-5.3% was used. Melting point of this alloy is 46.7 ℃, density 8.8 g/cm^2, tensile strength 37 MPa. All experiments are performed in laboratory air. Other conditions are as follows. Diameter of nozzle: 200 μm ; temperature of molten metal in the nozzle: 55 ℃; distance between nozzle and base plate: 2 mm; speed of metal jet: 1 m/s; diameter of metal drop: ~300 μm; frequency of ejection: 4~20 Hz; and scanning speed: 0.8~4 mm/s.

3. Examples of the formed models

At first, 2-D images were printed on the base plate on the basis of the data from the image scanner. The scanned original images and the printed metal images are shown in Fig. 7(a) and (b) respectively. Fine metal printing can be done using any kind of black and white image. Moreover, 2.5-D forming can be performed easily

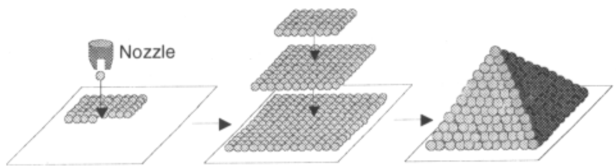


Fig. 1 Principle of metal-jet forming

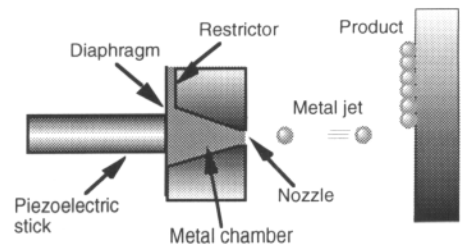


Fig. 2 Schematic illustration of metal-jet

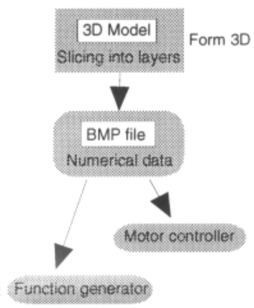


Fig. 3 Block diagram of 3-dimensional modeling

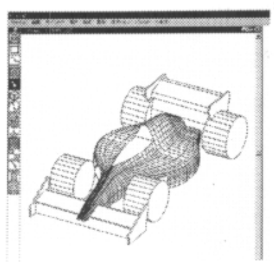


Fig. 4 Racing car designed by Form Z

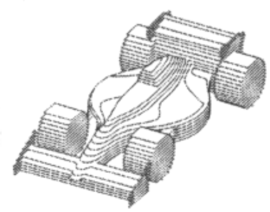


Fig. 5 3-D model sliced into layers

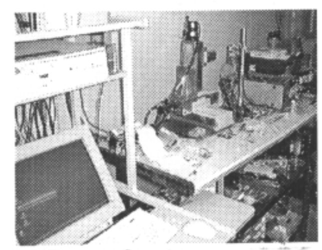
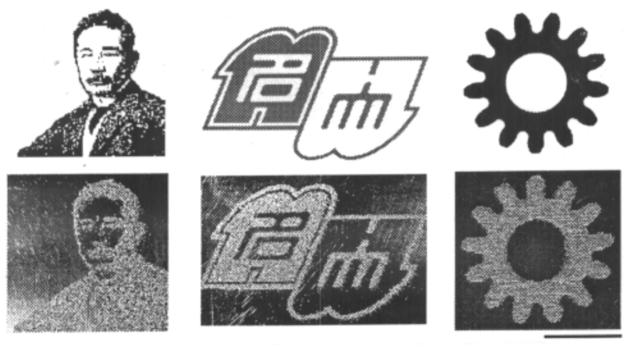


Fig. 6 Experimental apparatus



(a) Portrait (b) Logo of Nagoya University (c) Gear

Fig. 7 Some examples of metal printings

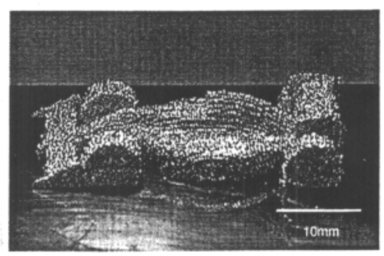
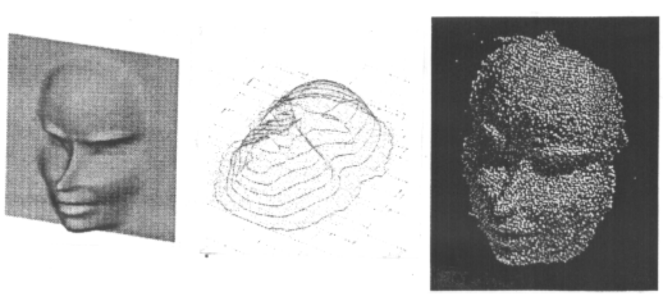


Fig. 8 3D model made of U alloy



(a) CAD model (b) Sliced model (c) 3D model

Fig. 9 3D modeling of human face

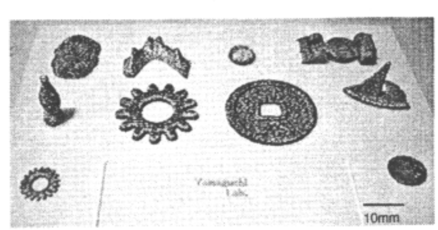


Fig. 10 3D models made of U alloy

by stacking on one another the same image layers. See gear wheel in Fig. 7(c).

