FABRICATION OF A RING GROOVE ON INNER SURFACE OF TUBE BY IRONING FROM OUTER SURFACE USING DISPLACEMENT CONTROL OF TUBE BOTTOM END

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Abstract. We proposed new method of fabrication of a ring groove to reduce Non-filled-area. Non-filled-area was found in a previous study and occurs between tube inner-surface and the plug projection after ironing. The methods are displacement control and upward force control. This study tried to verify the effect of applying upward force on the lower tube-end surface using the finite element analysis (FEA) and experiment. The FEA showed upward force was effective for reducing “Non-filled-area” in the former half of the process. However, the continuously applied upward force expanded the “Non-filled-area” in the latter half of the forming. Therefore, the upward force should be reduced in the middle of the process. The displacement control of the floor die was used for the control of the upward force. The FEA showed the suitable amount of the upward force and the optimum timing for reducing the force.

1. INTRODUCTION

Focusing on the fact that robots can operate more accurately than humans, methods have been developed to enable robots to replace tasks performed by humans in the past. An example is medical robots. Coreless motors with high controllability are used in medical robots. Coreless means motor in which the rotor consists only of coils, and the shape of the coils and their position in relation to the magnets greatly affect the motion. Therefore, high-precision parts are used for the motors of medical robots. The cylindrical housing of a motor used in a medical robot has a complex uneven for the inner surface. The inner surface of the housing is often axisymmetric and is formed by machining using an NC lathe. However, when high accuracy is required, it is structurally difficult and requires a large amount of machining time. If it becomes possible to replace this machining process with plastic forming, it can expect to reduce machining time and improving yield.

Yamauchi Engineering Co. proposed a new forming method for fabricating the concave parts to the inner surface of cylindrical parts by ironing[1]. The method placed a plug with a projection inside a cylindrical part on a floor die, and fabricated the concave part from inner surface of blank by ironing the outer surface of the cylindrical part using an ironing die[1]. The outline of the process is shown in **Figure 1** and the appearance of the plug is shown in **Figure 2**. In consideration of the manufacturing line, the plug is divisible and has a mechanism that allows it to contract in the radial direction. Therefore, The ironed tube can be unmounted from the constracted plug after deformation. In addition, Complex shapes can be formed according to the surface shape of the plug. In the previous study, a finite element analysis was conducted as a basic study of this processing method for clarifying suitable process conditions for improving formability[2], and the validity of the analysis results was verified by experiments on actual machines[3]. In addition, the previous study found that Non-filled-area were observed in the molded products as shown in **Figure 3**. The study suggested that a upward load on the tube end might be effective for suppression of the Non-filled-area, but this has not yet been verified. In this paper, we considered the conditions for reducing the Non-filled-area by two methods: displacement control, in which the floor die is lowered during the ironing process, and load control, in which force is applied to the floor die during the ironing process.

