Research Article

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Cold Plastic Forming of ABS Plastic Pipe

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ABSTRACT

This paper describes about cold plastic forming of ABS plastic pipe. Experiment and Finite element method (FEM) analysis of pipe expansion process were operated. The application of ABS plastic pipe for air conditioner is under consideration instead of metal pipe in Japan because of weight saving of air conditioner for lowering the gravity point against earthquake. The parts of ABS plastic pipe is generally produced by injection molding. The processes need the cooling time, and it takes much time. In addition, expensive mold die is needed for each application. Thus, cold plastic forming of ABS plastic pipe was proposed. The cold plastic forming of ABS plastic pipe chosen for this study is hardly studied by other authors. Product ability of cold plastic forming is higher than the injection molding or hot working. And the punch and die shape is simple comparing to these process. In this study, pipe expansion process was operated. The ABS plastic pipe has a 10 mm diameter and 8mm inner diameter and 1 mm thickness. At first, true stress and true strain curves at any strain rate were measured by ring compression test. Obtained flow stresses was used to FEM analysis. Experimental device for pipe expansion process was made by Dip Inc.. Objective inner diameter was 10 mm. FEM analysis was operated to clarify the deformation behavior such as load-stroke diagram. It was possible to produce the expanded ABS pipe. The whitening of worked pipe and strain recovery was observed. Analysis result was indicated the good agreement comparing to experimental result in load-stroke diagram.

Keywords

Cold Plastic, ABS plastic pipe, Lubricating oil.

Introduction

This paper reports cold plastic working of ABS plastic pipe and finite element analysis (FEM). Japan is prone to earthquakes, and weight reduction of domestic air conditioners is being studied as an earthquake countermeasure. There are many pipes inside the air conditioner, metal pipes are mainstream, and it is expected that the plastic pipes for the purpose of weight reduction are applied.

Plastic pipe is made usually injection molding, an expensive mold and long cooling time are required, so improvement of productivity is required. Therefore, in this study, we aimed to examine the cold plastic working of ABS plastic pipe whose has excellent mechanical properties as the experimental material. This time, expansion tube forming was the subject of research. There seems to be almost no example of plastic processing of plastic [1-3]. First, ring compression tests were conducted at various strain rates in order to clarify the cold deformation resistance of ABS plastic pipes. Subsequently, using a prototype machine, a cold tube expanding molding experiment was carried out. In addition, heat treatment was performed using pipes after tube expansion molding, and the shape of the plastic pipe was evaluated. FEM analysis was carried out to investigate the cold deformation characteristics of ABS plastic pipe.

Experimental Method and Experimental Condition

Compression tests were conducted to clarify the cold deformation resistance of ABS plastic pipes. The ABS plastic pipe used is transparent, diameter 10 mm, wall thickness 1 mm, length 70 mm. For the compression test piece, this pipe was cut out by a lathe to obtain a ring-shaped test piece having a thickness of 1 mm. The universal testing machine used is TENSILON (RTF-2430). Compared to metal, the plastic pipe has a greater influence of the strain rate, so the strain rate was changed according to the specification of the universal testing machine. Table 1 shows the strain rate and the set speed of the testing machine as test conditions. The target compression ratio was 70%. As the lubricating oil, graphite lubricating oil (shear friction coefficient 0.03) was used as low friction coefficient oil.

Strain rate [/sec]	Setting speed [mm/min]
8	480
6	360
4	240
2	120
1	60
0.1	6

Table 1: Compression test speed.

A prototype was used for the pipe expansion molding experiment. Figure 1 shows a photograph of a prototype (manufactured by Dip Co., Ltd., Ota City, Gunma Prefecture). The device is provided with a clamp and a punch for expanding the inner diameter from 8 mm to 10 mm. Figure 2 shows a photograph of punch. The outer diameter of the part where the pipe is clamped is 10 mm and the outer diameter of the expanded part is 12 mm. Figure 3 shows a photograph of clump. The outer diameter of the expanded portion is 10 mm. A compression type load meter (CLK-10 KNA) was used for load measurement. A high sensitivity displacement gauge (CDP-100) was used for stroke measurement. The load-stroke diagram was sequentially recorded on the laptop. Lubricating oil used was Cle5-56 for the tube expanding molding experiment. The device expands by pushing the punch into the plasic pipe at a constant speed with pneumatic pressure. This step consists of two steps. The first step is clamping, and the second step is pushing (expanding). After completion of the two steps, the clamp was removed and the pipe was taken out. The pushing speed was 41.99 mm/sec which is the maximum speed of the testing machine.

