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EFFECT OF BLANK DIMENSION ON FORMABILITY OF FORGING BLANK CONSISTING OF TWO METALS

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Abstract. We established a forging analysis method for a blank consisting of two metals. In this study, we evaluated the effect of the blank dimensions on the formability of a blank using this analysis method. The analysis results were compared with forging analysis results using just a stainless steel pipe as the blank. In both numerical analyses, we used stainless steel pipes with inside diameters of 7 mm and 10 mm. A verification experiment was conducted using the same conditions as these numerical analyses, and we confirmed that the result was the same as in the analyses. Also, we focused on the equivalent stress distribution. We confirmed that the blank is effective in forming hollow products.

1 INTRODUCTION

As a countermeasure against global warming, the energy consumption of vehicles must be reduced. Therefore, lightweight parts are being used in the automobile industry [1,2,3]. There have been a number of reports about this. For example, there are methods of making hollow parts out of metal by back extrusion [4] and using fiber-reinforced plastic (FRP), which is lighter than metal [5]. However, the shapes that can be formed by back extrusion are limited, and the manufacturing cost of FRP is higher than that of metals. Accordingly, forging by transverse compression may be possible for manufacturing complex parts. Therefore, we proposed the forging of stainless steel with an aluminum alloy insert. We compared the forging experiment with the numerical analysis from the viewpoint of the forming load and the shape after forming, and we established the forging analysis method [6]. On products using the forging method, aluminum alloy with a low specific weight is filled into the stainless steel pipe, so there is high-strength stainless steel on the outside, where high stresses are produced. Thus, we forge a blank with an aluminum alloy inserted in the stainless steel. With this process, we can form products that are lighter than conventional forged products, and complex forged parts with reduced weight can be produced if the aluminum alloy can be melted away by utilizing the different melting points of the two materials. However, we think that unlike conventional forging, there is an effect on formability because the forging blank consists of two metals. Therefore, the purpose of this study is to evaluate the effect of the material dimension on the formability on the forging blank. Transverse compression using a blank that consists of two metals is compared with that using a stainless steel pipe by itself. We use two inside diameters. We also perform a verification experiment using the same conditions as the numerical analysis and examine the effectivity on hollow forming using the forging blank.

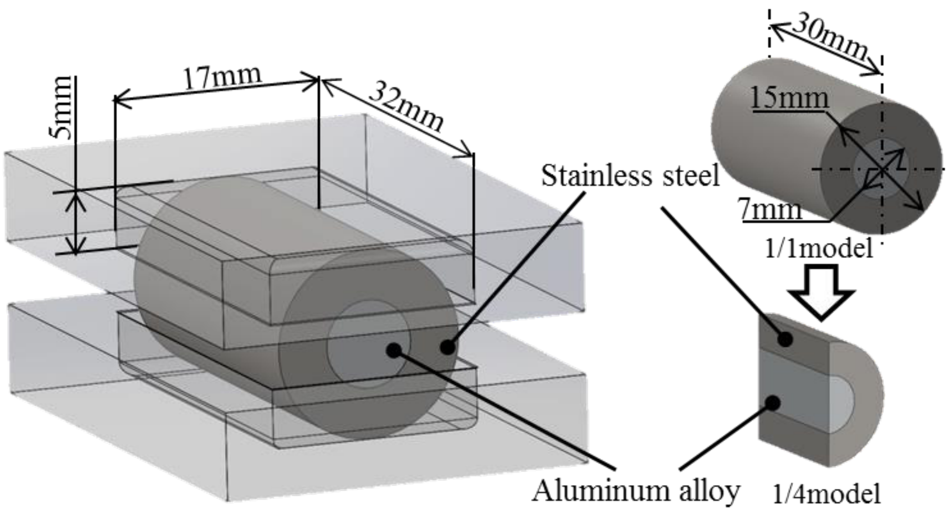
2 ESTABLISHMENT OF ANALYSIS METHOD

In this section, we compare the forging experiment with the numerical analysis from the viewpoint of the forming load and shape after forming and establish the forging analysis method.