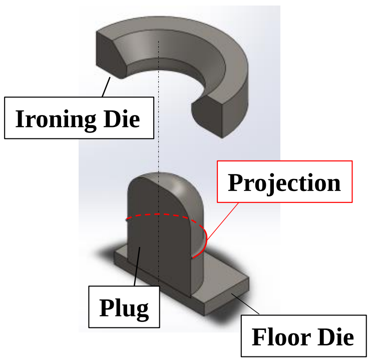


Figure 1: Schematic of tool

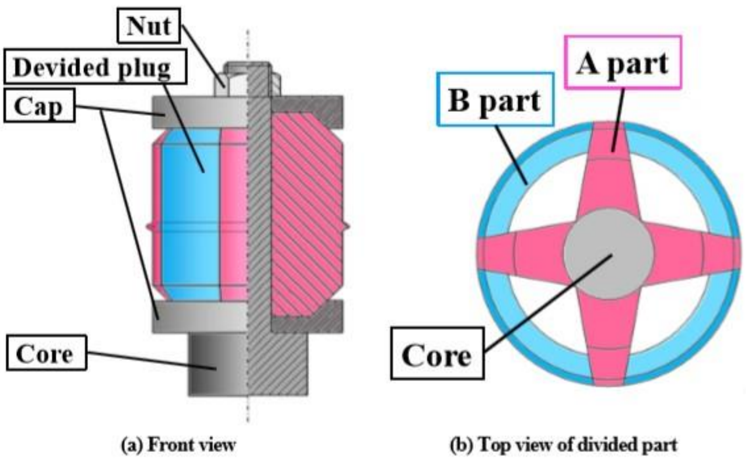


Figure 2: Schematic of plug

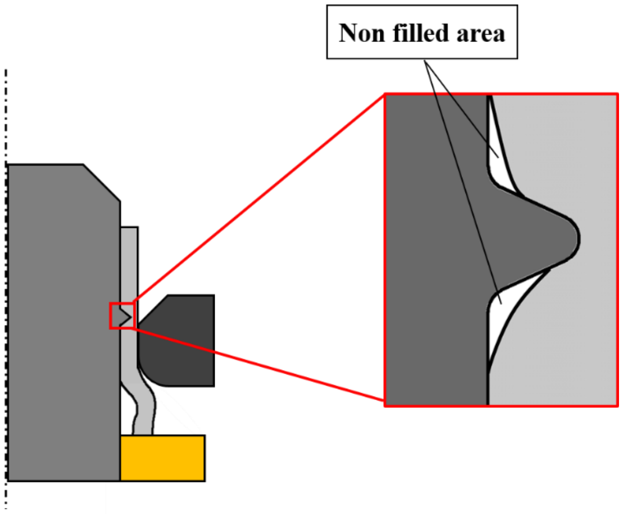


Figure 3: Non-filled-area

2. ANALYSIS MODEL

In the new method of controlling the force exerted by the floor die on the tube bottom end, it must be clarified whether forming is possible. In this process, the blank is undergone elasto-plastic deformation near the plug projection during forming, making it difficult to investigate the effect of processing conditions on formability solely through experiments. The FEM was carried out for observing the deformation and for clarifying the forming possibility and the occurrence of defects.

In this study, a commercial code ELFEN. It developed by Rockfield Software Ltd. was used for numerical analysis. The dynamic explicit scheme, which can be applied to adaptive meshes, was adopted because the material deforms severely at the plug projection in this process. The analytical model was a two-dimensional, symmetric model around y-axis, and rigid bodies were applied to the plug, ironing die, and floor die. A schematic diagram of the analysis is shown in **Figure 4**, and the conditions are shown in **Table 1**. The mechanical properties of aluminum alloy 5056 are shown in **Table 2**, and the true stress-plastic strain diagram is shown in **Figure 5**. The true stress-plastic strain diagram was approximated by the Swift's equation and extrapolated for analysis.

Previous studies have shown that the Non-filled-area occurs upper and lower the projection, and the Non-filled-area on the lower side is larger. Therefore, we thought that the Non-filled-area could be reduced by applying a force from below. The upward farce on the tube-bottom end was controlled by 2 methods, one is "Displacement-control method", and the other is "Load-control method". The upward force was given to the tube end by the floor die in the two methods. It is important to give a large upward force in the former half of the process, and small one in the latter half. In "displacement-control method", the floor die is fixed in the former half, and is suddenly lowered when the ironing die position x is x_{s}.. the positions x and x_s are measured from the floor die to the boundary of arc and straight part of the ironing die. The height difference between x_s and the projectiom height H_p, $x_s - H_p$, could be a dominant parameter. To control the upward force by analysis, a displacement control mechanism was considered in which the floor die was lowered during the ironing process to gradually unload the upward force. The position from the floor die to the straight part at the start of lowering of the floor die is considered to have an effect on formability as the straight part of the ironing die fills tube inner-part near the projection of the plug. The distance from the floor die to the straight part at the moment of lowering the floor die was x_s. The maximum value of x_s was set at the position where the shoulder of the die started ironing the blank, and the minimum value was set at the position where the end of the straight part passed the plug projection.

In “load-control” method, we considered a mechanism to increase the upward force by applying a force from the floor die. “Load-control” method applies the upward load F to the floor die, which is pushed against a stopper die, determining the tube-bottom end. The upward force F is suddenly lowered when the ironing die position x is x_f. the height difference $x_f - H_p$ could be a dominant parameter.