Figure 8 shows a 3-D model formed using the data shown in Fig. 5. This is, as it were, a precisely prototyped model generated from 3-D data. 3-D data of human face and the formed model are presented in Fig. 9 (a), (b) and (c). Forming is successfully done although the shape of the human face model consists of intricate surfaces. Other examples formed using this system are shown in Fig. 10.

4. Bonding strength between metal drops

A metal drop has three kinds of bonding surfaces OX, OY and OZ which are shown in Fig. 11. The shearing test between two drops was conducted. The shearing strengthes are shown in Fig. 12 in comparison with those of bulk material. The differences of these shearing strength are due to the time intervals (duration of oxidation) and the directions of collisions with the pre-ejected drops.

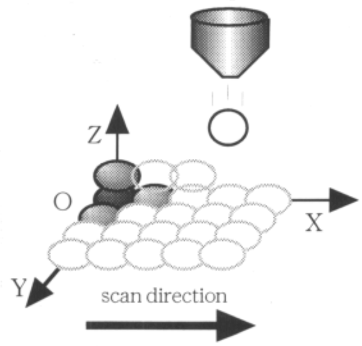
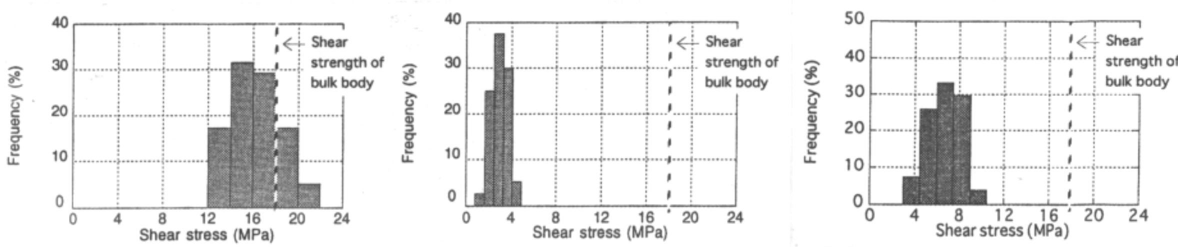


Fig. 11 Three kinds of bonding types

5. Forming by fine metal jet

In these experiments, the diameters of metal drops were relatively large. Thus, the structure is not fine, and the accuracy of forming is not sufficient. So, the forming was done using smaller drops. Drops of 80 μm in diameter were realized using the 50 μm nozzle. Some typical examples of micro parts made by these finer drops are shown Fig. 13, Fig. 14 and Fig. 15. Compared with the previously shown models, the surfaces are smoother and



