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Hot stamping of high-strength aluminium alloy aircraft parts using quick heating

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ABSTRACT

To improve the formability and productivity in conventional cold stamping of high-strength aluminium aircraft parts, a hot stamping process of heat-treatable aluminium alloy sheets using quick heating below the solution treatment temperature was developed. Quick heating just before forming has the function of producing sufficient strength increase in subsequent artificial ageing. This leads to the elimination of solution treatment and sizing processes for cold stamping. The effect of heating conditions was evaluated in hot hat-bending of A2024-T4 aluminium alloy sheets. In addition, an aluminium alloy aircraft part having high strength and dimensional accuracy was successfully produced by the present process.

1. Introduction

The use of high-strength aluminium alloys increases for not only automotive parts but also aircraft ones because of weight reduction [1]. Cold stamping of the high-strength aluminium alloy sheets becomes difficult due to small formability and large springback [2]. In the high-strength aluminium alloy parts, the strength is increased by heat treatments, and thus the production processes become complicated, especially for the strictly regulated aircraft parts shown in Fig. 1. The annealed sheets having comparatively high formability are cold-stamped and solution-heat-treated. The low temperature storage and cold sizing process are required to prevent natural ageing until artificial ageing and to correct the springback and the distortion caused by the solution treatment, respectively.

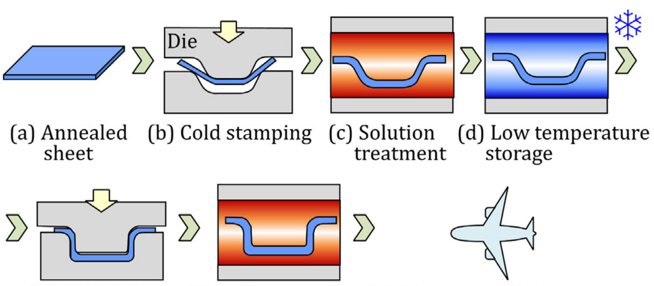

Fig. 1. Conventional production processes composed of cold stamping and heat treatments for high-strength aluminium alloy aircraft parts.

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Finally, the strength of the products is heightened by artificial ageing. In artificial ageing, distortion hardly occurs due to low temperature. It is desirable in aircraft industry to develop production processes having high productivity and formability for aluminium alloy aircraft parts.

Stamping processes at elevated temperatures are useful for materials having low formability [3]. Bariani et al. [4] improved the formability and springback for non-heat-treatable aluminium alloy sheets by means of hot stamping. On the other hand, the application of hot stamping processes to automotive high-strength steel parts is rapidly expanding in industry [5]. In hot stamping of the steel parts, the strength is heightened by die quenching held at the bottom dead centre of a press [6]. This is effective utilisation of heating, and the combination of forming and heat treatment is also attractive for high-strength aluminium alloy parts.

Lin et al. [7] proposed a hot stamping process of heat-treatable aluminium alloy sheets. In this process, the solution treatment is replaced with die quenching. Although the process was effective for 6xxx aluminium alloy sheets commonly employed for automotive parts [8], fracture occurred above 450 °C for 2xxx high-strength aluminium alloy sheets having a strength of 1.5 times as large as the 6xxx sheets [9], and thus the present process cannot be applied to the 2xxx sheets having a temperature for the solution treatment between 500 and 530 °C. In addition, the solution treatment during forming is prohibited in the regulation of manufacturing of aircraft parts because of scattered mechanical properties of the aluminium parts.

In the present study, a hot stamping process of high-strength aluminium alloy aircraft parts using quick heating was developed to eliminate the solution treatment and cold sizing process. Hat-shaped bending and deep drawing operations of heat-treatable A2024 and A6061 aluminium alloy sheets using resistance and furnace heating were carried out. The effect of heating conditions on the strength and springback was examined.

2. Hot stamping process of aluminium alloy aircraft parts

A hot stamping process of high-strength aluminium alloy aircraft parts using quick heating is proposed to improve the formability and productivity as shown in Fig. 2. T4 aluminium alloy sheets are fully natural-aged after the solution treatment, and are generally produced in aluminium industry. The solution treatment is omitted by means of the T4 sheets. Since the T4 sheets have small formability at room temperature, the sheets are hot-stamped. The heating temperature is set to be lower than the temperature of the solution treatment, and quick heating just before forming has the function of dissolving small clusters of solute atoms formed during natural ageing for producing sufficient strength increase in subsequent artificial ageing for the T4 sheets. To quickly heat the sheet, resistance heating [10] or furnace heating having an excessive temperature is used. The sizing process and the low temperature storage are also omitted by no solution treatment after forming.

The setup used for an experiment of hot hat-shaped bending using resistance heating and the dimensions of the tools are shown in Fig. 3. An A2024-T4 aluminium alloy sheet having 1.3 mm in thickness was employed for hot hat-shaped bending, where an A6061-T4 aluminium alloy sheet was also employed as a comparison. The surface roughnesses of the A2024-T4 and A6061-T4 sheets were 0.41 and 0.14 μmRa, respectively. The length and width of the aluminium alloy sheets were 130 mm and 20 mm, respectively. The sheet was rapidly resistance-heated for a current of 2 kA. The distance between the two electrodes was 120 mm. The electrodes were automatically released from the sheet just after heating, and the heated sheet was bent by the punch with 190 mm/s in speed after 0.2 s from the end of resistance heating. In furnace heating, the heated sheet was transferred to die for 5 s. The spacer plate having 1.5 mm in thickness was inserted between the sheet holder and the die to reduce friction of the flange portion. The bent sheet was fully cooled by holding at the bottom dead centre for 10 s.

