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Employment of concentrated-hard-sphere-suspension pad for V-bending of thin strip

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ABSTRACT

Purpose: Authors have suggested employment of dilatant fluid for metal forming tools, and report an application on v-bending of thin stainless steel strips in this paper.

Design/methodology/approach: An alumina concentrated hard-sphere suspension is employed as dilatant fluid for forming. The authors evaluate the suspension with backward extrusion test. Then, the authors try to bend SUS304 stainless strip with 0.25 mm thickness and 30 mm width on the pad of the suspension with a v-bend punch.

Findings: Behaviour of the suspension is revealed in backward extrusion test. Migration of water takes important role in it. In v-bending test, including acute angle bending, the authors bend the strip with only the v-bend punch and the alumina concentrated hard-sphere suspension pad successfully. It is thought that forming load is less than with general polyurethane tools.

Research limitations/implications: Spring-back in partial bending, which is similar to the suggested process, is larger than in bottoming and coining with dies and bending with polyurethane tools. Therefore, the authors are going to evaluate the spring-back in the suggested process in further study.

Practical implications: Polyurethane pad is used in bending process generally because of advantageous points in easy-design, and safe from scratch. However it has disadvantageous points in its limited life and necessity of large forming load. The alumina concentrated hard-sphere suspension can be employed for such the pad with unlimited life. In addition, such the dilatant fluid can be applied on other metal forming process as easy tool.

Originality/value: Employing dilatant fluid for forming tools is new idea. Authors try v-bending with an alumina concentrated hard-sphere suspension.

Keywords: Plastic forming; Sheet metal forming; Bending; Easy tool; Dilatant fluid; Concentrated hard-sphere suspension

1. Introduction

Elastomer tools [1-8], such as polyurethane, are generally used in bending, punching, deep drawing, bulging, embossing and other forming processes. Especially, we can see its most effective application in bending. Polyurethane-die-pad is easy to design, easy to set-up in manufacturing, and safe from scratch between die and product. In addition, the process using the polyurethane pad can keep spring-back smaller than the process using the steel die. However, it requires several times larger forming load than the latter, and the polyurethane pad has lifetime problem.

Life of elastomer tools is the common problem for the other processes. For punching process using polyurethane pad, that is well known as ‘Guerin Process,’ its life-time is several thousand cycles generally. K.Sato investigates life time of a polyurethane pad for punching of aluminium sheet. In the condition of cyclic 10% reduction of the pad, its lifetime is less than 4000 cycles[3].

Y.Kurosaki et.al. suggest the idea employing viscoplastic pressure medium with impact compression instead of elastomer pad [4,5]. They apply it onto piercing of 0.05-mm-dia fine holes on a SK3 foil with 0.01 mm thick. Such the fluid seems hopeful as an alternative tool for metal forming. It is free from lifetime problem. As shear rate increases, shear strain does as well, and increased deformation resistance of the fluid drives metal forming. Therefore they choose impact condition.

By the way, fluid tool must recover the shape in flat after the process. Such the recovery carried out by the internal shear stress caused by gravity. Figure 1 shows relationship between shear stress and shear rate of typical non-Newtonian fluid.

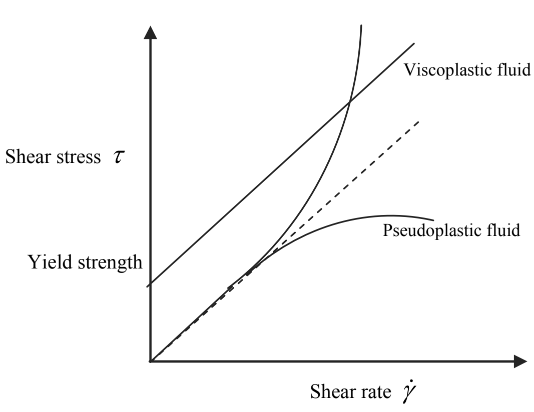

Fig. 1. Typical non-Newtonian fluid

Viscoplastic fluid has yield strength and we can say that the.viscoplastic fluid tool cannot recover its shape by itself in the case that its yield strength is larger than the internal shear stress caused by gravity. Moreover, viscoplastic fluid having large shear stress has large yield strength generally, and this is restriction to increase substantial forming load.

