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Experimental and analytical study on the lateral extrusion with a lost core

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In this paper, the author reports the lateral extrusion with a lost core (LELC) process [1] with experimental and analytical studies. The process is performed with a soluble core inside the hollow material, such as low temperature alloys and ice. It requires small load to bulge the hollow material, hence it can be applied on bulging thick hollow part to develop light shaft and gear parts for automobiles.

1. INTRODUCTION

Because of request for lighter parts for automobiles, many kinds of hollow parts are developed recently. The hydroforming process is one of the most hopeful way to obtain such a part. However the process requires too huge pressure to form the thick part, which must be enough strong as an engine or mission part.

Author has developed lateral extrusion with a lost core process (LELC) to form the hollow products . The process is illustrated in Fig.1. At first, cavity of the pipe, or channel material, is filled up by liquid of low temperature melting material, for instances, low temperature melting alloy, ice (or water) and wax. Then low temperature melting material is solidified to be a soluble core of pipe. The author calls this soluble core the ‘lost core.’ The third, the material is compressed longitudinally as a composite billet, and extruded for the lateral direction. After deformation, low temperature melting material is melted and removed. The forming load tends to stay at smaller load than the yield load of the pipe on longitudinal compression during the process. Hence, the process helps us to develop thick hollow products with small loads. In addition, the process can be performed by a simple compressing machine. It does not need sealing of tools unlike hydro-forming.

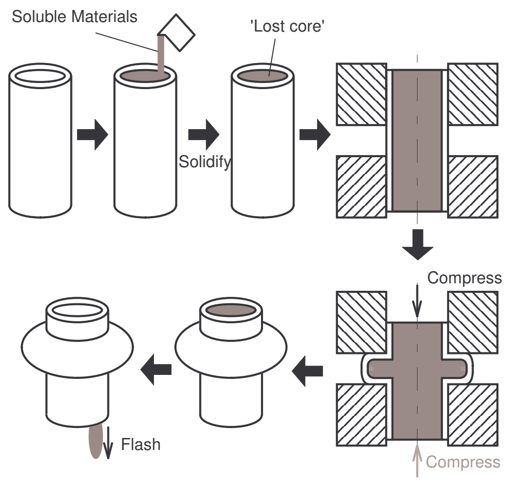


Fig.1 Lateral extrusion with lost core [1]

In this paper, the author reports the mechanism of the process with experimental and analytical results. The tools shown in Fig.2, experimental conditions in Table 1, and FE Analyzer, ANSYS V5.6, are adopted for the study.

Table 1
Experimental conditions

Testing machine	100 ton universal testing machine
Ram speed / mm·min^{-1}	1.0
Materials of specimen	A6063 and A1050 pipes annealed at 350℃ for 8 hours (outer diameter:φ 16, thickness: 1 mm) , C1220 pipes annealed at 550℃ for 90 minutes at 550℃ for 90 minutes (outer diameter:φ 15.88, thickness: 1 mm)
Materials of lost core	$Bi_{49}Pb_{18}Sn_{12}In_{21}$ low temperature melting alloy, and ice
Lubricant	Nippon-kouyu NPC-MO (MoS_2)

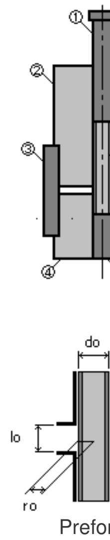


Fig. 2. Dies and specimen [2]

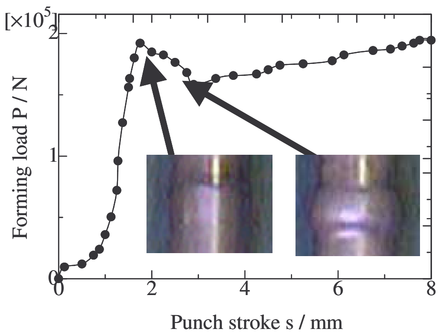


Fig. 3 Example of forming load [2]