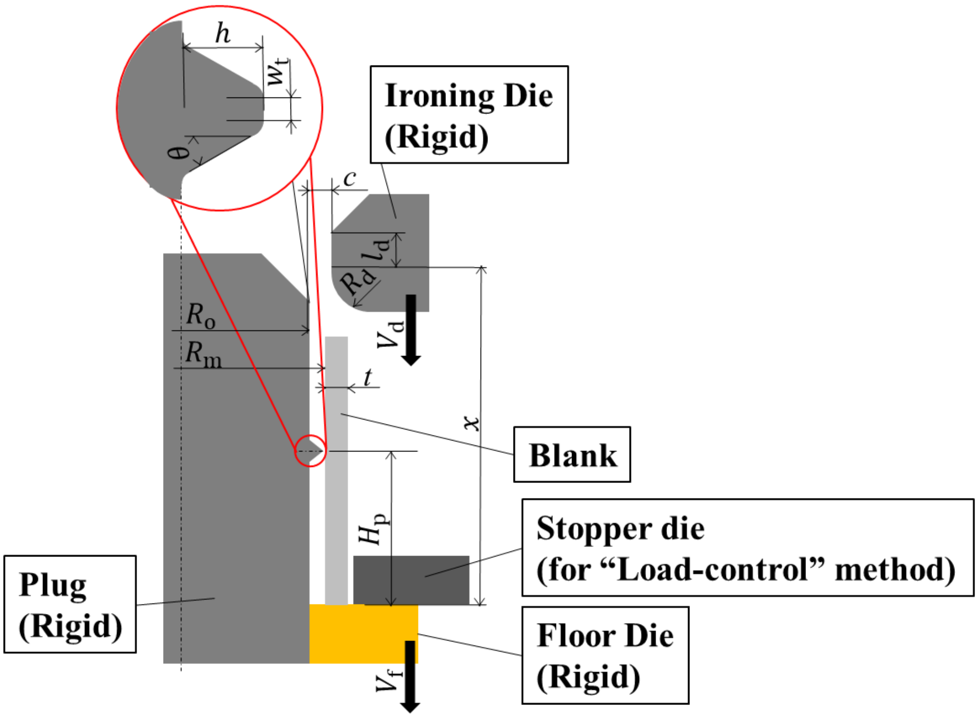


Figure 4: Definition of symbols

Table 1: Analysis conditions

Ironing Die	**Material type**	**Rigid**
Floor Die	**Material type**	**Rigid**
Plug	**Material type**	**Rigid**
Blank	**Material type**	**Elastro-plastic**
	Material	**A5056**
Coefficient of friction μ		**0.1**
Clearance c / mm		**2.0**
Thickness of blank t / mm		**2.0**
Ironing ratio η %		**0**
Inner radius of blank R_m / mm		**30**
Length of straight part l_d / mm		**2**
Radius of die shoulder R_d / mm		**26**
Position of projection H_p / mm		**10, 15, 20**
Height of projection h / mm		**0.8**
Width of projection w_t / mm		**0.2**
Taper angle θ / °		**30**
Subtract Position of projection from the distance from the floor die to the straight part at the moment of lowering the floor die x_s-H_p / mm		**-8, -4.5, -1, 2.5, 6, 9.5, 13**
Applied force F / kN		**4, 8, 10, 12, 16, 20**
Subtract Position of projection from the distance from the floor die to the straight part at the moment of unloading the floor die x_f-H_p / mm		**-8, -1, 6, 13**

Table 2: Mechanical properties(A5056)

Young's Modulus E / GPa	**69.2**
Poisson's ratio ν	**0.34**
Hardening exponent n value	**0.151**
Strength coefficient F value / MPa	**494**
Offset of yield strain ε_0	**6.47×10^{-5}**

