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1-Shot hot stamping of ultra-high strength steel parts consisting of resistance heating, forming, shearing and die quenching

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ABSTRACT

A 1-shot hot stamping process consisting of resistance heating, forming, shearing and die quenching was developed to produce small- and medium-size ultra-high strength steel parts. A rectangular sheet was resistance-heated to obtain a uniform distribution of temperature, and just after the end of heating, a sequence of forming, shearing and die quenching was performed by one shot to prevent the drop in temperature. An ultra-high strength steel spur gear having a hardness of 540 HV2 was produced by 1-shot hot stamping composed of heating, blanking and die quenching. The rollover was improved by partial compression of the blanked gear. An ultra-high strength stainless steel part having a hardness of 580 HV2 was produced by 1-shot hot stamping consisting of the heating, bending, shearing and die quenching, and no springback and quenching distortion of the produced part were observed by holding at the bottom dead centre of the press. An operation for thickening the edge of the punched hole was included in 1-shot hot stamping to improve the strength of a product.

1. Introduction

Net shape and near net-shape forming which eliminates or minimises finishing operations using cutting is attractive for the reduction in production cost. Although billet forging is a typical net shape forming process, the application of plate forging expands. Merklein et al. [1] reviewed bulk forming processes of sheet metals including plate forging. Plate forging processes are appropriate for production of cups having comparatively large thickness and plates having complicated cross-sectional shapes because of smaller change in shape than bar forging. Salfeld et al. [2] introduced plate forging processes of gear parts. Yoon et al. [3] developed a plate forging process of seat recliner parts having sector tooth. The dimensional accuracy of products is greatly improved by including forging operations in a sequence of stamping. However, the load of plate forging tends to increase due to large friction resistance for smaller height of plates than that of billets, and thus materials used for plate forging are limited to mild steel and aluminium having comparatively small flow stress. High strength steel parts are commonly hardened by nitriding and carburising after forging. Not only increase in production cost but also deterioration in dimensional accuracy by the heat treatment is problematic. Cai et al. [4] investigated die designs in net-shape forging of gears to improve the accuracy of the products. Maeno et al. [5] developed an automatic re-lubrication approach using load pulsation of a servo press to reduce the force in compression of aluminium alloy plates with flat dies, and investigated the mechanism of the automatic re-lubrication. Maeno et al. [6] extended the load pulsation to plate forging of stainless steel parts having high strength.

Hot stamping of quenchable steel sheets is a useful process for producing ultra-high strength steel parts. Neugebauer et al. [7] reviewed sheet metal forming processes at elevated temperatures including hot stamping, and Karbasian and Tekkaya [8] reviewed hot stamping processes of ultra-high strength steel parts. In the hot stamping processes, the forming load is small, the formability is high, and the springback hardly occurs. In addition, the stamped parts are hardened by die quenching, a tensile strength between 1.5 and 1.8 GPa. The combination of hot stamping and plate forging is attractive for the omission of post quenching and the decrease in forming load. However, the application of hot stamping is limited to large body-in-white parts of automobiles. Since a furnace is generally employed to heat steel sheets, the drop in temperature during transferring from the furnace for small parts is too large to stamp sheets. Kolleck et al. [9] applied induction heating to hot stamping to reduce the heating time. Wieland and Merklein [10] locally compressed three stacked sheets to examine the tool wear in hot stamping.

Mori et al. [11] proposed a hot stamping process using rapid resistance heating to improve the productivity. The sheets are heated in only 2 s to 900 °C required for quenching. Mori [12] exhibited that the oxide scale of the stamped parts is hardly

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generated due to rapid heating. The efficiency of resistance heating is higher than that of induction heating employed by Kolleck et al. [9] because of direct passage of current through sheets. Mori et al. [13] applied resistance heating to tailored die quenching, because desired portions for high strength are resistance-heated by setting pairs of electrodes. Mori et al. [14] resistance-heated a punched portion of a die-quenched steel sheet. However, the change in cross-sectional area in the current direction brings about non-uniform distribution of temperature, i.e. the temperature is high and low for small and large cross-sectional areas, respectively. Although resistance heating is mainly applied to hot stamping of rectangular sheets, Maeno et al. [15] applied this heating technique to hot forming of tubes, and Maeno et al. [16] produced ultra-high strength steel hollow parts from a quenchable tube by hot stamping suing resistance heating. In addition, Mori et al. [17] developed a spline forming process of ultra-high strength steel gear drums using resistance heating. Ozturk et al. [18] used resistance heating to a hot stamping process of titanium alloy sheets.

Although progressive and transfer dies mounted on a press are generally employed for plate forging, hot stamping is generally limited to one shot due to the temperature drop by contact with dies and during transfer. Osakada et al. [19] introduced 1-shot cold stamping processes using a servo press having multiple driving slides. In these processes, several stages are included in one shot by the multiple slides. The 1-shot process is useful for preventing the temperature drop after heating in hot stamping

In this paper, a 1-shot hot stamping process consisting of resistance heating, forming, shearing and die quenching was developed to produce small- and medium-size ultra-high strength steel parts.