Thus, authors would like to suggest employment of dilatant fluid for forming tools instead of viscoplastic fluid. Shear stress of dilatant fluid approaches zero when shear rate close to zero. Therefore, any dilatant fluid will recover its shape at last.

In this paper, the authors report an application on v-bending of thin stainless steel strips with a dilatant fluid pad.

2. Evaluation of alumina concentrated hard-sphere suspension

2.1. Employed alumina concentrated hard-sphere suspension

We often find an instance of dilatant fluid in the concentrated hard sphere suspensions, of which grain has weak cohesion force. We can change the behaviour of the suspension by choosing grain-liquid ratio and grain material with regarding its hardness and shape. The authors employ 16μm-dia alumina powder for it (Fig.2). Water to Alumina ratio is 1:4 by weight.

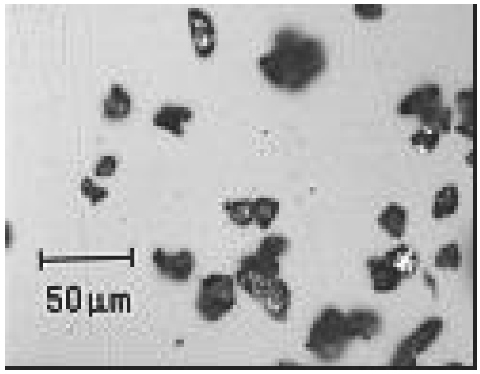

Fig. 2. Employed alumina powder

2.2. Backward extrusion test

Figure 3 shows a schematic drawing of backward extrusion test. The suspension in the container is extruded by hollow punch in speed of press machine employed for v-bending. Details of experimental condition are shown in Table 1.

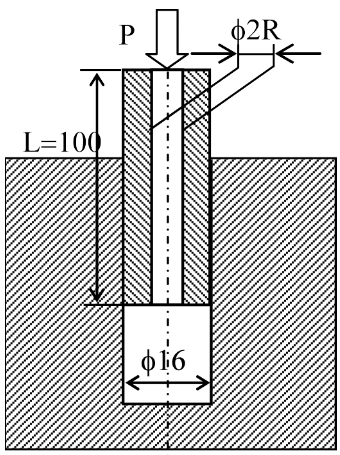

Fig. 3. Backward extrusion test

Table 1.
Condition of backward extrusion test

Specimen	Concentrated hard-sphere suspension of 16μm-dia alumina grain and water. Water to Alumina ratio is 1:4 by weight.
Forming machine	10KN air check press, 200KN hydraulic press, 1000KN universal testing machine
Punch speed	92mm/s- 1mm/min
Outer diameter of punch	ϕ16
Inner diameter of punch ϕ2R	ϕ12, ϕ 10, ϕ 9, ϕ 8
Punch length L	100mm

Shear stress τ_{wa} and shear rate $\dot{\gamma}_a$ can be expressed by the following equation [9],

$$\tau_{wa} = \frac{Rp}{2L} \tag{1}$$

$$\dot{\gamma}_a = \frac{4Q}{\pi R^3} \tag{2}$$

where,
R: inner radius of the punch.
p : pressure in the container.
L:length of the punch.
Q:flow rate.

Equilibrium of forces on extrusion punch gives:

$$Ap + 2\pi RL\tau_{wa} = P \tag{3}$$

The pressure in the container p is given by following equation.

$$p = \frac{P - 2\pi RL\tau_{wa}}{A} \tag{4}$$

where,
P: punch load
A: area of the section of the punch.

The above result must be corrected with regarding inlet and outlet effect. Corrected shear stress τ_w is given as following equation by Bagley correction[10],

$$\tau_w = \frac{Rp}{2(L+nR)} \tag{5}$$

where n is given by Bagley plot. Corrected shear rate $\dot{\gamma}$ is given as following equation by Rabinowitsch correction[11].

$$\dot{\gamma} = \frac{4Q}{\pi R^3}\left(\frac{3}{4} + \frac{d\log\dot{\gamma}_a}{4d\log\tau_w}\right) \tag{6}$$

thus, we obtain viscosity of the suspension as following equation.

$$\eta = {\tau_w}/{\dot{\gamma}} \tag{7}$$

2.3. Evaluation of the alumina suspension

Figure 4 shows one of typical load change during backward extrusion test. The load increases until the head of the flow goes out of the outlet of the extrusion punch. It is thought that supernatant water and the layer having more moisture content is purged in this term.