2.1 Numerical analysis

2.1.1 Analysis model

The forging analysis in this study was conducted using Simufact.forming 11.0 (Simufact Engineering). For the forging model in this study, we simulated a case where transverse compression was applied to the blank by rectangular dies. The blank model and blank dimensions are one-fourth scale, as shown in Figure 1(b). We used stainless steel (SUS304) and aluminum alloy (A2017). The upper and lower dies are treated as rigid bodies. We fixed the lower die, and we set the relation between the stroke and forming velocity as shown in Figure 2 at the upper die. In this analysis, mesh sizes of 0.3 mm and 0.5 mm were used for the aluminum alloy and the stainless steel, respectively. We used two temperature setting cases in the analysis. In the first case, the temperature of the stainless steel is 973 K, and the temperature of the aluminum alloy is 773 K. In the second case, the temperature of the stainless steel and the aluminum alloy are 297 K.



(a) Analysis model (b) One-fourth scale model

Figure 1: Forging blank model consisting of two metals

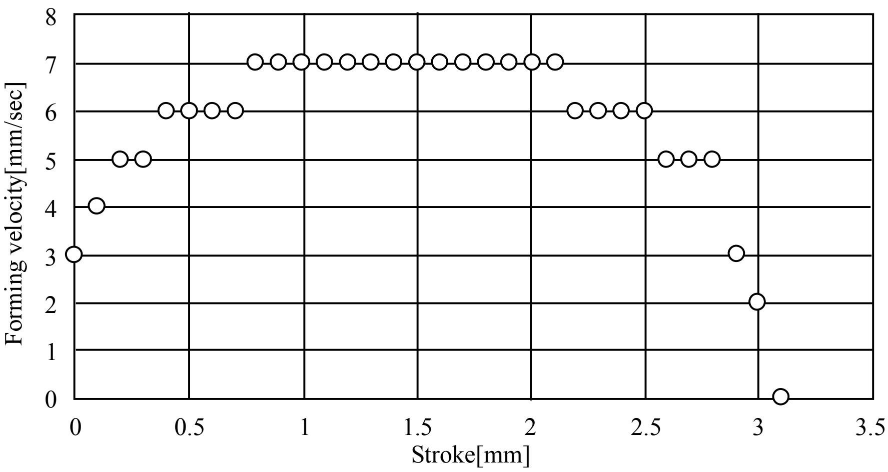


Figure 2: Relationship between forming velocity and stroke

2.1.2 Material properties

In the analysis method, we used stainless steel (SUS304 JIS G4318) and aluminum alloy (A2017 JIS H4040) properties obtained from a compression test. Therefore, we explain the compression test. A cylinder test piece that is φ15×15 was pressed in the axial direction by a servo press H1F60 (Komatsu). At the time, the stroke was 4 mm. The temperature conditions of the stainless steel and aluminum alloy are shown in Tables 1 and 2. For the temperature condition, we took into account processing the heat that evolves when the blank temperature is 293 K. Also, we set four different forming velocities to take into account the strain rate dependency. The mean forming velocities in Tables 1 and 2 are averaged from the contact between the blank and the upper die to the bottom dead point. We obtained the relationship between the true stress and the plastic stress of the stainless steel and aluminum alloy.

Table 1: Set temperature and mean forming velocity of the stainless steel in the compression test

	Setting temperature	Mean forming velocity
Case1	293K	3.12mm/sec
Case2	293K	5.1mm/sec
Case3	293K	10.2mm/sec
Case4	293K	33.8mm/sec
Case5	373K	3.12mm/sec
Case6	373K	5.1mm/sec
Case7	373K	10.2mm/sec
Case8	373K	33.8mm/sec
Case9	973K	3.12mm/sec
Case10	973K	5.1mm/sec
Case11	973K	10.2mm/sec
Case12	973K	33.8mm/sec

Table 2: Set temperature and mean forming velocity of the aluminum alloy in the compression test

