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Study on Application of "JAZ*" (JFE Advanced Zinc) to High-Strength Galvannealed Steel Sheet†

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Abstract:

Influence of "JAZ"(JFE Advanced Zinc), which was developed by JFE Steel, on press formability of high-strength galvannealed steel sheet was investigated. Friction coefficient of "JAZ*" is lower than that of conventional galvannealed steel sheet when it is applied to high-strength galvannealed steel sheet under simulating conditions of press forming of automobile body parts. In laboratory-scale press-forming tests, it was found that the press formability of high-strength galvannealed steel sheet improved by the application of "JAZ*." It can be estimated that the effect of "JAZ*" on press formability is 2–4% in elongation and 0.2–0.3 in Lankford value (r-value). In addition, high-strength galvanealed steel sheet with "JAZ*" technology shows excellent press formability in actual press-forming tests.*

1. Introduction

In order to satisfy both crashworthiness and auto body weight reduction, application of high strength steel sheet to the automobile body structural parts has been increasing in recent years. In addition to the above, in the case that corrosion resistance is also required, high strength galvannealed steel sheet (hereinafter, GA) is used frequently for the parts. However, the use of high-strength GA has been limited because it is known that the mechanical properties such as elongation and Lankford value (hereinafter, *r*-value) affecting press-formability decrease with increasing of tensile strength in steel sheets. Therefore it is considered that improvement of press formability is the most important issue for expanding the application of high strength GA to automobile parts. One-way to improve the press formability of high-strength GA is to control the microstructures of the steel for having high elongation or high-*r*-value as reported by various papers[1)]. It is also expected that to reduce the friction coefficient of the GA surface improve the press formability as another way.

Up to now, much research and development work based on mild steel has been done for reducing the friction coefficient of GA, and some of them were applied for automotive body parts practically. Double-layered GA[2)] in which Fe-Zn electroplating is performed on the GA top layer, thin film type Ni-Fe-O lubrication treatment[3)], and phosphate based films[4)] are the some of the examples. On the other hand, based on a completely different concept from the conventional method, JFE Steel has been developed a new highly lubricated GA called "JAZ*" (JAZ: JFE Advanced Zinc). "JAZ*" has nano-scale modified layer on the surface[5–7)], which contribute to a high sliding property and excellent press formability. Press formability of "JAZ*" is superior to that of conventional GA, while other properties such as weldability, phosphatability and so on are on the same level as conventional GA[8,9)].

Using mild steel as the base material, "JAZ*" has been already used by a large number of automakers. Mass production systems for "JAZ*" also have been established at a total of 5 lines of JFE Steel as well as at ThyssenKrupp Steel AG (Germany) and Guangzhou JFE Steel Sheet (China) by providing the mass production technology from JFE Steel. Besides production at JFE Steel Galvanizing (Thailand) is scheduled for supplying this product more globally.

This paper describes the sliding property and press

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formability when "JAZ*" is applied to high strength GA.

2. Sliding Characteristics

2.1 Sliding Characteristics Required in Steel Sheets for Automotive Parts

Due to the complex shapes of automotive parts, it is known that sliding conditions differ depending on the shape and position of part. As shown in **Fig. 1**, Higai et al. analyzed the sliding speed and contact pressure of positions with risk of fracture in press forming of representative automotive parts (total of 10 positions in 6 type parts). They classify sliding conditions into the following 3 large groups[10].

The first, Group A, is inflow positions where the material passes the bead. The sliding speed is high, at 200–1 000 mm/min, and contact pressure is also high, at 50–150 MPa.

The second, Group B, is positions in which the contact area is comparatively large, where the material moves on the die shoulder or surface, as in drawing and stretch forming. Here, the sliding speed is 60–500 mm/min, and contact pressure is 4–20 MPa.

The third, Group C, comprises positions where material moves slightly on top of the die and contact pressure is extremely low, as in stretch forming. Here, the sliding speed is slow, at 10–40 mm/min, and contact pressure is also low, being 1–15 MPa.

