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An extrusion method of tube with spiral inner fins by utilizing generation of spiral outer fins/grooves

Takashi Kuboki (2)*, Michiaki Ishikawa, Shohei Kajikawa, Makoto Murata

The University of Electro-Communications, 1-5-1 Chofu Gaoka, Chofu-shi, Tokyo, Japan

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ABSTRACT

This paper presents a new extrusion method for fabrication of a tube with spiral inner fins. The spiral fins are formed by utilizing the generation of spiral outer fins or grooves, which drive the metal to circumferentially move with twist deformation. The effect of the outer fins/grooves is examined for realizing the circumferential metal flow. The position of the mandrel has an ability to flexibly control the spiral angle. This method would drastically enhance the productivity and reduce the manufacturing cost, as the tube would be manufactured directly from a billet through only one process.

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1. Introduction

Tubes with spiral inner fins, which are concisely called "spiral fin tubes" here, are one of the important and useful components in industry. The spiral fin tubes are used in chemical plants, electric devices and so on. The representative tubes are shown in Fig. 1(a) and (b). The tubes with large inner fins accelerate chemical reactions in the chemical industry, as the area of the tube inner surface is large. They are used in petroleum refineries, for example. The tubes with small inner fins enhance the heat change efficiency when they are mounted in air conditioners and refrigerators. The small fins enlarge the contact area between the tube material and the fluid inside, and affect the fluid flow for higher heat transfer [1].

The spiral fin tubes are conventionally manufactured by many forming processes. In the case of copper tubes, the tubes are manufactured by extrusion, pilger rolling, drawing and ball spin forming with a spiral plug inside the tube [2]. Some engineers proposed a new method that twists a tube, which is formed in ball spin forming with a straight plug inside [3]. In any case, a number of processes are needed, and it leads to the problem of low productivity and high manufacturing cost. In the case of cold forging, new processes have been developed for manufacturing helical solid parts with large teeth for gears [4].

The development trend of new extrusion processes could solve the problem. Conventional processes have the limit that the cross-section of the extruded tubes are completely uniform. New processes have started to break through the limit. A new extrusion method with a tapered mandrel can flexibly change the thickness in the longitudinal direction [5]. Another process is proposed for extending the flexibility over the length in the composite extrusion [6]. A new method by Takatsuji et al. succeeded in fabricating a spiral angle up to 7.5° using a rotatable plug in the extrusion [7]. Shiraishi et al. proposed an extrusion method for spiral fin tubes with a complicated mechanism using a clay billet [8]. However, the method is too complex to realise for metal billets. Khalifa et al. developed a new process called helical profile extrusion (HPE), which could fabricate a solid bar with three large protrusions [9].

This paper presents a new extrusion method for fabrication of spiral fin tubes. The method utilizes the generation of spiral outer fins or grooves, which drive the metal to circumferentially move. Schematic illustrations of the tubes are shown in Fig. 1(c) and (d). The tube with outer fins would be used in commercial refrigeration and air conditioning equipment that need high heat change efficiency. The tubes with outer grooves would be used in air conditioners, where the tubes are connected with flat sheet metals and outer fins should not exist. Moreover, the possibility of flexible control of the spiral angle is also examined as shown in Fig. 1(e). The proposed extrusion method would drastically enhance the productivity and reduce the manufacturing cost, as the spiral fin tube would be manufactured directly from a billet through only one process.

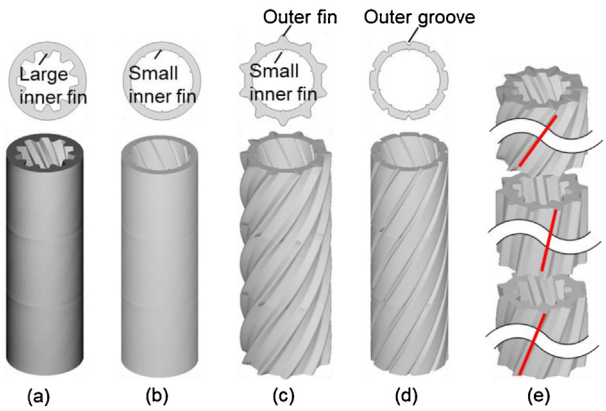

Fig. 1. Tubes with inner fins.

* Corresponding author.
E-mail address: kuboki@mce.uec.ac.jp (T. Kuboki).

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2. New extrusion method and fundamental mechanism

2.1. Extrusion method using a die with grooves/fins

Fig. 2 shows schematic illustrations for extrusion set-up and tools, and Fig. 3 shows the tool geometries. The unique point of the proposed method is that the die has spiral grooves/fins for generation of fins/grooves on the outer surface of the tube just as the mandrel has spiral grooves for fabrication of spiral fins on the tube inner surface. If the mandrel grooves were large enough, the mandrel grooves would twist the tube to some extent without the help of the spiral grooves/fins on the die. This phenomenon without the die grooves/fins is confirmed by the authors' previous research [10]. However, the fabrication of small fins is also needed in industry, and then a more effective extrusion method is demanded. In order to meet the demand, this paper proposes a new method which adds the die grooves/fins for twisting the tube by generating outer fins/grooves.