	Setting temperature	Mean forming velocity
Case1	293K	3.12mm/sec
Case2	293K	5.1mm/sec
Case3	293K	10.2mm/sec
Case4	293K	33.8mm/sec
Case5	373K	3.12mm/sec
Case6	373K	5.1mm/sec
Case7	373K	10.2mm/sec
Case8	373K	33.8mm/sec
Case9	773K	3.12mm/sec
Case10	773K	5.1mm/sec
Case11	773K	10.2mm/sec
Case12	773K	33.8mm/sec

2.2 Forging experiment

In the forging experiment, a transverse compression load was applied to the blank by two rectangular dies like in the numerical analysis. We used stainless steel (SUS304 JIS G4318) and aluminum alloy (A2017 JIS H4040). For the heat condition, the aluminum alloy was at ambient temperature and was inserted into the heated stainless steel. The heated blank in this study was given a transverse compression load by the servo press. In addition, the stroke in the forging experiment was 2.84 mm. The blank was cut after forging using a fine cutter to observe the shape of the cross section.

2.3 Comparison of forging experiment and numerical analysis

We show the relationship between the forming load and stroke in Figure 3. In this study, we show a comparison of the forging experiment and the numerical analysis case for the heated blank. As shown in Figure 3, the forming load in the forging experiment coincided with the result in the numerical analysis. Next, Figure 4(a) shows the shape of the cross section given by the heat forging experiment. Figure 4(b) shows the shape of the cross section given by the heat numerical analysis using the material properties that were provided from the compression tests. And, we show the shape of the cross section that was given by cold forging experiment in Figure6(a). we show the shape of the cross section that was given by cold numerical analysis using material property that was provided by compression tests in Figure6 (b).In addition, Figure6 shows the dimensions of the cross section shape after forming.

In case of the heated blank, the blank is distorted uniformly, as shown in Figures 4(a) and (b). The burr of the aluminum alloy on the end face is pressed by the dies. As shown in Figure 5, the dimensions after forming in the forging experiment and the numerical analysis are almost identical. In case of blank at normal temperature like heated blank, the blank after cold forming in Figure6(a) and (b) distort uniformly. As shown in Figure7, the dimension after forming in the forging experiment and the numerical analysis are almost identical. It is concluded that the numerical analysis accurately represents the forging experiment and the blank after forming, as shown in Figure 3. Therefore, we established the forging analysis method for a blank consisting of two metals.

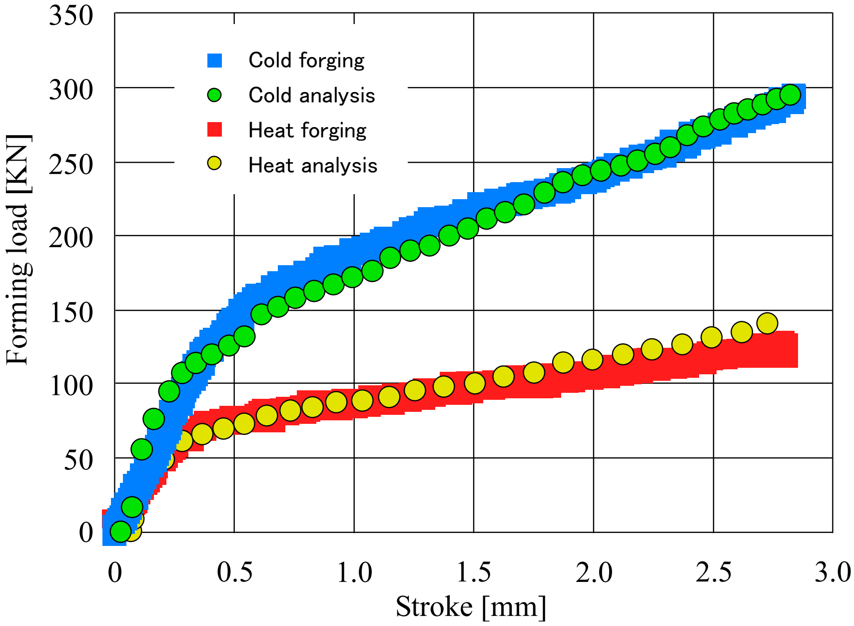
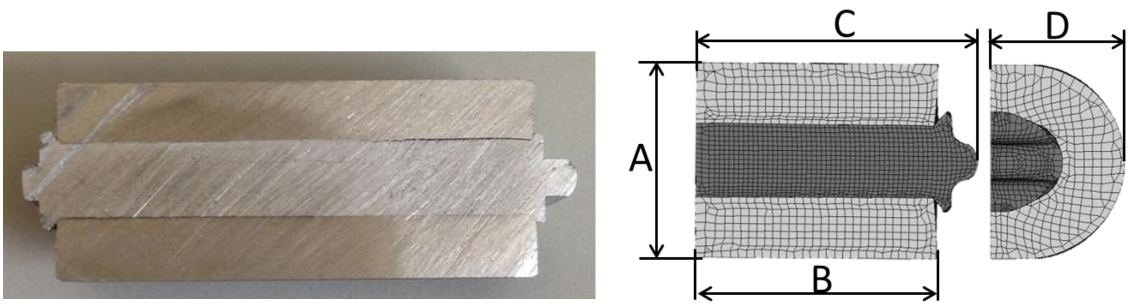