Based on the fact that the sliding distance of the material is comparative long in Groups A and B, Higai et al. showed that the dynamic friction coefficient is controlling for these groups, and because the sliding distance is short in Group C, the static friction coefficient is controlling in this case[10].

In other words, by conducting sliding tests for 3 conditions corresponding to Groups A–C in Fig. 1, it is considered to evaluate the sliding characteristics necessary in press-forming of automotive parts.

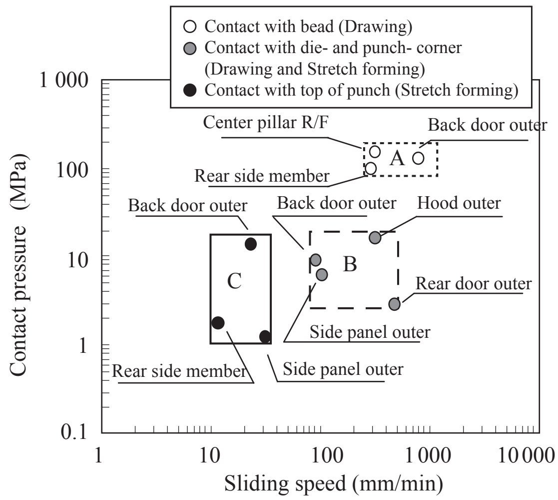
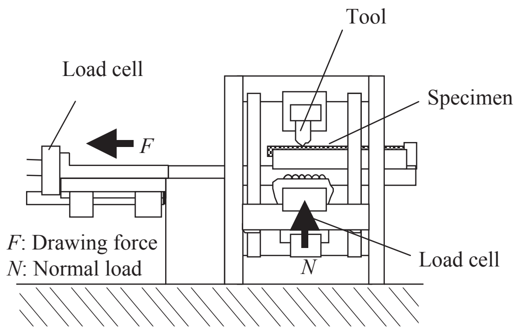


Fig. 1 Relationship between sliding speed and contact pressure of press forming of typical automobile body parts

2.2 Sliding Characteristics of High Strength GA Having "JAZ*" Layer

Using a mild steel sheet and 590 MPa, 980 MPa of tensile strength grade steel sheets (in all cases, thickness: 1.2 mm) as the base material, the friction coefficients of conventional GA and "JAZ*" were measured



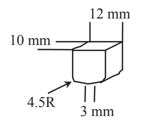
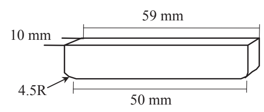
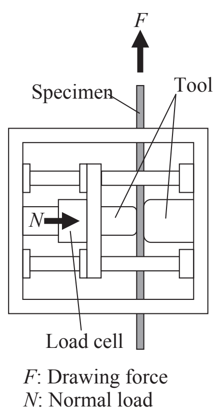
	Condition A	Condition B
Kind of test	Flat sliding	Flat sliding
Kind of friction coefficient	Dynamic	Dynamic
Geometries of test tools		
Tool material	SKD11 (JIS G 4404)	SKD11 (JIS G 4404)
Contact area	3×10 mm	50×10 mm
Sliding length	100 mm	100 mm
Contact pressure	130.4 MPa	7.8 MPa
Sliding speed	1 000 mm/min	200 mm/min

Fig. 2 Schematic diagram of the flat sliding friction test and testing conditions



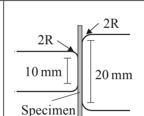
	Condition C
Kind of test	Drawing
Kind of friction coefficient	Static
Geometries of test tools	
Tool material	SKD11 (JIS G 4404)
Contact area	10 × 30 mm
Sliding length	20 mm
Contact pressure	7.0 MPa
Sliding speed	10 mm/min

Fig. 3 Schematic diagram of the drawing friction test and testing conditions

under conditions A−C, corresponding to the above-mentioned Groups A−C. With conditions A and B, measurements were conducted using the flat sliding test machine under the test conditions shown in **Fig. 2**. The dynamic friction coefficient (μ) is obtained by measuring the normal load (N) and the drawing force (F) and calculating $\mu = F/N$.

