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A new incremental in-plane bending of thin sheet metals for micro machine components by using a tiltable punch

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ABSTRACT

This paper proposes an innovative incremental in-plane bending of thin metal sheets for manufacturing microscopic machine components. The unique feature of the process is that a tiltable punch having a beating face with trapezoidal profile is used. The beating face enables the punch to bend thin metal sheets in in-plane manner. Working conditions, including indentation and feeding pitch, can easily and flexibly control the bending radius and even the bending direction. The in-plane bent thin sheet products are expected to be used as springs, conical cylinders, bushes and other components of micro machines such as medical instruments.

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1. Introduction

Microstructural components have diversely been used as parts in medical devices, precision machines, optical MEMS (Micro Electro-Mechanical Systems), Bio MEMS and so on. In many cases, these micro-components are fabricated by technologies using radiated lights such as LIGA (Lithographie, Galvanoformung, Abformung) processes. LIGA processes would be effective and suitable for the fabrication of components which require high precision, such as micro gears. On the other hand, technology of plasticity would be suitable for the fabrication of miniature chassis or boxes for mounting micro gears and other components which do not require high precision, as technology of plasticity would realize high productivity and reasonable production costs.

Incremental forming would have the potential ability of fabricating microstructural components. Saotome et al. [1] developed a process called "incremental forming by hammering" for fabrication of microstructural chassis. Incidentally, incremental forming has been used for forming in ordinary scales as well. Matsubara [2] controlled toll paths by computer numerical control. Malhotra et al. [3] improved formability by tool path optimization. Martins et al. [4] applied incremental forming for the fabrication of polymers. All the above forming utilizes point beating. On the other hand, the authors proposed incremental in-plane bending with tilted punch for sheet metal with 2 mm thickness [5]. The method utilized line beating, which would realize higher productivity than point beating. However, it was not applicable for bending thinner sheet metals in micro scales.

This paper proposes an innovative incremental forming for manufacturing microscopic machine components. The unique feature of the process is that a tiltable punch having a beating face with trapezoidal profile is used. The beating face enables the punch to give thickness distribution. This mechanism would be applicable for micro forging. It gives local slopes on material's top surface or makes a large tilted surface flexibly. In this paper, the mechanism was applied for in-plane bending of thin sheet metal as an example. The in-plane bent thin sheet products are expected to be used as springs, conical cylinders, bushes and other components of micro machines such as medical instruments.

2. In-plane-bending using a tiltable punch

2.1. Mechanism of in-plane bending of thin sheet metals

The proposed method bends thin sheet metals in in-plane manner by introducing a new movement mechanism of tiltable punch. The method was invented based on the authors' previous research on in-plane bending with a tilted punch for 2 mm-thick sheet metal [5]. However, the previous tilted punch is not applicable for thinner sheet metals as the tilt angle should be adjusted precisely in a small amount for thinner metals.

In the present method, the punch is gradually and automatically tilted during each beating. The movement is shown in Fig. 1. The tilting motion generates a small bending deformation at each beating, and a repeat of beatings bends the sheet metal at a radius. If out-of-plane deviation should be prevented, a gate-shaped jig would be effective, though it was not used in this research.

Fig. 2 describes the mechanism of tilting motion caused by the tiltable punch having a beating face with trapezoidal profile. The trapezoidal profile is composed of toe and heel sides. When the

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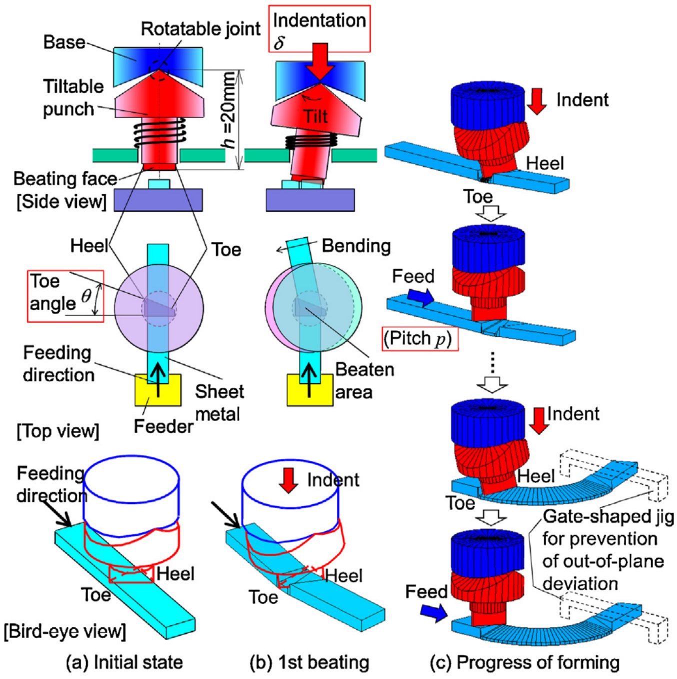

Fig. 1. In-plane bending with tiltable punch.

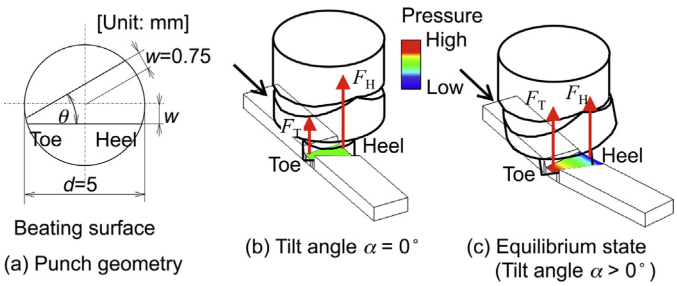

Fig. 2. Punch geometry and mechanism of tilt motion.

punch is pushed downwards to beat the sheet metal, the toe side indents the sheet metal deeper than the heel side.