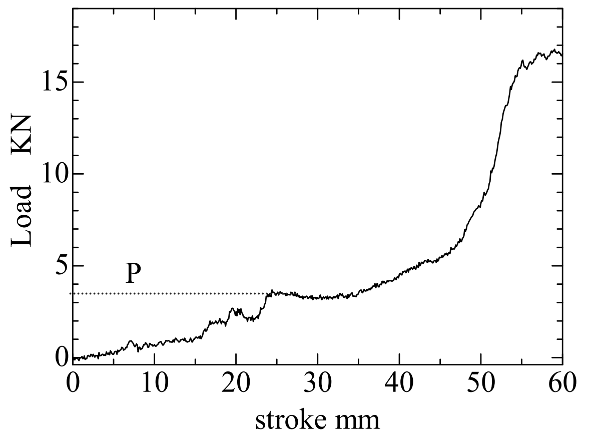

Fig. 4. Load change in backward extrusion test (ϕ2R=8, punch speed:1mm/s)

After then, the load change becomes flat for a while. This load is employed for calculation of τ_w and $\dot{\gamma}$ to evaluate typical behaviour of the suspension during forming process. Next the load increases again because of squeeze of the water from the suspension. After finishing squeezing, Then load becomes constant again. Thus, migration of water takes important role in the change of the load. Figure 5 shows relationship shear stress τ_w and shear rate $\dot{\gamma}$. Viscosity of the employed suspension archives 1.4×10^{14}Pa•s. We can say it is enough large with regarding to the viscosity of silicon polymer fluid used in the Kurosaki's experiment,, i.e. 5000 Pa•s. However it recovers its shape in flat successfully after the forming process with no problem.

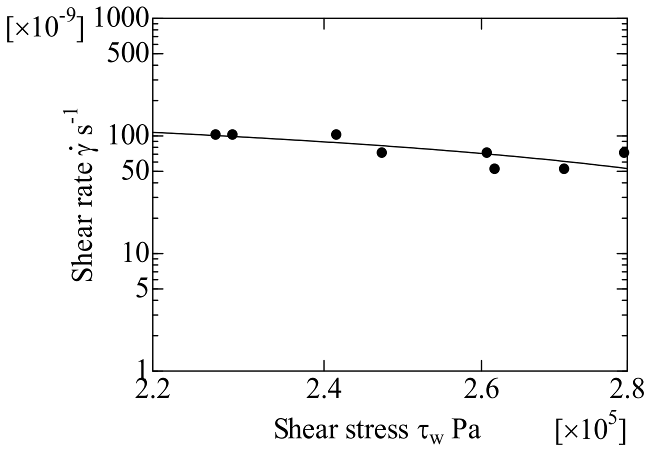

Fig. 5. Shear stress τ_w and shear rate $\dot{\gamma}$

3. V-bending with alumina concentrated hard-sphere suspension pad

3.1. Experimental conditions

Figure 6 shows equipment for the experiments of V-bending. Displacement of punch and load is recorded with dynamic strain amplifier and a laptop computer.