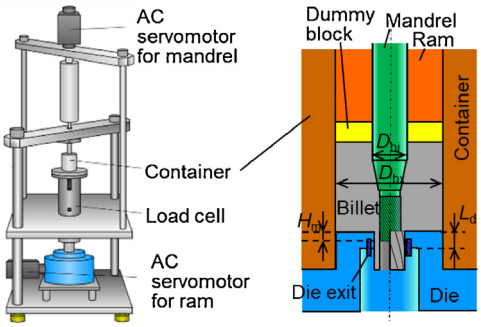

Fig. 2. Composition of experimental set-up and tools.

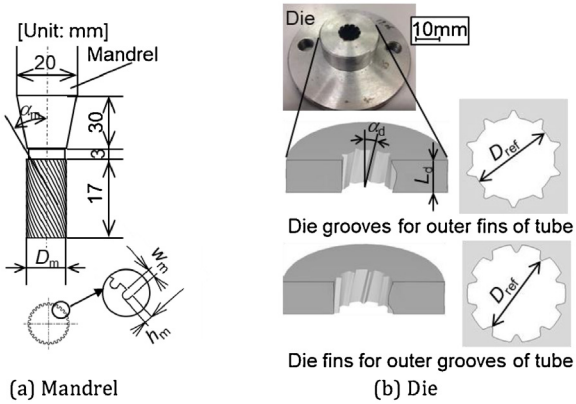

Fig. 3. Tool geometries.

Table 1
Standard extrusion condition.

Items	Parameters	Values and details
Billet	Material	Special pure lead (Pb > 99.99 mass%)
	Outer diameter D_{bx}/mm	35
	Inner diameter D_{bi}/mm	20
	Initial length L_b/mm	55
Die	Number of grooves N_d	10
	Spiral angle α_d/°	30
	Diameter D_{ref}/mm	11
	Groove/fin shape	Triangle Trapezoid
	Groove/fin width w_d/mm	0.58–1.15
	Groove/fin height h_d/mm	0.25–1.0
	Bearing length L_d/mm	8
Mandrel	Number of grooves N_m	30
	Diameter D_m/mm	8.8
	Spiral angle α_m/°	30
	Groove shape	Semicircle
	$w_m \times h_m$/mm	0.25×0.1
	Mandrel-tip position H_m/mm	Equal to L_d (=8 mm)
Others	Ram velocity v_r/mm s^{-1}	0.1
	Extrusion ratio R_{ex}	9.8–18.6 (depending on fin/groove size)

The shapes of die grooves/fins are shown in Fig. 4. Three types of die grooves or fins were prepared. A trapezoid was used for examination of the mechanism of twisting metal flow.

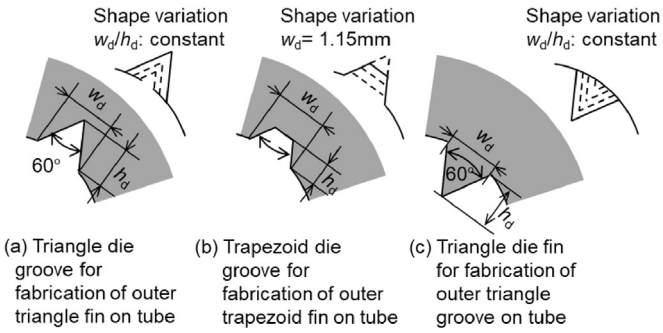

Fig. 4. Shapes of die fins and grooves.

2.2. Preliminary examination using the finite element method

The finite element method (FEM) was carried out for examination of the effect of the die groove for driving metal to flow in the circumferential way. Elastic–plastic analysis was carried out using the commercial code ELFEN, which was developed by Rockfield Software Limited, Swansea. A von Mises' yield criterion was adopted, and the normality principle was applied to the flow rule. Constraints were dealt with by the penalty function method. A dynamic explicit scheme and adaptive mesh were applied. 3-node triangle elements were employed.

The analysis was conducted in plane strain, which assumed longitudinal strain is zero. The inside surface of the material was constrained and the rotational displacement was given to the die as shown in Fig. 5. The model roughly estimates torque, which can be generated by different fin or groove geometries. In the actual extrusion, on the other hand, the tube is extruded between the constrained die and mandrel in 3-dimensional manner. However, the analysis qualitatively and relatively shows the roles of the die grooves and fins. The die groove/fin shapes are the same to those in Table 1. The material is assumed lead.

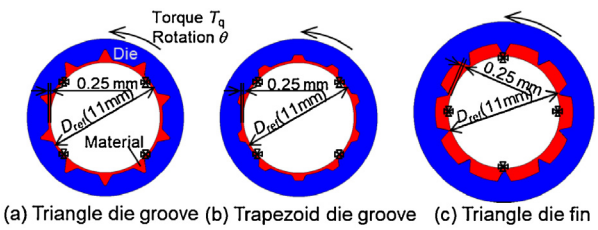

Fig. 5. Dimension in FEM model for evaluating die groove/fin effect.

Fig. 6 shows the relationship between rotation angle and torque, and the effect of die groove/fin shape on the relationship. Fig. 7 shows the magnified view of deformation under the conditions which are denoted by "a1" . . . "c4" in Fig. 6. The torque increases with increase of rotation angle. Torque increases with increase of die groove width w_d and height h_d for the triangle die groove as shown in Fig. 6(a). This would be attributed to increase of equivalent strain by shear deformation, which is observed at the

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