If the tilt angle α is assumed to be zero as shown in Fig. 2(b), the resistant load on the heel side F_H must be larger than that on the toe side F_T, because the heel side has a larger area. As a result, a tilting moment is generated. When this moment inclines the punch as shown in Fig. 2(c), the pressure on the toe side increases due to the work hardening, leading to the increase of resistant force at the toe side F_T. When the moment, which is generated by F_T and F_H, is zero, the tilting motion stops and an equilibrium state is obtained.

The tilting motion of the punch generates the thickness distribution along the sheet metal breadth, which bends the sheet metal due to volumetric constancy. After lifting up the punch, the sheet metal is fed in longitudinal direction, followed by the second beating. Repeated forming of incremental beating bends the sheet metal in in-plane manner as shown in Fig. 1(c). As the toe side of the sheet is thinner than the heel side, the toe side becomes extrados and the heel side becomes intrados of the bending arc.

The toe angle θ, set indentation δ_s and feed pitch p are the dominant parameters in the process. In particular, the bending radius r would flexibly and freely be controlled by changing the set indentation δ_s and feed pitch p, even during the in-plane bending process.

The effect of the parameters is schematically explained in Fig. 3. The sheet metal would be bent following the mechanism explained above. When the indentation δ is large, the bending radius is small because of the larger tilting angle α as shown in Fig. 3(b). The smaller feed pitch p would also result in smaller bending radius, because smaller p would decrease the contact area and the punch load F, and the elastic deformation of the machine would decrease, leading to the larger actual indentation δ_a.

Furthermore, it is noteworthy that the sheet metal would be bent in the opposite way by just increasing feed pitch p. When feed pitch p is large enough, some area of the sheet metal would be unbeaten on the toe side, resulting in opposite-way bending as shown in Fig. 3(c). Therefore, the bending radius and direction would flexibly be changed by changing feed pitch during the process as shown in Fig. 3(d).

2.2. Possible final products

More complicated final products for miniature and micro machines can be manufactured from the bent sheet metals, which are shown in Fig. 3. Some examples of final products are shown in Fig. 4.

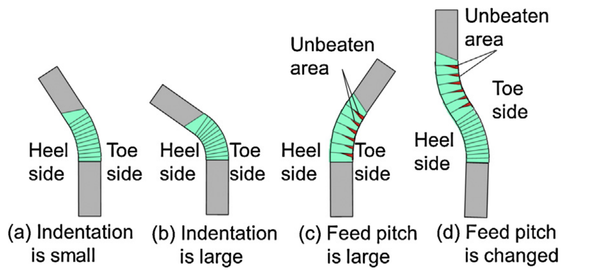

Fig. 3. Schematic illustration of effect of working condition on bending curve of sheet metal.

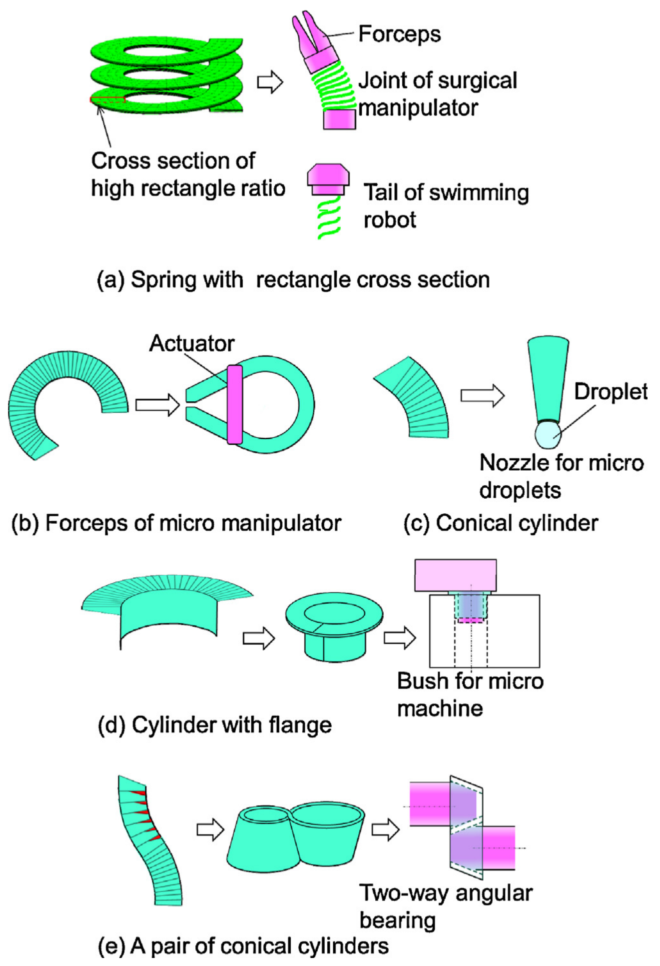

Fig. 4. Possible final products.

Some of them may be used in medical or biomedical fields. Recently, surgical manipulators have been developed for reducing damage to patients during surgical operation of internal organs, because the manipulators need only small holes in the abdomen. Kawashima et al. have developed a new manipulator

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