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Formability of micro sheet hydroforming of ultra-fine grained stainless steel

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Abstract

The formability of ultra-fine grained stainless steel is investigated in micro hydromechanical deep drawing. The materials used are ultra-fine grained stainless steel and SUS304-H with thickness of 20 and 50 μm. The micro cups are successfully fabricated for the ultra-fine grained stainless steel but it cannot be fabricated for SUS304-H with thickness of 20 μm. The fracture type of ultra-fine grained stainless steel foil is the shortage of tensile strength at plain strain state and does not change with a decrease of the thickness. In contrast, the fracture type of SUS304-H foil changes to the bending deformation with decreasing the thickness due to its low ductility. The ultra-fine grained metal foil is required to obtain the high formability and fabricate the sharp micro cups.

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Keywords: Micro sheet hydroforming; Micro hydromechanical deep drawing; Formability; Ultra-fine grain

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1. Introduction

The trend toward of miniaturization of metal components has been growing in the medical, electronic and telecommunication devices. Micro sheet forming is widely used for the fabrication of these micro metal components. However, several problems come up with scaling down into micro scale (Geiger et al., 2001). In micro scale, it is difficult to fabricate the complex shape component due to the difficulty of manufacture of tiny tools especially female die. Moreover, the friction force increases with scaling down because the area in which cannot keep the lubrication increases in micro scale (Putten et al., 2007). Due to this tribological size effect, the formability in micro sheet forming is inferior to that in macro sheet forming. To solve these problems in micro sheet forming, the authors have developed a micro hydromechanical deep drawing (MHDD) in which the fluid pressure is used instead of the female die. Previously, it has been revealed that the friction force can be reduced and the wrinkling can be restricted by applying the fluid pressure in MHDD (Sato et al., 2014). However, the formability at MHDD is not as high as that at macro hydromechanical deep drawing.

When the target size is scaling down, the mechanical properties of metal foil are deteriorated. The ratio of thickness to grain size becomes small with scaling down because the foil thickness becomes thin although the grain size is almost the same. It causes the decrease of material strength and ductility (Fu et al., 2011) and the increase of the surface roughness (Furushima et al., 2014). It is known that these poor mechanical properties decrease the formability in micro sheet forming. Therefore, it is desirable to use an ultra-fine grained metal foil to achieve high formability in micro sheet forming. From these backgrounds, the hydromechanical deep drawing is performed using ultra-fine grained stainless steel to improve the formability. The formability of ultra-fine grained stainless steel foil is compared with that of the normal stainless steel foil and fracture types of each material are clarified.

2. Experimental procedure

The material used is the ultra-fine grained stainless steel foil of with thickness of 20 and 50μm. The average grain size is 1.88μm and 2.29μm, respectively. As a comparison material, the normal stainless steel was used. The mechanical properties of the materials used are listed in Table 1.

A micro hydromechanical deep drawing machine shown in Fig. 1 was used. In this machine, the pressure generation, blanking, drawing and knockout process can be performed in the same axis to improve the handing of tiny workpiece. A pump with maximum fluid pressure of 20MPa was used. The tooling dimension of MHDD is shown in Fig. 3. The sharp punch shoulder radius (r_p=0.1mm) was employed. The drawing ratio is DR=(D_o/D_p=)1.74. The constant gap method was employed in which the blank holder is fixed. The forced pressurization was used in which the fluid pressure is continually applied during the MHDD process. A machine oil was used for the fluid medium and a high viscosity lubricant was applied to the blank surface of die side. The punch speed was set up at 0.4mm/s.

3. Results and discussion

3.1. Drawn micro cups

Fig. 3 shows the effect of fluid pressure on success and fracture of micro cups at each material. The micro cups were successfully fabricated at ultra-fine grained stainless steel of with thickness of 20 and 50μm and SUS304-H with thickness of 50μm. In all of the materials, the fracture occurs with an increase of the fluid pressure. It is because the friction force between the blank and blank holder increases (Sato et al., 2014). However, the micro cup cannot be fabricated for SUS304-H with thickness of 20μm. The appearance of each micro cup is shown in Fig. 4. The micro cups cannot be fabricated for the normal SUS304-H foil when the thickness is reduced to 20 μm, although it can be successfully fabricated at ultra-fine grained stainless steel foil with a thickness of 20 μm. It was found that the formability of ultra-fine grained stainless steel becomes higher than that of normal stainless steel when the foil thickness decreases.

For ultra-fine grained stainless steel with thickness of 20 and 50μm and SUS304-H with thickness of 50μm, the fracture occurs at punch shoulder after the cylindrical part was fabricated at side wall. It seems that the fracture was caused by the shortage of strength at punch shoulder which is the typical fracture type in conventional deep drawing. On the other hand, for the SUS304-H with thickness of 20μm, the fracture occurs before the material fits in the punch shoulder and the cylindrical part at side wall is fabricated. The fracture type of SUS304-H foil with thickness of 20μm is different from the other materials and thicknesses.