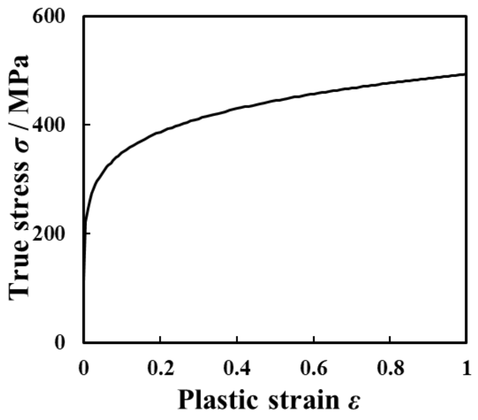
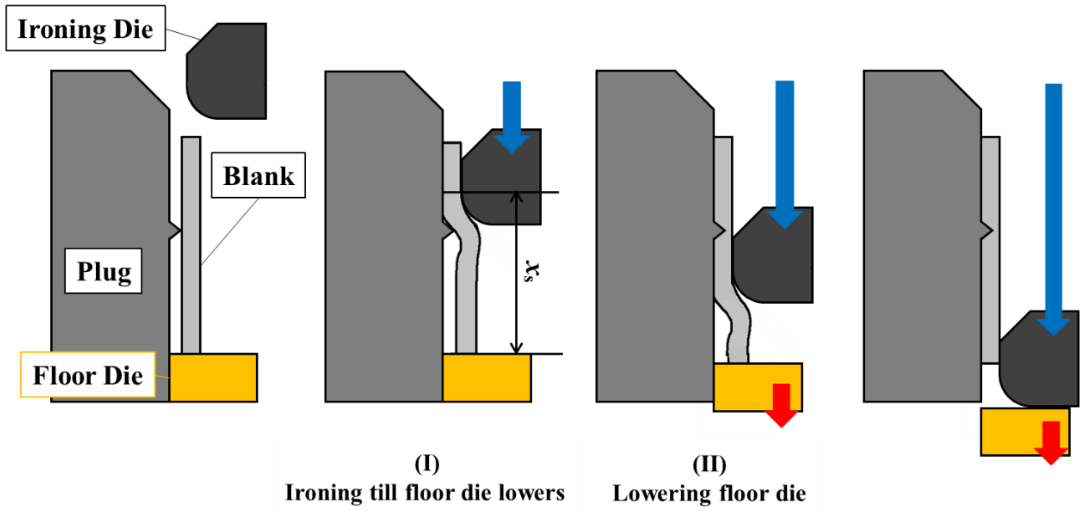
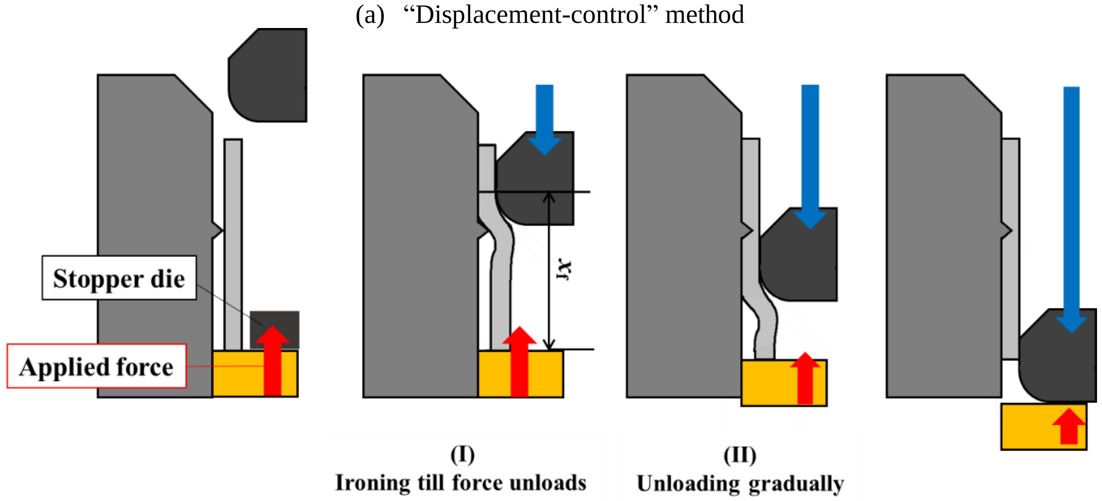


Figure 5: True stress – plastic strain diagram



(a) “Displacement-control” method



(b) “Load-control” method

Figure 6: Process of two methods

3. EVALUATION OF FORMABILITY

Figure 7 shows an overview of the defects revealed by the analysis. Non-filled-areas where no material was supplied to the inner diameter side occurred at the upper and lower of the projection. In order to clarify the effect of controlling the upward force on formability, it is necessary to evaluate this forming defect quantitatively. The upper Non-filld-area S_1 and lower one S_2 were measured for evaluating formability. The blank and plug are considered to contact each other when the gap between them is less than 0.005 mm.