With condition C, measurements were made using the draw sliding test machine under the test conditions shown in **Fig. 3**. The normal load, N and F were measured in the same manner as above, but unlike the flat sliding test, the tool was forced from both the front and back sides. Therefore, the static friction coefficient (μ') was calculated by $\mu' = F/2N$. In these tests, commercial washing oil was used as the lubricating oil. This oil was coated on the specimens after ultrasonic degreasing of the specimens with alcohol. The viscosity and density of the washing oil were 2.0 mm^2/s at 40°C and 0.82 g/cm^3, respectively.

The friction coefficients for conditions A, B, and C were shown in **Figs. 4-6**, respectively. Under all conditions, "JAZ*" showed lower friction coefficients than the conventional GA in all tensile strength level of base material. In addition, the friction coefficient of "JAZ*" is almost same independent of kind of base material. This shows that "JAZ*" can be applied to high strength GA, and improved press-formability can also be expected in case of application to high strength GA.

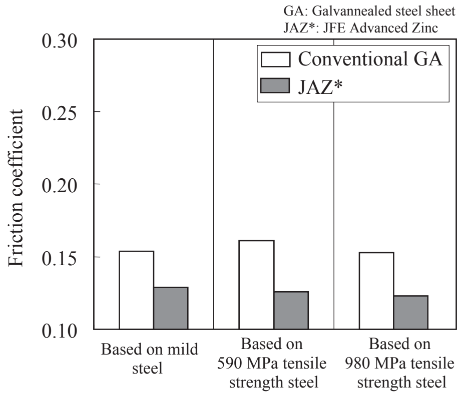


Fig. 4 Friction coefficient of "JAZ*"under Condition A

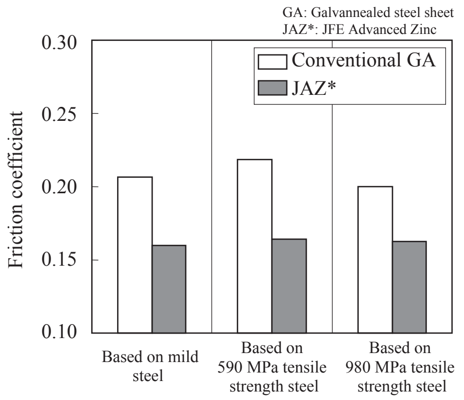


Fig. 5 Friction coefficient of "JAZ*"under Condition B

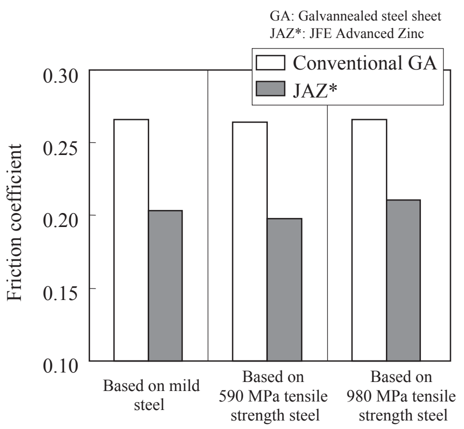


Fig. 6 Friction coefficient of "JAZ*"under Condition C

2.3 Effect of Contact Pressure on Friction Coefficient

The contact pressure with the die in actual press forming is affected not only by the shape of the formed part, but also by the tensile strength of the base material. Contact pressure tends to increase with higher tensile strength of the base materials. Therefore, the effect of contact pressure on the friction coefficients for conventional GA and "JAZ*" were investigated by changing the contact pressure in condition A. Lubricating oil coating was performed in the same manner and washing oil as explained in the previous section.