Table 1. Mechanical properties of used materials.

	Yield stress (MPa)	Tensile strength (MPa)	Elongation (%)
Ultra-fine grained stainless steel of 50μm in thickness	522	875	46
Ultra-fine grained stainless steel of 20μm in thickness	537	800	26
SUS304-H of 50μm in thickness	1217	1334	2.4
SUS304-H of 20μm in thickness	1238	1461	0.6

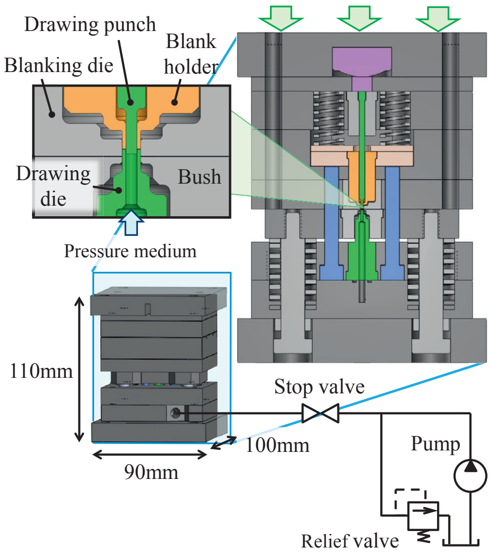

Fig. 1. MHDD tool set and systems.

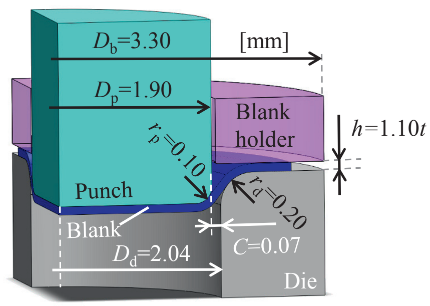

Fig. 2. Tooling dimension of MHDD.

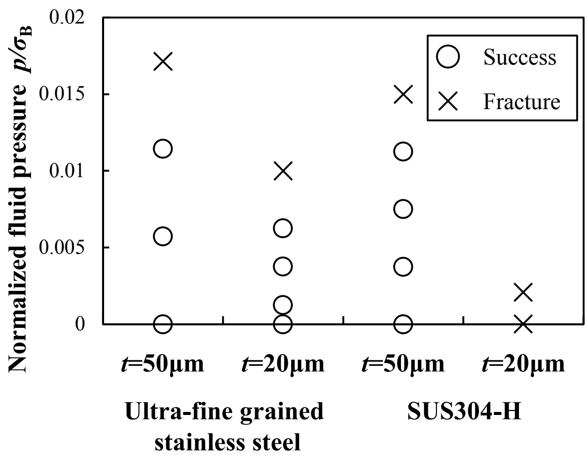

Fig. 3. Effect of normalized fluid pressure on success and fracture of micro cups at each material.

3.2. Analysis of fracture type at each material

To reveal the main factor of the fracture at each material, the measured punch force was compared using the tensile strength. During the deep drawing process, the material at side wall is subjected to the plain strain deformation. Normally, the fracture occurs when the stress applied to material reaches the tensile strength at plain strain state. The tensile strength at plain strain state can be expressed by 1.15 times of tensile strength σ_B obtained by the tensile test. Fig. 5 shows the relationship between fracture by shortage of tensile strength at plain strain state and fracture at each material. For ultra-fine grained stainless steel foil, as the fluid pressure increases, the normalized punch force increases and fracture occurs when the normalized punch force reaches one at both thicknesses. This means that the fracture occurs by the shortage of tensile strength at plain strain state. Ultra-fine grained stainless steel shows the typical fracture type in the conventional deep drawing. On the other hand, SUS304-H foil was fractured before the normalized punch force reaches one. It was revealed that the fracture types of ultra-fine grained and normal stainless steel foil are different.

Fig. 6 shows the effect of punch shoulder radius on success or failure at SUS304-H of 20μm thickness. Although the micro cup cannot be fabricated at r_p=0.1 mm, it can be fabricated by increasing the punch shoulder radius to r_p=0.2mm. At the small punch shoulder radius, the outside of material is subjected to the strict tensile deformation by the bending. The ductility of material has to be large enough for this tensile deformation by the bending. However, the ductility of SUS304-H with thickness of 20μm is much lower than the other materials. Therefore, the fracture is resulted by the bending deformation due to its low ductility. In contrast, at the large punch shoulder radius, the bending deformation at punch shoulder decreases and the material is not subjected the strict tensile deformation. This is the reason why the micro cup can be fabricated by increasing the punch shoulder radius at SUS304-H with thickness of 20 μm. In short, the decrease of ductility with a decrease of the foil thickness changes the fracture type from the shortage of tensile strength to the strict bending deformation. From these results, it can be said that the ultra-fine grained stainless steel has a high formability even with scaling down, and it is useful to fabricate the sharp micro cup as compared with the normal stainless steel.