The heating conditions of the aluminium alloy sheets for hot stamping and the conditions of artificial ageing of the hot-stamped sheets are shown in Tables 1 and 2, respectively. Although the heating temperature of this process is lower than that of the solution treatment, higher temperature was employed as a comparison.

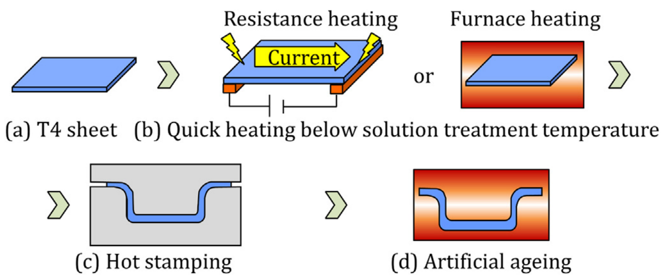

Fig. 2. Hot stamping process of high-strength aluminium alloy aircraft parts using quick heating.

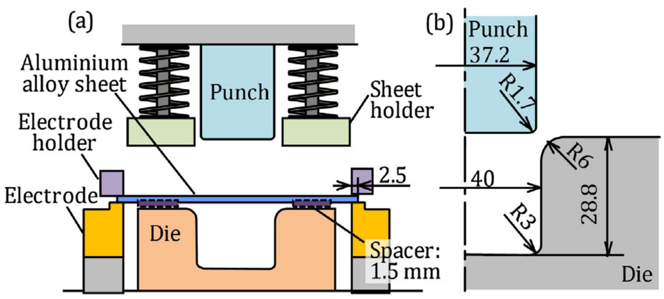

Fig. 3. (a) Setup used for experiment of hot hat-shaped bending using resistance heating and (b) dimensions of tools.

Table 1
Heating conditions of aluminium alloy sheets for hot stamping.

Heating	Heating temperature T [°C]	Heating time [s]	Average heating rate [°C/s]
Resistance	150–540	1.1–3.4	112
Furnace	150–540	30–420	3.2 (400 °C), 12.7 (500 °C)

Table 2
Conditions of artificial ageing of hot-stamped sheets.

Sheet	Temperature [°C]	Time [h]
A2024	191	9
A6061	177	9

3. Results of hot hat-shaped bending

3.1. Deformation behaviour

The bent A2024-T4 aluminium alloy sheets into a hat shape by cold and hot stamping for resistance heating are shown in Fig. 4. Although the springback for cold stamping is large, springback hardly occurs for T = 400 °C. The bent sheet above T = 500 °C was fractured by local melting near the solidus temperature, and this result is similar to that for AA2024-T3 sheets by Wang et al. [9]. Since the heating temperature of the present process is lower than the temperature of the solution treatment, the high-strength aluminium alloy sheets such as A2024-T4 can be formed.

The relationship between the springback angle of the bent aluminium alloy sheets and the heating temperature for resistance heating is shown in Fig. 5 The springback angle decreases with increasing heating temperature because of reduction in flow stress, and is almost zero around T = 400 °C. The springback for the A2024-T4 sheet is larger than that of the A6061-T4 sheet. It is found that cold stamping of high-strength aluminium alloy sheets such as A2xxx age hardened becomes difficult from the point of view of not only formability but also springback.

In hot stamping under dry friction, severe seizure was caused on the sidewall by slipping over the die surface, and graphite powder was applied on the punch and the die surfaces. The sidewall surfaces of the hot-stamped aluminium sheets and the

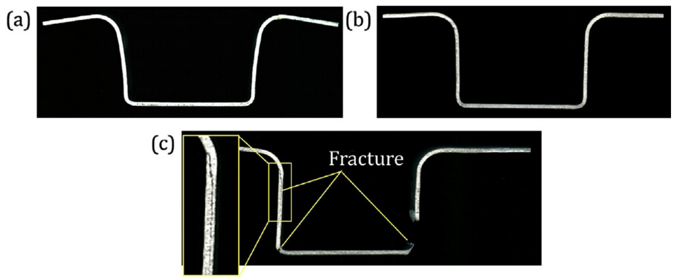

Fig. 4. Bent A2024-T4 aluminium alloy sheets into hat shape by cold and hot stamping for using resistance heating of T = (a) 20, (b) 400 and (c) 500 °C.

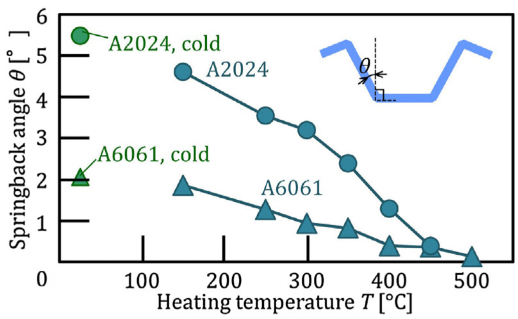

Fig. 5. Relationship between springback angle of bent aluminium alloy sheets and heating temperature for resistance heating.