(a)O-X type
Time interval: 0.1 s

(b)O-Y type
Time interval: 100 s

(c)O-Z type
Time interval: 100 s

Fig. 12 Distribution of shear strength

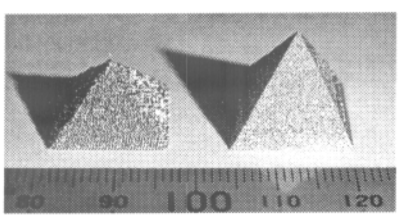


Fig. 13 Comparison between two pyramids made by 200 μm and 80 μm drops

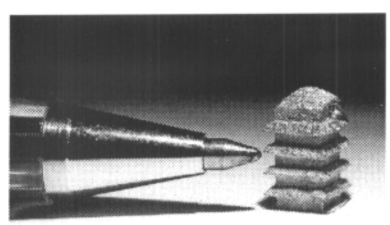


Fig. 14 Pagoda made of fine metal drops

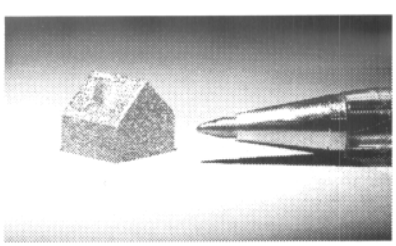


Fig. 15 Micro house made of fine metal drops

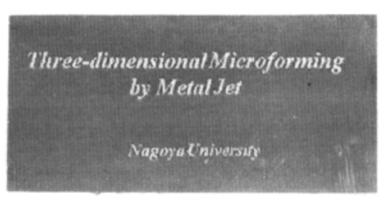


Fig. 16 Embossed printing

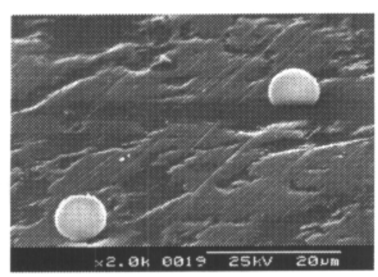


Fig. 17 Ultra fine metal drops ejected on base plate

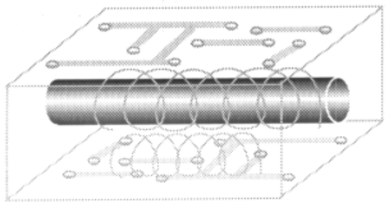


Fig. 18 Concept of 3-dimensional electro-magnetic structure

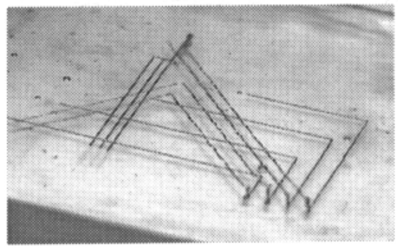


Fig. 19 3-dimensional electric circuit

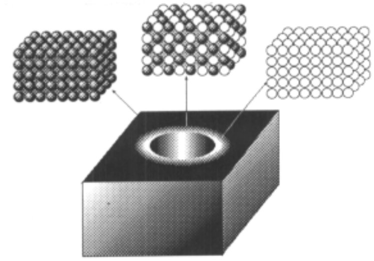


Fig. 20 Concept of 3-dimensional functional gradient material

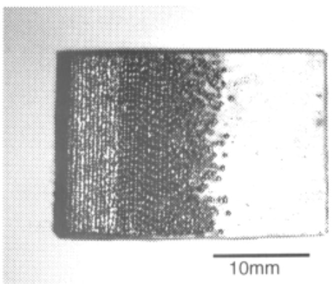
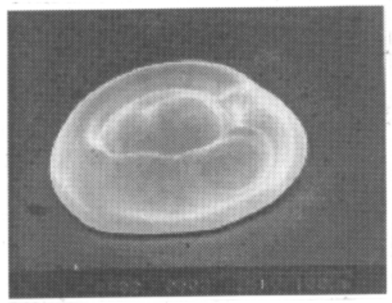
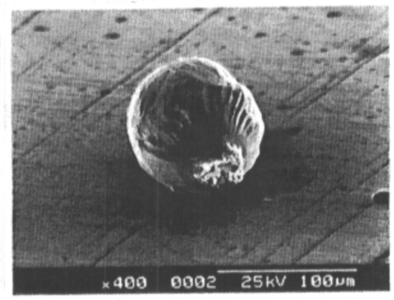


Fig. 21 Basic sample of 3-dimensional functional gradient material



(a) gold drop



(b) nickel drop

Fig. 22 Drops of high melting temperatures

the edges sharper. Further, the embossed-like printing was done as shown in Fig. 16. The fineness of this printing is almost the same as the conventional ink-jet printing because the diameter of the metal drop is almost the same as that of an ink-jet printer's dot.

To form a finer structure, it is necessary to use a finer jet nozzle. Figure 17 shows ultra-fine metal drops jetted out of another type of metal-jet nozzle. The diameter of the drops is only 8 μm. Fine structure can be formed using this nozzle, though it takes 40000 times as long in comparison with 300 μm drops to make the same model if the forming is done by a single jet nozzle.

6. Forming of functional structure

The key point in this study is the advantage of being able to form a 3-D functional structure. Virtually any kind of 3-D structure can be formed by jetting several kinds of materials through multi-nozzles.

If an electric conducting material and insulator are used, an electromagnetic structure with a 3-D electric circuit and coil can be realized as shown in Fig. 18. Figure 19 show an example of a 3-D electric circuit formed from metal and resin.

Further, by distributing different material jets of different functions, 3-D functionally gradient material can be generated as shown in Fig. 20. Figure 21 is a basic example of a functional gradient structure made of metal and resin.

These examples are all made of U alloy and resin. Recently, the author developed a new nozzle which can eject gold, silver and nickel. Fig. 22 shows the drops of gold and nickel. The author is attempting to form a 3-D micro structure using these metals of high melting temperatures.

7. Conclusion

1) A metal-jet nozzle was developed. This nozzle can eject drops of fusible alloy with a melting point of 47°C. 3-D models were formed using this nozzle.
2) Bonding strength between two drops are clarified.
3) Fine structure was formed by smaller metal drops.
4) Formation of a 3-D functional structure was shown along with some basic examples.