The measurement results were shown in **Fig. 7**. With both conventional GA and "JAZ*," a tendency in which the friction coefficient decreases with increasing of contact pressure can be seen. In explaining this, it can be thought that the effect of trapping of the lubricating oil becomes more remarkable as contact pressure increases[11]. On the other hand, when conventional GA and "JAZ*" are compared at the same contact pressure,

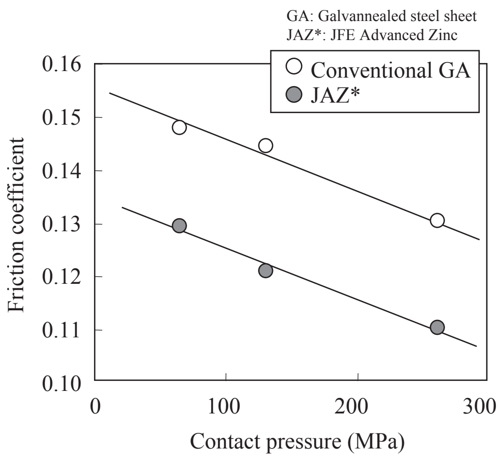


Fig. 7 Effect of contact pressure on friction coefficient under modified Condition A

the difference between the two materials is almost the same in the contact pressure range of 65–260 MPa. This shows that "JAZ*" has excellent sliding characteristics even under high contact pressure conditions, assuming the case of press forming of high strength steel sheet.

2.4 Lubrication Mechanism

In order to elucidate the mechanism of improved lubrication with "JAZ*," the friction coefficient of "JAZ*" was measured without oil under condition A. The results of evaluation of the friction coefficient are shown in **Fig. 8**, and a drawing force chart is shown in **Fig. 9**. Even in a non-oil coated condition, "JAZ*" displays a lower friction coefficient in comparison with conventional GA. Oscillatory up-and-down variation can be observed in the load chart measured during sliding of conventional GA. This is considered to be the result of repeated sticking with the bead and sliding (stick-slip phenomenon), due to the high sticking property between the conventional GA surface and the bead. In comparison with conventional GA, this variation is substantially reduced with "JAZ*," even under the non-oil coated condition.

Based on this, it can be estimated that the surface modified layer of "JAZ*" itself suppressed sticking between the GA and the tool.

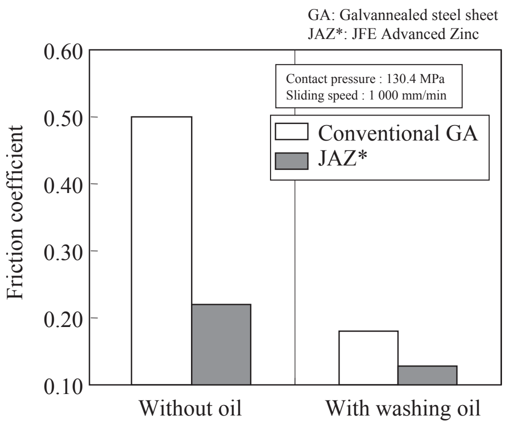


Fig. 8 Friction coefficient of "JAZ*" without oil

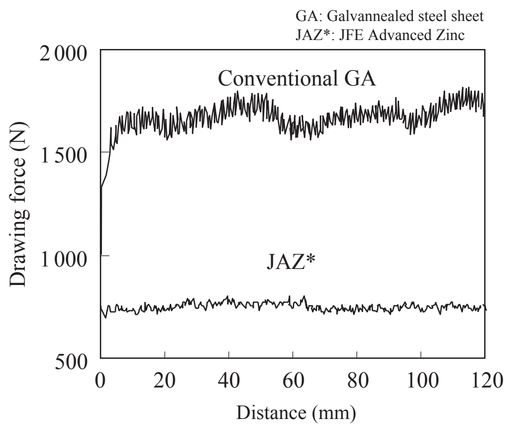


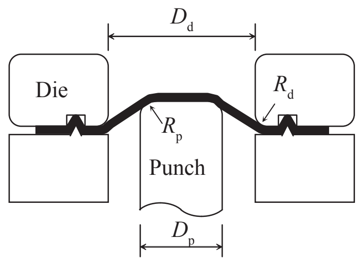
Fig. 9 Evolution of drawing force during sliding test without oil

