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Improvement of formability in deep drawing of ultra-high strength steel sheets by coating of die

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ABSTRACT

The formability of deep drawn ultra-high strength steel sheets in dies coated with either titanium nitride (TiN) or Vanadium carbide (VC) at different drawing speeds and ironing ratios was investigated. TiN was deposited via chemical vapour deposition and physical vapour deposition (PVD) while thermal diffusion was used for VC deposition. In non-coated dies, seizure occurred on both surfaces of the die and the side wall of the drawn cup irrespective of the deep drawing conditions. The deep drawability is improved with coating of die. Whereas in coated dies, seizure became significant only during deep drawing extreme conditions of 120 mm/s for TiN-coated dies; and this was prevented in VC-coated dies across all drawing conditions. The VC-coated die was suitable for deep drawing of ultra-high strength steel sheets. The delayed fractured observed in the ultra-high strength steel cups occurred for a large amount of ironing ratio and drawing speeds; and this can be prevented by appropriate heat treatment.

1. Introduction

To reduce fuel consumption of automobiles, the reduction in weight of body panels is intensively required in automobile industry (Kleiner et al., 2003). The strength of high strength steel sheets increases, and ultra-high strength steel sheets more than 1 GPa have been used. The ultra-high strength steel sheets are generally formed into automobile body panels by hot or cold stampings. In the hot stamping, the formability and flow stress of the sheet are increased and reduced by heating, respectively, and then defects such as large springback and fracture are prevented. However, the productivity is not high due to the ejection from the furnace and the die quenching (Mori, 2012). On the other hand, the sheet in the cold stamping is formed in the low formability and high flow stress although the productivity is high.

In the cold stamping of ultra-high strength steel sheets, the bending is conventionally used. In the bending, the springback and fracture tend to occur. The springback is large due to the high strength, and the dimensional accuracy of the formed products deteriorates. To decrease the springback, the finishing reduction at the bottom dead centre in bending (Mori et al., 2007) was developed. In the bending of concave sheet, the fracture tends to occur because the tensile stress is generated around the edge of the corner (Wang and Wenner, 1974). The limit of fracture is improved by controlling microstructure and heat treatment (Hasegawa et al., 2004). The effect of the quality of sheared edge on the fracture was investigated by Sartkulvanich et al. (2010), Mori et al. (2010) developed a smoothing of sheared edge to improve the quality. In addition, Abe et al. (2013) proposed the relaxation of tensile stress in the bending using gradually contacting punch. The springback and fracture are prevented in the bending ultra-high strength steel sheets. On the other hand, wrinkling tends to occur in the bending of convex sheet because the compressive stress is generated around the edge of the corner (Wang et al., 1974). The seizure tends to occur when the wrinkles are compressed by the tools. The phenomenon is accelerated by high strength of the sheet, and thus the utilisation of ultra-high strength steel sheets is limited (Yao, 2011).

In automobile industry, stamping including deep drawing in addition to bending for the ultra-high strength steel sheets is desirable to form complex shape panels. Wang et al. (2011) showed that the limiting drawing ratio of the ultra-high strength steel was about 2.1, and then the drawability of the ultra-high strength steel sheets is not low. However, Takagi et al. (2012) showed that the delayed fracture of the formed ferrite-martensite dual phase steel parts tends to occur under high stress and high diffusible hydrogen content condition. The ferrite-martensite dual phase steel sheets are conventionally used in the automobile industry, and then the effects of actual forming conditions on the critical delayed fracture are still unclear.

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Nomenclature

c	clearance between punch and die
d	diameter of punch
n	number of products
r	ironing ratio
t_0	thickness of blank
v	drawing speed
x	distance from bottom centre
z	distance from cup bottom

On the other hand, Shahani and Salehinia (2008) indicated the problem of the occurrence of the seizure during deep drawing. During deep drawing, the movement of the blank into the die cavity induces compressive circumferential stresses in the flange, which tends to cause the flange to wrinkle during drawing as well as shrink flanging. The prevention of the occurrence of seizure during deep drawing is desired. Kim et al. (2007) evaluated the occurrence of the seizure in the mild steel sheet by the deep drawing test, and then Kim et al. (2009) applied to the evaluation of the high strength steel sheets. The deep drawing test is useful for evaluating the occurrence of the seizure in the ultra-high strength steel sheets. Although CrN coating of die is effective for 980 MPa steel sheets (Sresomroeng et al., 2011), the effect of coating of dies on the seizure resistance and deep drawability of ultra-high strength steel sheets is still unclear.