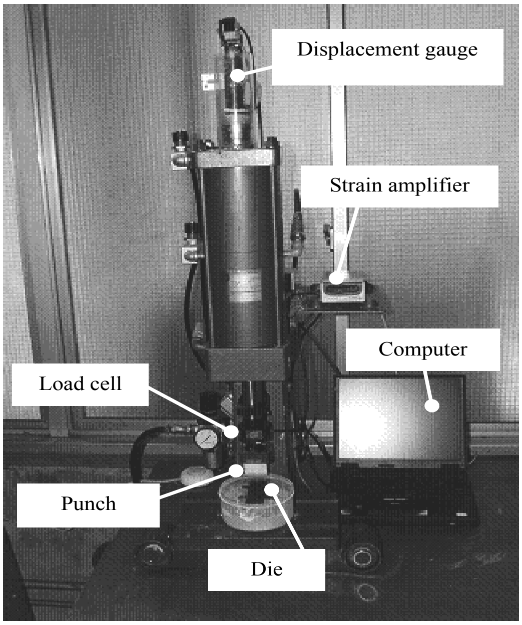

Fig. 6. Equipment for V bending experiment

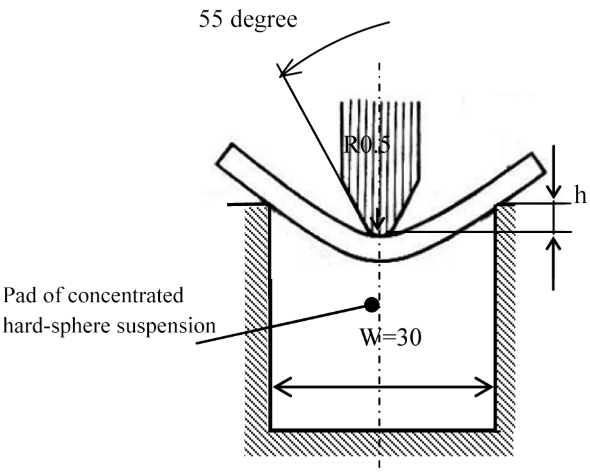

Fig. 7. Employed die and alumina concentrated hard-sphere suspension pad

Table 2.
Condition of V-bending test.

Specimen	SUS304 stainless strip with 0.25mm thickness and 30mm width
Forming machine	10KN air check press
Punch speed	92mm/s(max)
Punch	V-bending punch (Top angle: 55 degree)
Punch stroke h	0–30 mm

Figure 7 illustrates the employed die with alumina concentrated hard-sphere suspension pad. Detail of experimental condition is shown in Table 2. The authors investigate bending angle and forming load with changing stroke end point of the bending punch.

3.2. Results and discussions

Figure 8 shows sample strips bent by the same tools shown in Fig.7. The left one is a sample product of partial bending without the alumina suspension pad (air bending), and the right one is with it. Span between the die shoulders (W=30mm) is too wide for partial bending, however we can see that the strip is bent successfully in the case using alumina suspension pad. This indicates the suspension can transmit enough load for bending. Figure 9 shows relationship amongst punch stroke hand forming load. Forming load with the suspension pad seems to be less than the process with the general polyurethane pad. Figure 10 and 11 shows relationship between bending angle and stroke-end point. The bending angle becomes more accurate with larger load in the bending using the alumina suspension pad.

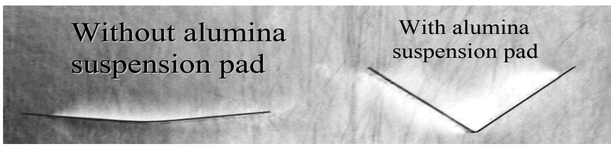

Fig. 8. V-bending samples. The left one is a sample of partial bending without the alumina suspension pad (air bending), and the right one is with it

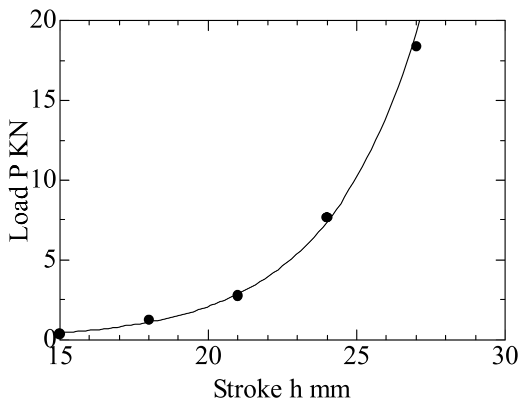

Fig. 9. Punch stroke and forming load

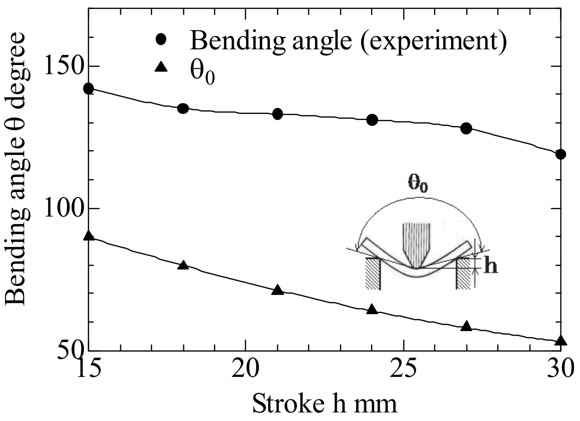

Fig. 10. Bending angle in partial bending (air bending)