3. Press-Formability

3.1 Press-Formability with Small-Scale Model Test

3.1.1 Stretch-formability

Stretch forming test was conducted in order to verify the effect of application of "JAZ*" to high strength GA. To eliminate the effect of mechanical properties, test specimens were prepared by "JAZ*" treatment in the laboratory on the surface of high strength GA produced in actual mill. As base materials, high strength GA (thickness: 1.2 mm) with tensile strengths from 440 MPa to 980 MPa and different elongation properties were used. Measurements were performed with a punch having a diameter of 100 mm and shoulder radius R_p of 10 mm and a die with a diameter of 153 mm, as shown in the schematic diagram in **Fig. 10**. Stretch-formability was evaluated by the limiting dome height (hereinafter, LDH). A lock bead was placed on the blank holder to prevent material inflow from the flange. Lubricating oil coating was performed with washing oil in the same manner as above.



D_p	φ100 mm
R_p	10 mm
D_d	φ153 mm
R_d	10 mm
Blank holding force	980 kN

Fig. 10 Schematic diagram of conical stretch forming test

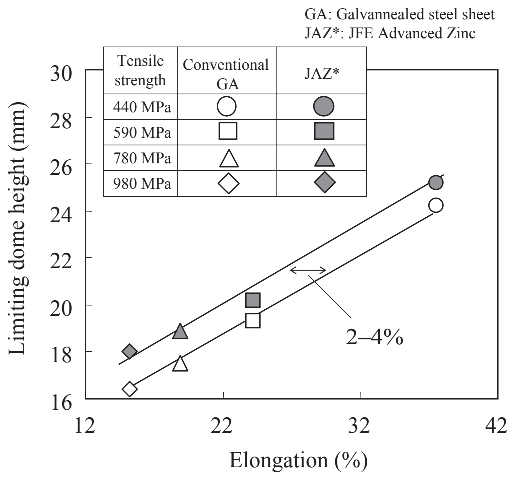
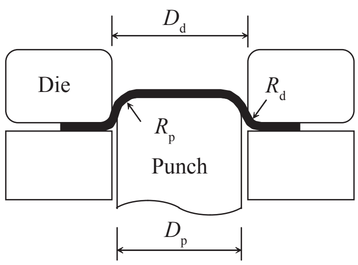


Fig. 11 Influence of elongation on limiting dome height in conical stretch forming

Figure 11 shows the relationship between the elongation of the steel sheet and the LDH in the conical stretch-forming test. The LDH shows an increasing tendency with increasing elongation, and a good correlation between elongation and the LDH was observed. Moreover, when "JAZ*" was applied to high strength GA, the LDH at the same elongation is higher in comparison with the conventional GA, showing that application of "JAZ*" improves stretch-formability of high strength GA. The reason is considered that outflow of the base material from the punch contact area was promoted because of sliding resistance decrease. From this result, the effect of applying "JAZ*" to high strength GA is estimated as equivalent to 2–4% when converted to elongation.

3.1.2 Deep-drawability

Deep drawing test was conducted in a similar manner using mild and high strength GA (thickness: 1.2 mm) with tensile strengths from 270 MPa to 980 MPa and different *r*-values as the base material. Tests were performed using a deep drawing test machine (50 t). As shown in the schematic diagram in **Fig. 12**, a punch having a diameter of 50 mm and shoulder radius R_p of 5 mm and a die with a diameter of 53 mm and a shoulder radius R_d of 8 mm were used. The test materials were processed into circular specimens with different diameters, and formability was evaluated by changing the blank holding force in the range of 4.9–88.2 kN. In deep drawing, it is known that fractures generally tend to occur easily as the blank holding force increases, and conversely, wrinkles tend to occur easily when the blank holder force decreases. Circular specimens were formed, and whether each formed specimen had fractures or wrinkles was evaluated as shown in the schematic diagram. From the obtained maximum blank diameter without both defects and the punch diameter (50 mm), as the ratio of them the limited drawing ratio (hereinafter, LDR) was calculated in **Fig. 13**. As in the previous experiments, washing oil was used as the lubricating oil.