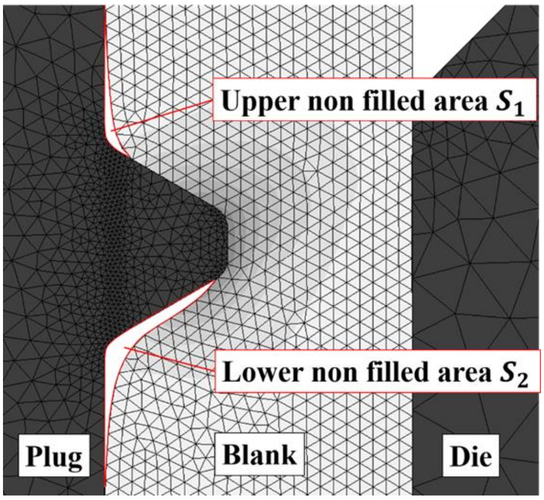


Figure 7: Symbols of Non-filled-areas

4. RESULTS

Figure 8 shows the effect of x_s - H_p on the Non-filled-areas S_1 and S_2 for "Displacement-control" method. First, we discuss the tendency commonly observed in S_1 and S_2. These tend to decrease as the timing of lowering the floor die becomes later. i.e. with decrease of x_s - H_p when x_s - H_p is positive. This is due to the fact that the floor die does not descend until the straight part of the ironing die irons the vicinity of the plug projection, while the floor die supports the bottom end of the tube. At x_s - H_p =1mm, where x_s is almost equal to the plug projection height H_p, the upward force from the floor die is considered to be sufficient enough for transferring the plug shape to the tube inner surface. At x_s - H_p = 15.6 mm, where the timing of lowering is considered to be earlier, S_1 and S_2 increase. This is because the floor die descended before the straight part of the ironing die reached the plug projection, which caused the material to move downward and increased the Non-filled-areas.

Figure 9 shows the results for "Load-control" method for various upward load F. S_1 and S_2 tend to decrease with increasing load. This is because the force applied to the floor die during the ironing process acted to provide sufficient upward force for forming the concave. Furthermore, as in the displacement control, the later the timing of unloading the force applied to the floor die is, the more the Non-filled-area decreases. In addition, the upper Non-filled-area S_1 increased as the projection height H_p increased, and the lower Non-filled-area S_2 tended to decrease as the projection height H_p increased. This is because the higher the projection height, the longer the upward force is applied after the concave part is transferred, and the blank is deformed upward based on the projection. In addition, the upper Non-filled-area S_1 was smaller than the result obtained by displacement control under the condition. The lower Non-filled-area S_2 was smaller than the result obtained by displacement control only when certain conditions were satisfied.

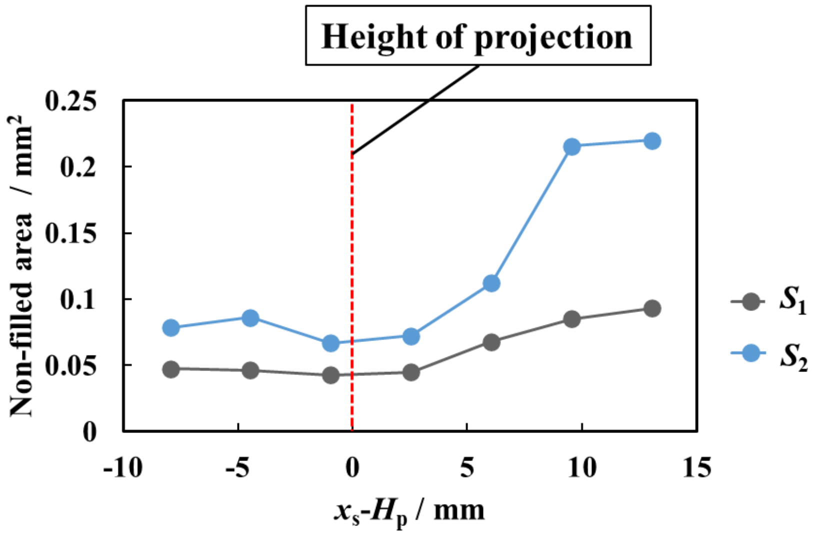


Figure 8: Non-filled-areas of “Displacement-control” method (H_p = 20 mm)