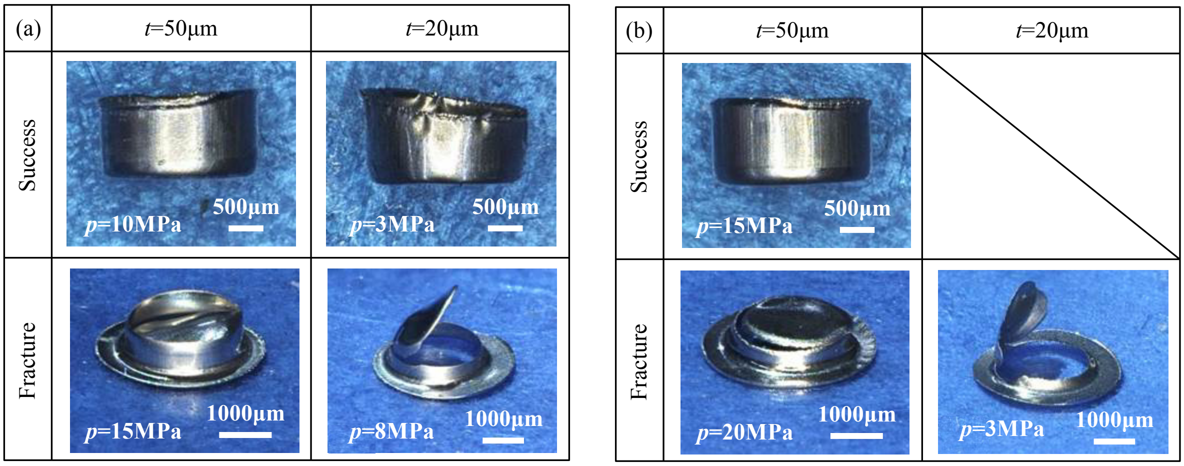

Fig. 4. Appearance of drawn and fractured micro cups in MHDD at 0.1mm punch should radius (a) using ultra-fine grained stainless steel, (b) using SUS304-H.

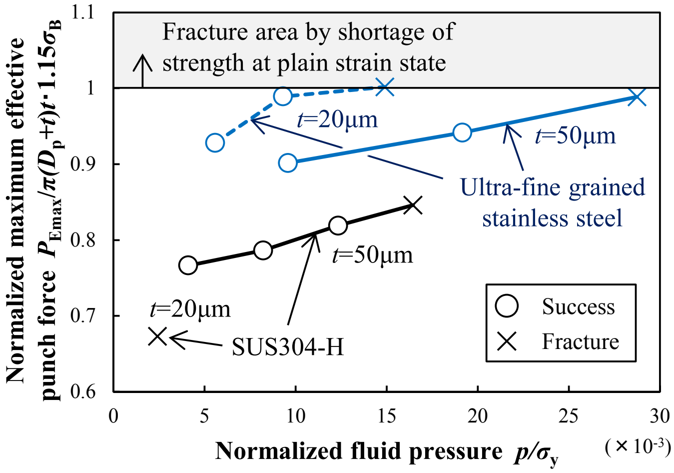

Fig. 5. Relationship between fracture by shortage of tensile strength at plain strain state and fracture at each material.

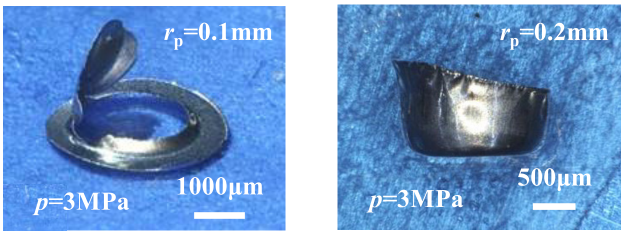

Fig. 6. Effect of punch shoulder radius on success or failure at SUS304-H with thickness of 20μm.

4. Conclusion

The ultra-fine grained steel was used in the micro hydromechanical deep drawing to clarify its formability. As a comparison material, the normal stainless steel (SUS304-H) with thickness of 20 and 50μm was used. As a result, the micro cups were successfully fabricated at ultra-fine grained stainless steel even at thickness of 20μm although it cannot be fabricated at SUS304-H. It was clarified that the formability of ultra-fine grained stainless steel is higher than that of SUS304-H. The fracture type of the ultra-fine grained stainless steel foil is the shortage of strength at plain strain state which is the typical fracture type in the conventional deep drawing. In contrast, for the SUS304-H, the fracture type is changed to the bending deformation with a decrease of the foil thickness. The decrease of ductility with a decrease of the foil thickness causes this difference of fracture types and formability of metal foil. Therefore, the use of ultra-fine grained metal foil is desirable for micro sheet forming to obtain the high formability and fabricate the sharp micro cups.

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