D_p	φ50 mm
R_p	5 mm
D_d	φ53 mm
R_d	8 mm

Fig. 12 Schematic diagram of deep drawing test

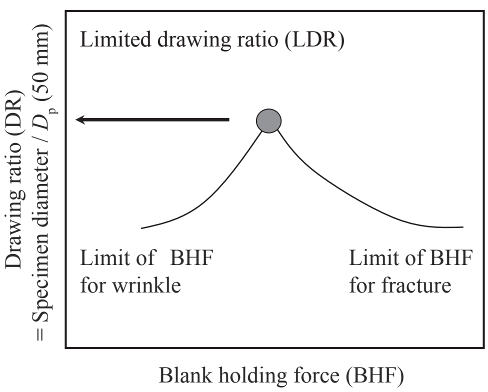


Fig. 13 Schematic diagram of method of evaluating limited drawing ratio

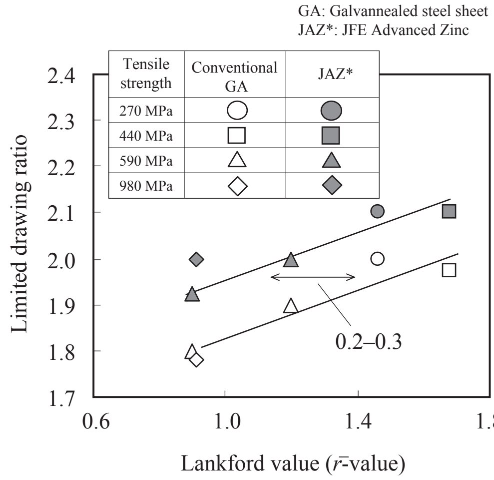


Fig. 14 Influence of Lankford Value (*r*-value) on limited drawing ratio in deep drawing

Figure 14 shows the relationship between the *r*-value and LDR. The limited drawing ratio shows an increasing tendency as the *r*-value increases, independent of the tensile strength of the base material. Furthermore, at the same *r*-value, LDR is increased by application of "JAZ*" to high strength GA in comparison with conventional GA, showing that application of "JAZ*" to high strength GA improves deep drawability. The reason is considered that inflow of the base material from the flange area is promoted because of sliding resistance decrease. Based on this result, the effect of application of "JAZ*" to high strength GA can be estimated as equivalent to 0.2–0.3 when converted to the *r*-value.

3.2 Actual Press-Formability Using Model Dies

3.2.1 Model of rear side member

An actual press-forming test was performed with conventional GA and "JAZ*" produced on an actual mill, based on 590 MPa of tensile strength grade steel sheet having approximately the same mechanical properties. Forming was performed with a 1 200 t single action mechanical press machine using a model rear side member of actual part scale. The test was performed while varying the blank holding force in pressing, and the occurrence of fractures and wrinkles in the formed

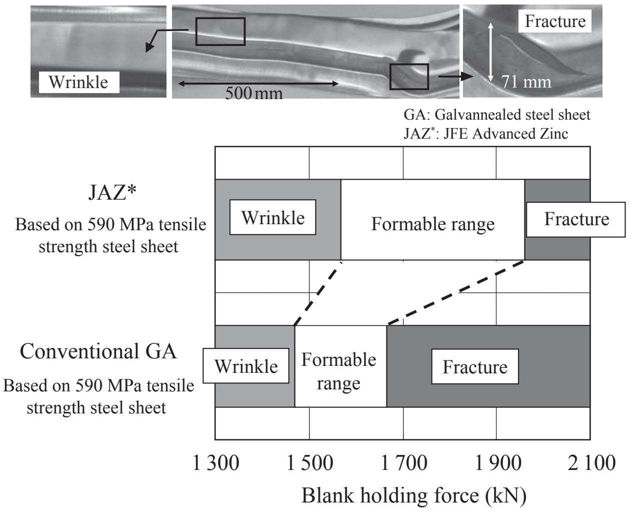


Fig. 15 Formable range of blank holding force measured in actual press forming of the model rear side member