In the present study, the effect of coating of dies on deep drawability of ultra-high strength steel sheets was investigated under different conditions. This attempt represents an effort towards increasing the life span of the drawing die and also improves the quality of the surface finish of the deep drawn cup.

2. Conditions of deep drawing using coated dies

The material properties of ultra-high strength steel sheets are shown in Table 1. The sheets are 1.2 mm thickness of cold-rolled ones conventionally used for automobile parts, and are made of ferrite-martensite dual-phase steel. The mechanical properties of the sheets were measured from the tensile test. The specimens were cut in the 0°, 45° and 90° directions with respect to the rolling direction of the sheet, and the averages of the measured values are shown. The ultra-high strength steel sheets have the tensile strengths above 1 GPa. The limiting drawing ratio was measured by the deep drawing with 34 mm diameter of punch and 37 mm diameter of die.

The die-set used for deep drawing using coated dies is illustrated in Fig. 1. The die-set was installed into a 800 kN mechanical servo press. The blankholder force was generated by 4 gas springs. The punch force was measured by the load cell on the punch head. The temperatures of drawn cup and die corner were measured by the 2 thermographies.

The conditions of deep drawing are given in Fig. 2 and Table 2. The diameter of the circular blank is 70 mm at limiting drawing ratios of both sheets. The drawing speed v was between 8.3 and 120 mm/s. The occurrence of seizure was accelerated in deep drawing involving ironing of the side wall of cup. The ironing ratio r is given by Eq. (1), where t_0 and c are the thickness of the blank and the clearance between the punch and die, respectively.

Table 1
Material properties of ultra-high strength steel sheets.

Sheet	Tensile strength [MPa]	Elongation [%]	n-Value	Limiting drawing ratio	Surface roughness [μm Ra]
980 MPa	1008	11.4	0.12	2.06	0.46
1180 MPa	1215	8.2	0.10	2.06	0.58

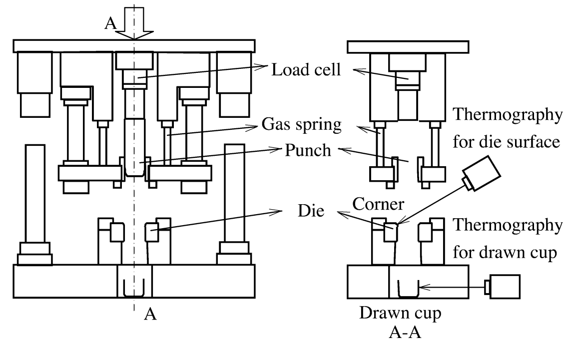

Fig. 1. Die-set used for deep drawing using coated die.

Table 2
Conditions of deep drawing.

Ironing ratio r [%]	Drawing speed v [mm/s]	Lubricant
−25, 0, 15, 20, 25	8.3, 15, 20, 40, 80, 120	Rust-preventive oil (5 mm²/s at 40 °C)

Table 3
Surface roughness and Vickers hardness of coating.

Die	Surface roughness in die land		Vickers hardness [HV]	Coating thickness [μm]
	Arithmetic mean [μm Ra]	Maximum height [μm Rz]		
Tool steel	0.03	0.19	815	0
TiN coated (CVD)	0.03	0.34	2500	4.0
TiN coated (PVD)	0.03	0.43	3000	3.1
VC coated	0.02	0.12	2700	6.0

$$r = \frac{t_0 - c}{t_0} \quad (1)$$

The clearance was increased by the large diameter of the punch d for 37 mm in diameter of the die. The lubricant having a 5 mm²/s viscosity of a rust-preventive oil was applied on the die side of the blank. Each deep drawing test was performed at least two times to prevent the scatter of results. In repeated forming, the blanks were manually fed 100 times, and the number of strokes per 1 min was approximately 5.

The die is made of the tool steel SKD11, and then the polished die surface is coated. The surface roughness and Vickers hardness of coated die are given in Table 3. TiN-coated dies are deposited by physical and chemical vapour depositions, respectively. In TiN-coated by physical vapour deposition, the deposition temperature is about 500 °C. In TiN-coated by chemical vapour

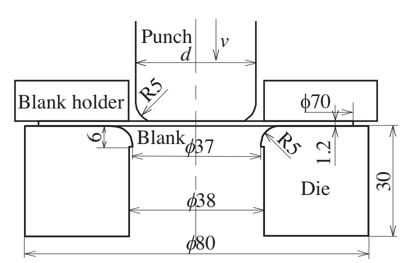

Fig. 2. Conditions of deep drawing using coated die.