Figure 3: Relationship between forming load and stroke



(a) Shape of cross section after the experiment (b) Shape of cross section after the analysis

Figure 4: Comparison of experiment and analysis

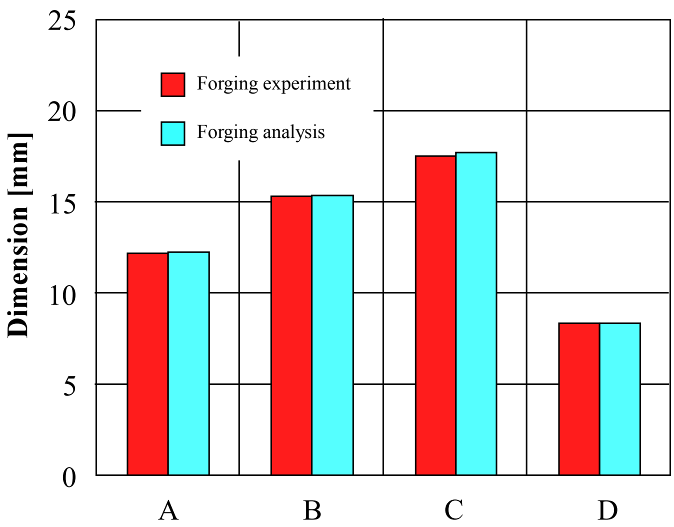
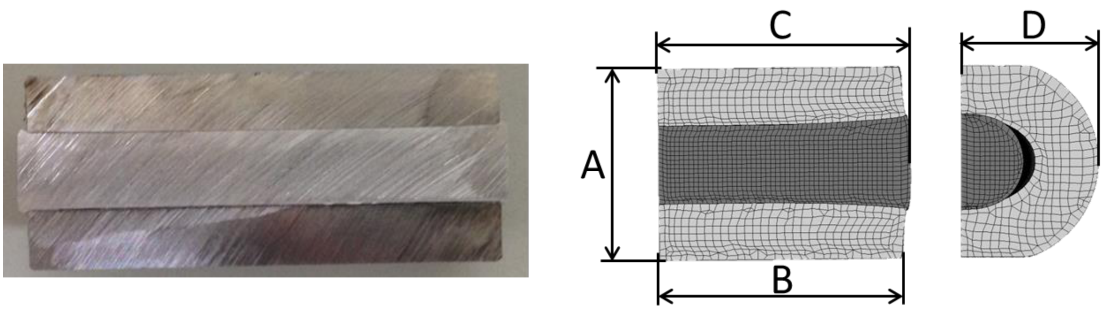