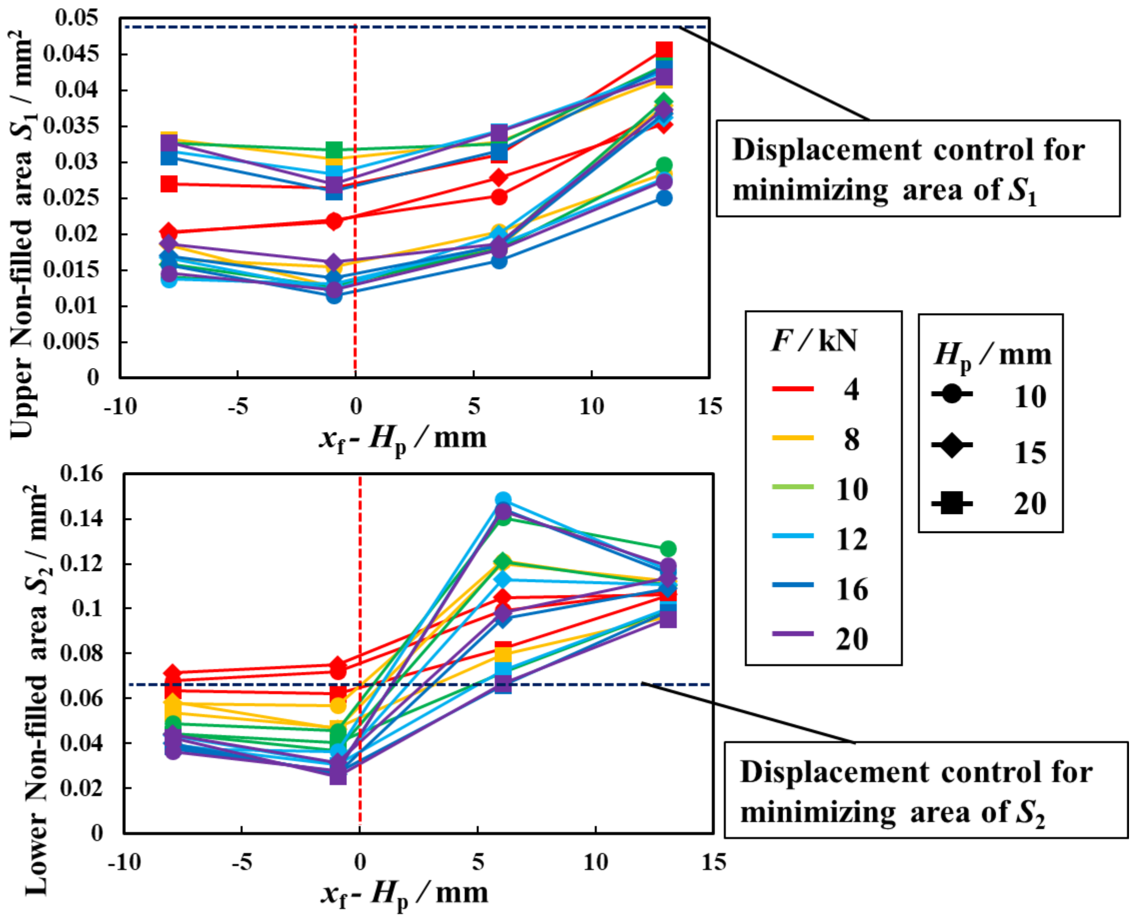


Figure 9: Non-filled-areas of “Load-control” method

5. Conclusions

This paper tried two methods in ironing tube from outside for transfering plug shape to tube inner surface. One is “Displacement-control” method and the other is “Load-control” one.

- Non-filled-areas S_1 and S_2 tend to decrease as the timing of lowering the floor die becomes later. This is due to floor die supports the bottom end of the tube and the tube-inner part fills the plug projection.
- The die position for starting lowering the floor die x_s should be almost equal to the projection height H_p as the force should work until the shape transfer from plug to tube is completed.
- In “Load-control” method, the Non-filled-areas, upper side S_1 and lower side S_2, decreased with increasing upward load. This is because the upward force on the rubr-bottom end worked to make the tube inner surface fit to the plug surface.
- The upper Non-filled-area S_1 was smaller than the result obtained by displacement control all the examined conditions. The lower Non-filled-area S_2 was smaller than the result obtained by displacement control under suitable conditions.

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