2. 1-Shot hot stamping of ultra-high strength steel spur gear

2.1. 1-Shot hot stamping composed of resistance heating, blanking and die quenching

To prevent the large increase in forging load, a 1-shot hot stamping process of ultra-high strength steel parts was developed. In this process, hot stamping is applied to plate forging of small- and medium-size ultra-high strength steel parts without post heat treatment (see Fig. 1). By heating the plate, the forming load is considerably small. In addition, post treatment can be omitted by die quenching. In the conventional hot stamping processes, large-size

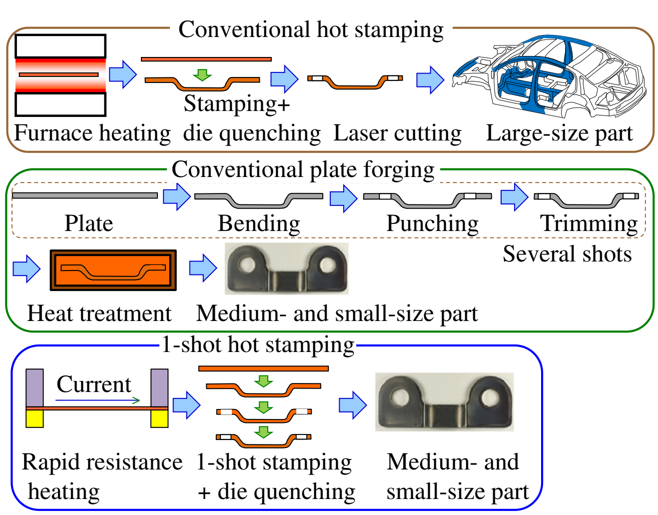

Fig. 1. Conventional hot stamping, conventional plate forging and 1-shot hot stamping.

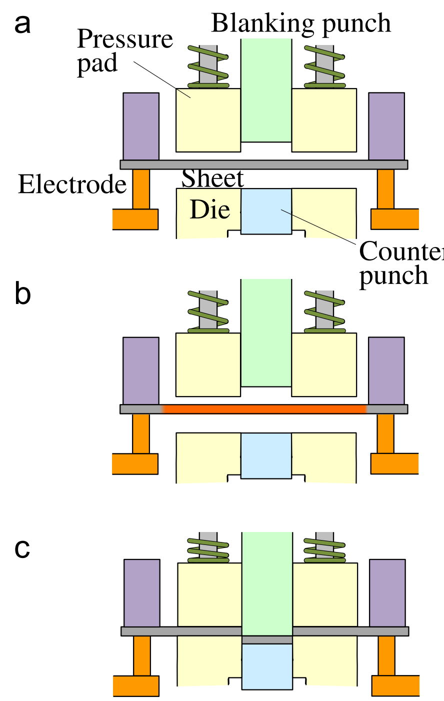

Fig. 2. 1-shot hot stamping of ultra-high strength steel spur gear consisting of resistance heating, blanking and die quenching: (a) setting; (b) resistance heating and (c) blanking and die quenching.

parts are produced because of slow forming systems using furnace heating. As the size of products decreases, the drop in temperature after taking from the furnace becomes large. Although forming and shearing stages are separated into several shots in the conventional plate forging processes, resistance heating, forming, shearing and die quenching are included in one shot of hot stamping to prevent the temperature drop of the heated sheet. The sequence of heating, forming, shearing and die quenching is required to be rapid enough, and thus rapid resistance heating developed by Mori et al. [11] is chosen for 1-shot hot stamping. Laser cutting is omitted in compaction with the conventional hot stamping.

First, an ultra-high strength steel spur gear was produced by a 1-shot hot stamping process composed of resistance heating, blanking and die quenching to examine the forming shape and quenchability (see Fig. 2). A quenchable steel sheet is rapidly heated by passing current between the electrodes. During heating, the sheet is not in contact with the blanking and counter punches, the die and the pressure pad to prevent heating of these tools. The rectangular sheet is resistance-heated to obtain a uniform distribution of temperature, and just after the end of heating, blanking and die quenching are performed by one shot to prevent the drop in temperature. The blanked sheet is quenched by sandwiching between the blanking and counter punches. By a sequence of heating, blanking and die quenching, the ultra-high strength steel spur gear was produced without the post heat treatment.

A quenchable steel sheet (C: 0.22, Si: 0.15, Mn: 0.45, Cr: 0.30, Ti: 0.02 and B: 0.0035 mass%) having 3 mm in thickness was employed for 1-shot hot stamping of a spur gear, and is similar to 22MnB5 conventionally employed for hot stamping measured by Merklein et al. [20]. The variations of the tensile strength and the elongation with the heating temperature for the quenchable steel sheet measured from the tensile test are given in Fig. 3. A 250 kN screw driven type universal testing instrument was employed for the tensile test, and the sheet was heated with an electric furnace in the air and not direct resistance heating. The heating velocity,