Figure 5: Dimensions of cross section shape after forming



(a) Shape of cross section after the experiment (b) Shape of cross section after the analysis

Figure 6: Comparison of cold experiment and cold analysis

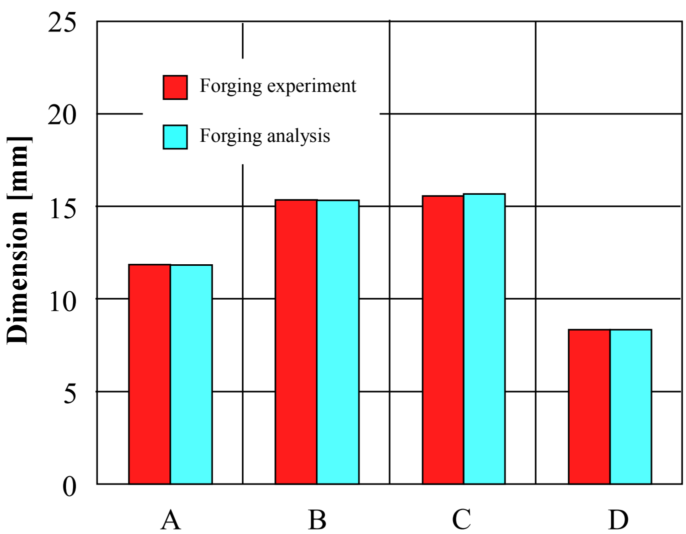


Figure 7: Dimension of cross section shape after cold forming

3 FORMABILITY ASSESSMENT ON BLANK

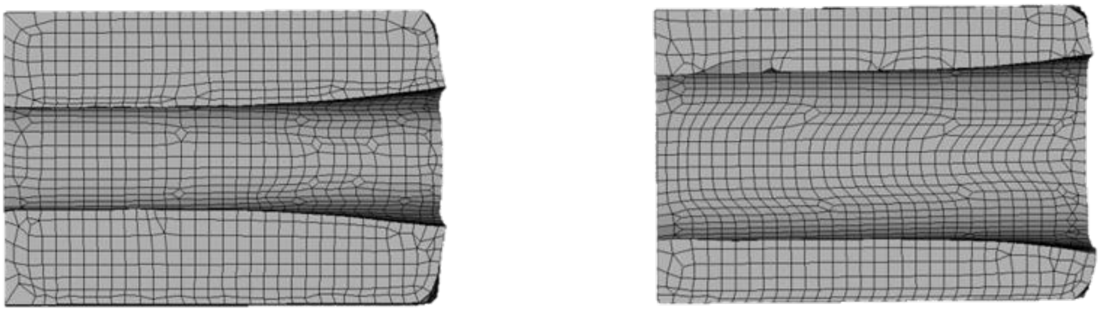
3.1 Numerical analysis

The purpose of this study is to evaluate the effect of the material dimensions on the formability of the forging blank using the analysis method. Therefore, we performed numerical analysis of the blank and stainless steel pipe using the dimensional conditions shown in Table 3. We compare the numerical analysis of the two-metal blank and stainless steel pipe blank and evaluate the formability of the blanks. In the analysis, the temperature of the blank is 293 K, and the stroke is 4.5 mm. The other analysis conditions are similar to the analysis method.