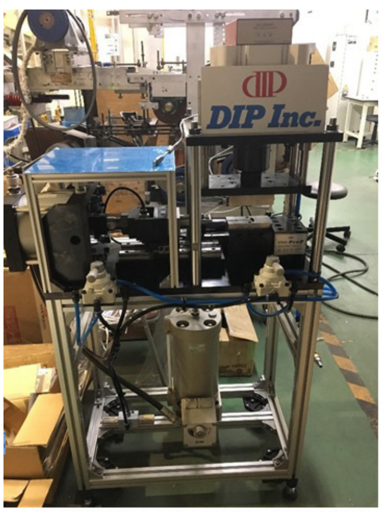

Figure 1: Test machine (Made by DIP Inc.).

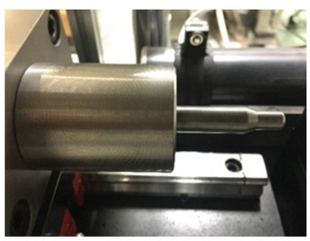

Figure 2: Punch.

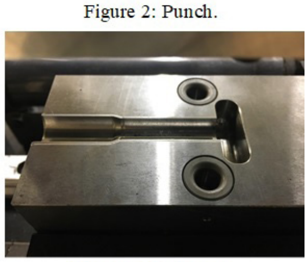

Figure 3: Clump die.

Heating treatment of the ABS plastic pipe will return to the almost former form of testing for strain recovery. For this reason, in the heat treatment test, a method was adopted, in which the ABS plastic pipe after the test was taken out from the testing machine together with the punch and the ABS plastic pipe was heated in water together with the punch. Experimental temperature was 75°C, 85°C, 95°C for 1 minute, 5 minutes, 10 minutes respectively.

Analysis Method and Analysis Condition

Commercially available finite element method software DEFORM was used for the analysis. The analysis model was a two-dimensional axisymmetric model. Figure 4 shows the analysis model. Figure 4 (a) shows a model before analysis, and Figure 4 (b) shows a model after analysis. For the deformation resistance, the value obtained above was used. Table 2 shows the analysis conditions. Young's modulus of ABS resin was 2,500 [MPa], Poisson's ratio was 3.5. The material model was rigid plastic. We think that it is preferable to use rigid-plastic for improvement of analysis accuracy, but solution did not converge at the present time. Other analysis conditions were the same as the experimental conditions. The analysis time was about 90 minutes.

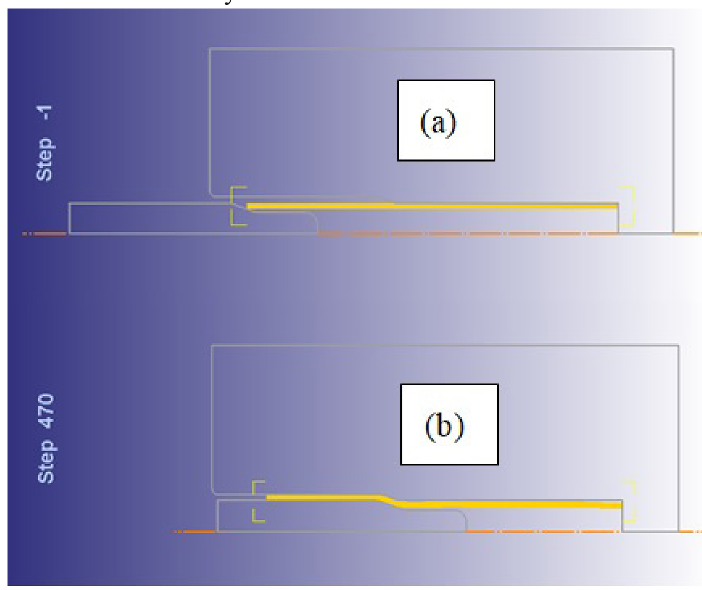

Figure 4: Analysis model.