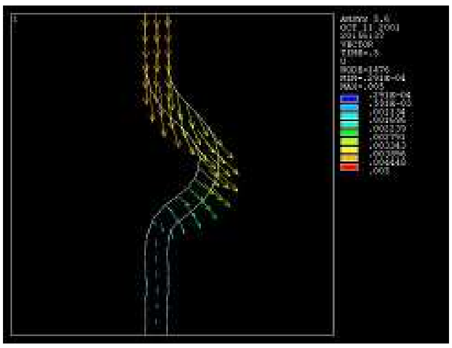


Fig. 4. Simulated velocity istribution [2]

2. FORMING MECHANISUM AND COMPARISON WITH HYDROFORMING

Figure 3 shows the forming load during the process in an example experiment. The load reaches the peak at the beginning of the process, and decrease after the peak. The result indicates that the change of the state of the material from the simple axial compression to bulging process at the peak. Before the peak, the pipe is bulged little. However, it begins to bulge after the peak. At the beginning of the process after then, the bulging load is smaller than the peak. The load increases along the bulging. The bulged flange does not touch the bottom face of upper die when the distance between upper and lower die is almost longer than the inner radius of pipe. In such the case, the pipe bulges at the upper part of itself when the load exceeds the yield load of the initial pipe.

Figure 4 shows the result of deformation analysis. The author uses isotropy models for the pipe and lost core. We can see the lost core acts like a mandrel, which changes the material flow from the axial direction to the lateral direction. Figure 5 shows the pressure distribution on the inner face of the pipe. We can see the pressure does not work inside

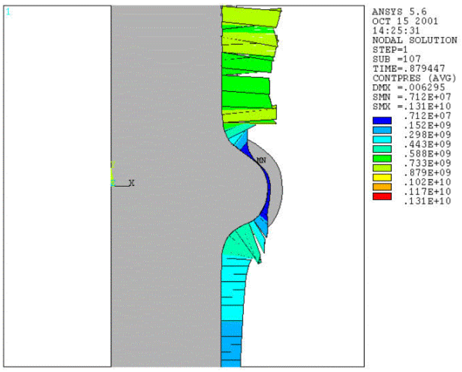


Fig. 5. Simulated pressure distribution at the inner surface of the pipe[2]

the flange to bulge the pipe. The pipe does not seems to be bulged by internal pressure, but by the extrusion from the container of the upper die. Figure 6 shows typical strain distributions of both bulged products by the LELC and the hydorforming without axial compression. Definition of symbols are as followings.

Reduction of the thickness:

$$\varepsilon_n = LN\left(\frac{t}{T}\right) \quad (1)$$

t: Thickness of wall after forming, T: Initial thickness of the wall

Circumference strain:

$$\varepsilon_\theta = LN\left(\frac{d}{D}\right) \quad (2)$$

d: Bulged diameter, D: Initial diameter
Meridian strain:

$$\varepsilon_\phi = -(\varepsilon_\theta + \varepsilon_n) \quad (3)$$

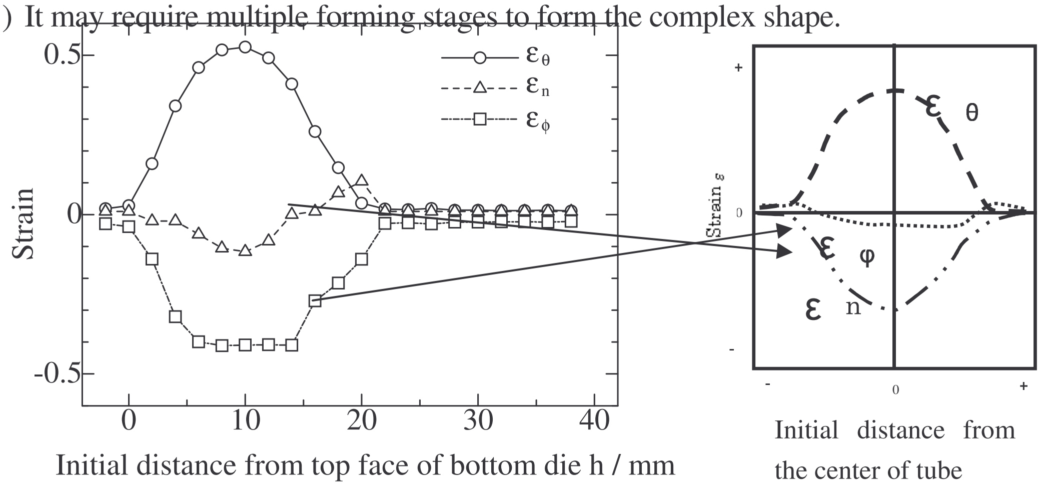
Meridian strain $\boldsymbol{\varepsilon_\phi}$ corresponds to the extruded material form the container of the upper die into the cavity. With regarding Fig.6, we can say that, in the LELC process, circumference strain $\boldsymbol{\varepsilon_\theta}$ is created from extruded material into the cavity mainly, unlike hydroforming without axial compression, in which $\boldsymbol{\varepsilon_\theta}$ is created from the reduction of the thickness of the wall $\boldsymbol{\varepsilon_n}$. This is the difference of the deformation mechanism between LELC and plain hydroforming. It is illustrated in Fig.7. The advantages of the deformation mechanism of the LELC process are :

(1) $\boldsymbol{\varepsilon_n}$ is kept in small value. Hence, the bulge limit is very high.

(2) Large forming load is not needed. It contributes to the die life, simple equipments, and forming of thick products.

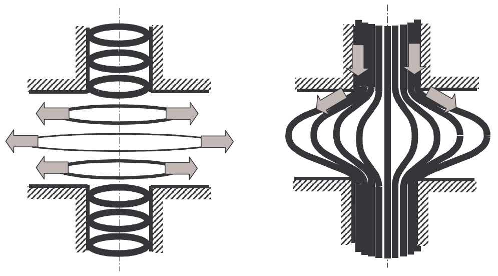
However the mechanism has following disadvantages also.

(1) It may require multiple forming stages to form the complex shape.



(a) LELC (C1220, l_0=8mm) (b)Hydroforming

Fig. 6. Strain distributions [2-4]



(a) Hydroforming without axial compression (b)LELC

Fig. 7. Typical deformation mechanisms

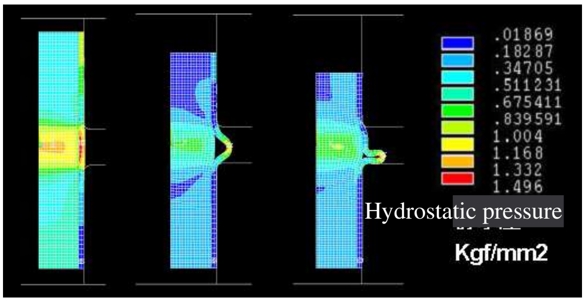


Fig. 8. Example of yielding of the pipe

(2) Dedicated process design to the target shape is needed.
(3) Adding and removal steps of lost core are required.

With regarding the mecahnisum, we can say that the lost core acts as a mandrel rather than the pressure transmission in hydroforming. Therefore, following matters should be considered when we choose the material of lost core.
(1) It must expand when it is solidified.
(2) It must be enough strong to resist the load suffered from the pipe to support the pipe and changes its flow direction. However, too high flow stress of the core makes total load too high to involves wrinkle of pipe such as shown in Fig.8.

3. CONCLUSIONS

In this paper, comparing with the hydroforming, the author reports deformation mechanism of LELC process to form hollow product. In LELC process;
(3) ε_n is kept in small value. Hence, we can obtain the product having large bulged part.
(4) Large forming load is not needed. It contributes to the die life, simple equipments, and forming of thick products.
However;
(3) It may require multiple forming stages to form the complex shape.
(4) Dedicated process design to the target shape is needed.
(3) Adding and removal steps of lost core are required.

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