Table 3: Blank dimensional conditions in the analysis

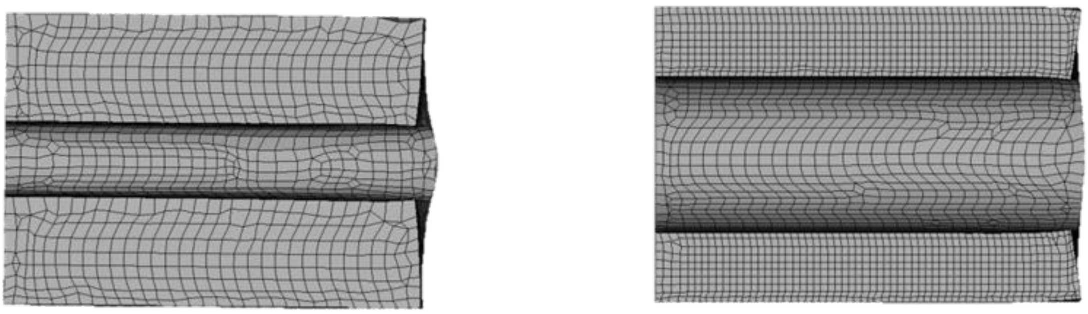
	Stainless steel		Aluminum alloy
	Outer diameter	Inside diameter	
The blank1	15mm	7mm	7mm
The blank2	15mm	10mm	10mm
Stainless steel pipe1	15mm	7mm	
Stainless steel pipe2	15mm	10mm	

In Figures 8 and 9, we show the stainless steel pipe after each numerical analysis using the analysis condition shown in Table 3.



(a) Inside diameter for the 7 mm case (b) Inside diameter for the 10 mm case

Figure 8: Stainless steel after numerical analysis with the two-metal blank



(a) Inside diameter for the 7 mm case (b) Inside diameter for the 10 mm case

Figure 9: Stainless steel after numerical analysis with the stainless steel pipe as the blank

As shown in Figure 8, the inside diameter of the end face was larger than that of the symmetry plane in the case of the two-metal blank. However, the inside diameter of the end face was smaller than that of the symmetry plane in the case of the stainless steel pipe blank. It is thought that the deformation shown in Figure 8 was produced by the aluminum alloy discharging from the pipe. This discharge is produced by applying the compression load. Therefore, we learned that the inside diameter of the end face became larger than that of the symmetry plane due to the discharging of the aluminum alloy in the case of the two-metal blank.

3.2 Verification experiment

In this study, we conducted a verification experiment to validate the analysis result. The verification experiment was conducted for four experimental cases using the same condition as the numerical analysis using a servo press (H1F60, Komatsu). We used stainless steel (SUS304 JIS G4318) and aluminum alloy (A2017 JIS H4040). The stroke in the case of the blank is 2.6 mm, and the stroke in the case of the stainless steel pipe as the blank is 4.5 mm. We show the shape of the cross section after each experiment in Figures 10 and 11.

(a) Inside diameter for the 7 mm case

(b) Inside diameter for the 10 mm case

Figure 10: Shape of cross section after the verification experiment with the two-metal blank

(a) Inside diameter for the 7 mm case

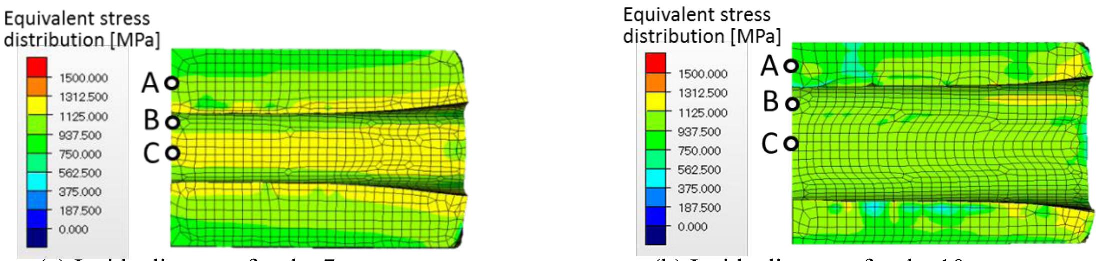
(b) Inside diameter for the 10 mm case

Figure 11: Shape of cross section after the verification experiment with the stainless steel pipe as the blank

As shown in Figure 10, the inside diameter of the end face was larger than that of the symmetry plane in the case of the two-metal blank. As shown in Figure 11, the inside diameter of the end face was smaller than that of the symmetry plane in the case of the stainless steel pipe blank. These deformations were confirmed in the numerical analysis. Therefore, we proved the validity of the analysis results.