Analysis model	2 dimention
Material model	Rigid plastic body
Element count	3000
Punch speed [mm/sec]	1
Step increment [sec/step]	470
Shear coefficient friction of between punch and material	0.12

Table 2: FEM analysis conditions.

Experimental Result and Analysis Result and Discussion

Figure 5 shows a photograph of the ABS plastic pipe before and after the ring compression test. Because the graphite lubricant remained, it was black as a whole, but the material itself retained transparency. In addition, although the compression ratio was about 70%, no crack was found in the ABS plastic. Figure 6 shows a photograph of the ABS plastic pipe after tube expanding. Whitening was observed in the expanded part. It is considered that whitening of the plastic is caused by inhibition of light transmission by voids of several tens of nanometers in size and fibrils in which oriented molecular chains are gathered inside the craze generated inside the plastic. After expanding tube forming, the material was tightened so that it could not be easily removed from the punch. It is thought that this is due to the strain restoration peculiar to the plastic material. After the tube expansion, the size of the pipe after a sufficient length of time was 67.5 mm in length, 23.0 mm in length of expanded part, 9.5 mm in inner diameter, 11.5 mm in outer diameter and 1.0 mm in wall thickness. It became clear that about 5% shrinkage occurs in the radial direction in tube expanding molding.

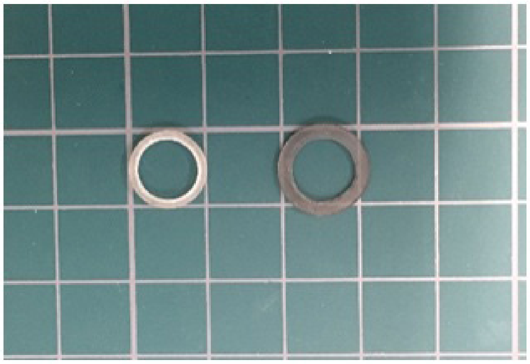

Figure 5: ABS ring of before and after test

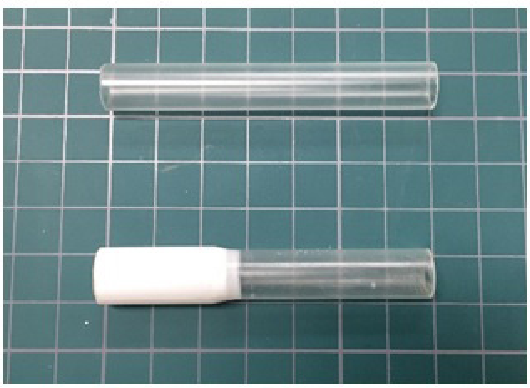

Figure 6: ABS pipe of before and after test

Figure 7 shows the deformation resistance curves of the ABS plastic obtained in the ring compression test at each strain rate. The validity of the deformation resistance curve obtained by analysis was confirmed. Within the scope of this research, the deformation resistance decreased as the strain rate increased. Generally, it is said that the elastic modulus and the yield stress increase as the strain rate increases for the plastic material. However, what is obtained in this experiment is the opposite tendency, which is considered to be due to softening due to process heat generation.

Figure 8 shows the results of the heat treatment experiment. At 95°C, 5 minutes, 10 minutes and 85°C, 10 minutes no cracks occurred in the plastic pipe, whitening can also be suppressed, and it became a very clear ABS plastic pipe. The uniform composition was destroyed by heating at 95°C,10 minutes, and it turned to light orange. White vertical stripes were observed in the processing direction at 95°C, 1 minute, 85°C., 10 minutes. It is thought that strain recovery by heat was not completed and it was in the process of strain recovery. It was considered that whitening was not suppressed at 85°C, 1 minute and 75°C, 1 minute, 5 minutes, 10 minutes, and strain recovery by heat was not performed.

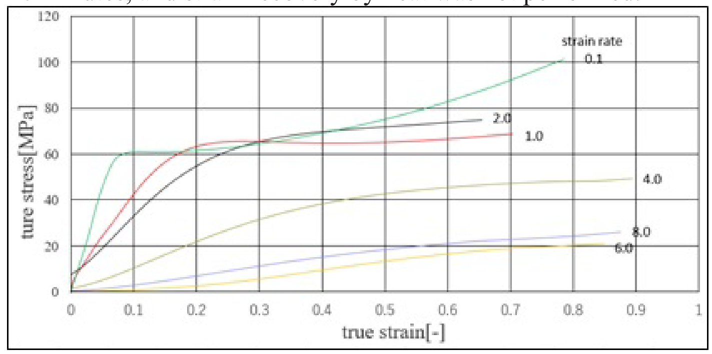

Figure 7: Flow stress curve.