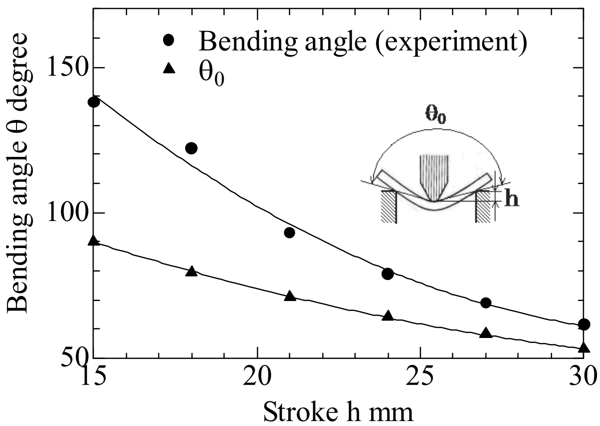

Fig. 11. Bending angle with alumina concentrated hard-sphere suspension pad

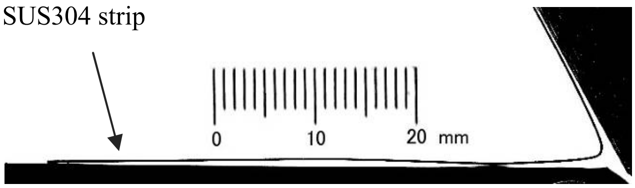

Fig. 12. Photograph of profile of a bent strip (h=24mm)

In partial bending, accuracy of bending angle is limited, because of too wide die-shoulder. Narrower span between the die shoulders might be necessary for extra accuracy.

Figure 12 shows photograph of partial shape of a bent strip. It is not straight because of return of the bend process. Figure 13 illustrates typical bending process with the suspension pad. At the beginning of the process (Fig.13(a)), the strip is bent at the top of the punch. Then the strip is bent at the side of the punch(Fig.13(b)). It is as well as the case using V-bend die.

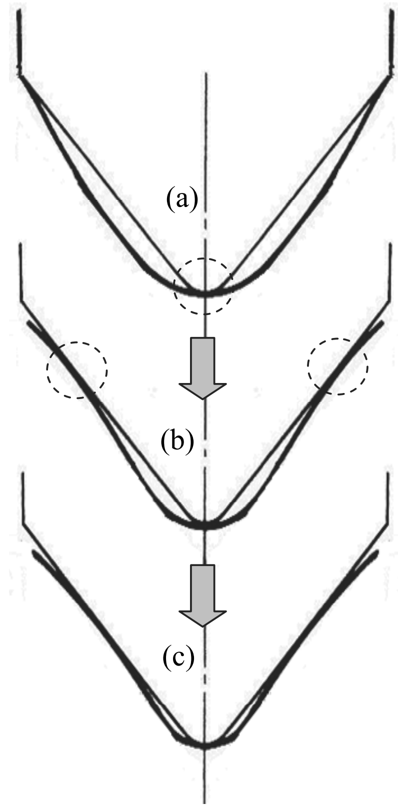

Fig. 13. Bending process with the suspension pad

4. Conclusions

Authors have suggested employment of dilatant fluid for metal forming tools, and report an application on v-bending of thin stainless steel strips with alumina concentrated hard-sphere suspension pad. Shear stress of dilatant fluid approaches zero when shear rate close to zero. Therefore, there is no barrier for dilatant fluid to recover its shape by the gravity. Backward extrusion test is employed for evaluation of the suspension. Migration of water takes important role in the change of the load. Shear stress does not change match within the capable shear rate from the ability of the employed press machine. In v-bending test including acute angle bending, the authors bend the strip with only the alumina concentrated hard-sphere suspension pad and v-bend punch successfully.

The authors think such the dilatant fluid tool, or concentrated hard-sphere suspension, can be employed for other forming processes, such as bending, punching, deep drawing, bulging, embossing and tube forming.

Nomenclature

A	area of the section of the punch in back extrusion test.
h	stroke of bending punch.
P	punch load.
p	pressure in the container in back extrusion test.

Q flow rate.
R inner radius of the back extrusion punch.
W span between die shoulders.
$\dot{\gamma}_a$ shear rate.
η viscosity.
θ_0 mechanical bending angle.
τ_{wa} shear stress.

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