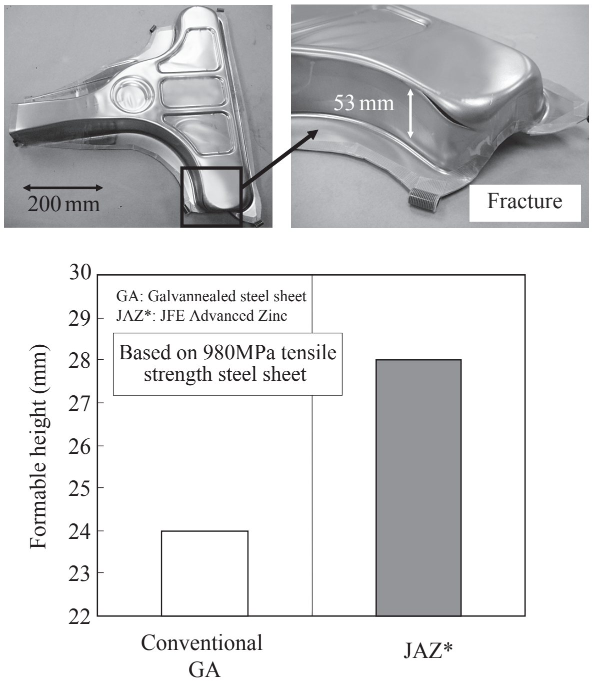


Fig. 16 Formable height without fracture in actual press forming of the model center pillar

parts was observed. Here, a wider formable range without occurrence of either fractures or wrinkles indicates higher press-formability.

Figure 15 shows the formable range of the test materials. In comparison with conventional GA, "JAZ*" has a wider formable range. It is clear that "JAZ*" has superior press-formability in comparison with conventional GA.

3.2.2 Model of center pillar

An actual press-forming test was performed in the same manner with conventional GA and "JAZ*" produced on an actual mill based on 980 MPa of tensile strength grade steel sheet having approximately the same mechanical properties. Forming was performed with the 1 200 t single action mechanical press machine, using part of a model center pillar of actual part scale. The formable height without occurrence of fracture was evaluated by varying the forming height by controlling the stroke from the bottom dead point. Here, a higher formable height without fracture indicates higher press-formability.

Figure 16 shows the formable height without fracture of the test materials. In comparison with conventional GA, "JAZ" has a higher formable height. "JAZ*" clearly possesses superior press-formability in comparison with conventional GA.

4. Conclusion

Automotive applications of high strength GA have been expanded in recent years. In order to improve the press-formability of high strength GA, application of "JAZ*," which has excellent sliding characteristics, to high strength GA was studied in this paper, and the following conclusions were obtained.

(1) "JAZ*" can be applied to high strength GA as well as mild GA and displays excellent sliding characteristics under the sliding conditions required with automotive steel sheets. Obtained friction coefficients of "JAZ*" are almost same independent of the tensile strength of base material.

(2) As effects of application of "JAZ*" to high strength GA, when converted from the results of small-scale model forming evaluations to mechanical properties, the estimated effect is equivalent to an improvement of 2–4% in elongation and 0.2–0.3 in the *r*-value.

(3) Improved formability by application of "JAZ*" to high strength steel sheet were also observed in actual-scale press evaluation tests using 590 MPa and 980 MPa of tensile strength grade steel sheets as a base material.

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