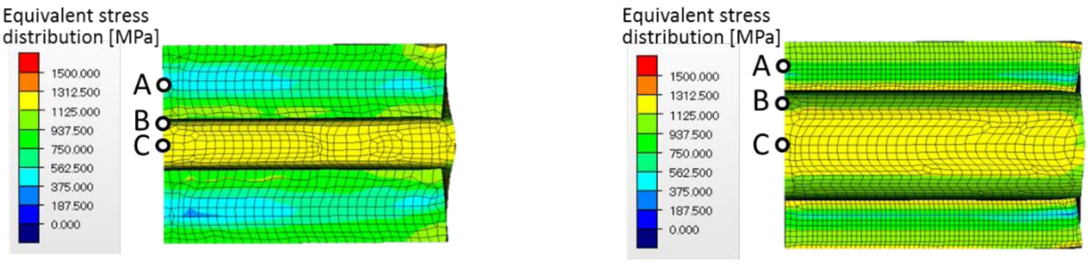
3.3 Equivalent stress distribution

We confirm the equivalent stress distribution in the numerical analysis. We show the equivalent stress distribution after each analysis in Figures 12 and 13.



(a) Inside diameter for the 7 mm case (b) Inside diameter for the 10 mm case

Figure 12: Equivalent stress distribution of stainless steel with the two-metal blank



(a) Inside diameter for the 7 mm case (b) Inside diameter for the 10 mm case

Figure 13: Equivalent stress distribution of stainless steel with the stainless steel pipe used as the blank

As shown in Figure 13, the equivalent stress on the inside was larger than in the other regions in the case of the stainless steel pipe blank. As shown in Figure 12(a), we confirmed the distribution for the blank with an inside diameter of 7 mm. The stress causes failure, but as shown in Figure 12(b), we do not confirm high stresses on the inside for the blank with an inside diameter of 10 mm. The initiation stress is evenness. Therefore, we confirmed the equivalent stress values at points A, B, and C shown in Figures 12 and 13. The equivalent stress values are shown in Figure 14.

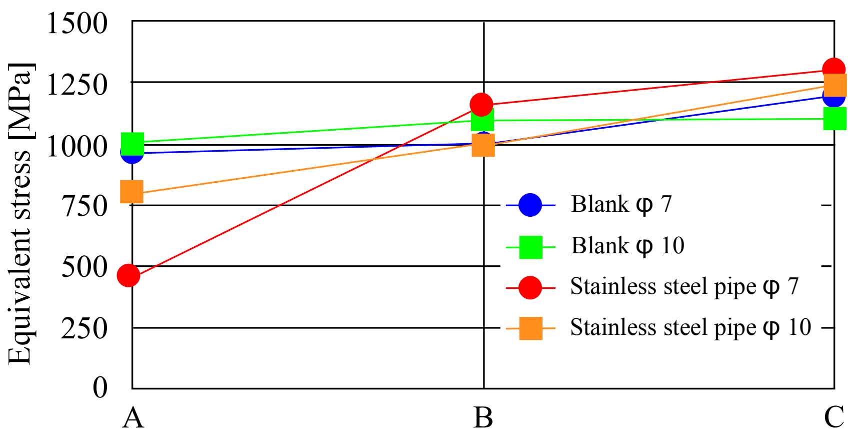


Figure 14: Equivalent stress value for each numerical analysis

As shown in Figure 14, we confirmed the stress to be about the same as the other analysis result for the blank with an inside diameter of 10 mm. However, the stress difference at the three points for the blank with an inside diameter of 10 mm is smaller than that for the other analysis. Therefore, for this pipe, the blank with an inside diameter of 10 mm is effective in forming hollow products.

4 CONCLUSION

(1) We learned that the inside diameter of the end face became larger than that of the symmetry plane due to the discharging of the aluminum alloy in the case of the two-metal blank.
(2) We confirmed that the stress difference in the stainless steel was reduced when the inside diameter was increased.
(3) For this pipe, the blank with an inside diameter of 10 mm is effective for forming hollow products.

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