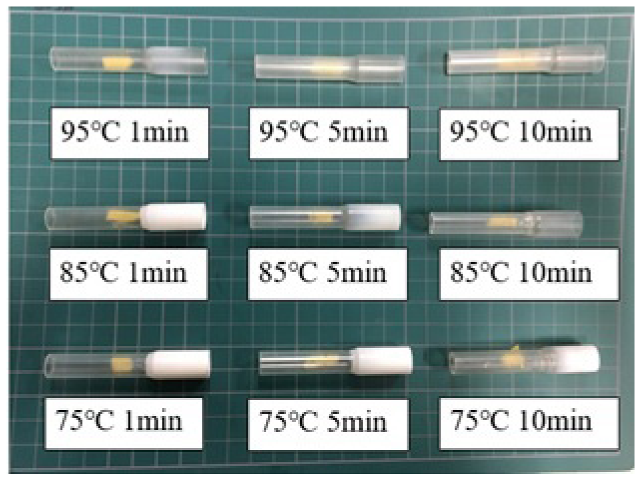

Figure 8: ABS plastic pipe after heat treatment.

From these results, the higher the temperature, the faster the strain recovery, the whitening with the expansion rate of 25% could be completely suppressed. It was also found that strain recovery is hardly performed unless the temperature is higher than 75°C.

Figure 9 shows the experimental results and analysis results of the load-stroke diagram in tube expansion. In the experiment, the load showed a sharp rise immediately after contact between the punch and the material, and showed a gentle rise when the punch stroke was 6 mm or more. On the other hand, the analysis result showed that the load value became almost constant when the punch stroke was 6 mm or more.

The vibration of the load seen at the beginning of the analysis result is the fluctuation caused by the convergence of the solution peculiar to the static implicit method. In the experiment, since the plastic pipe tightens the punch by restoring strain, the frictional force increases when pushing in the punch, and the punch stroke appeared in the rise of the load after 6 mm. In the analysis, it is considered that it is possible to reproduce the experiment by rigid plastic analysis considering strain recovery. In addition, since good agreement was obtained between the experimental value and the analysis value up to the punch stroke of 6 mm, it is considered that the validity of the material test of this research was proved.

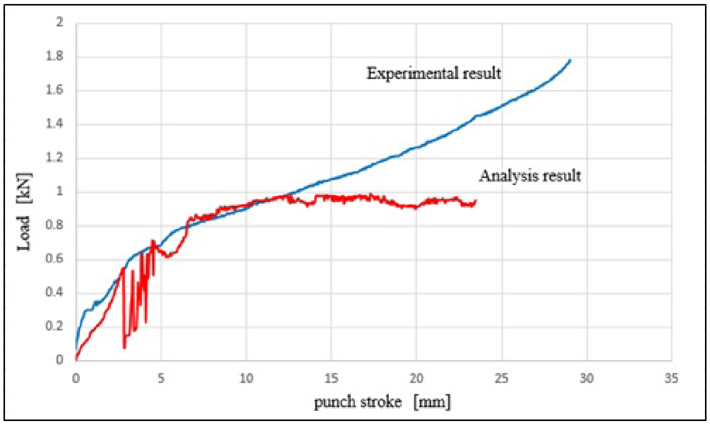

Figure 9: Relationship between punch stroke and load.

Summary

- The compression deformation resistance of the ABS plastic at a strain rate of 0.1 to 8.0/sec was measured.
- It was possible to cold expanding at an inner diameter expansion rate 25% of ABS plastic pipe.
- Whitening and strain recovery were observed in the ABS plastic pipe after expansion.
- The whitening of ABS plastic pipe with expansion rate of 25% could be suppressed by heat treatment.
- The load-stroke diagram was estimated by finite element method analysis and a certain degree of agreement was obtained by comparison with experimental values.

Acknowledgment

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