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Technical Report

Automotive Solution (1): Development of Hot Stamping of Improved Productivity

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Abstract

The use of hot-stamped parts for structural members is increasing to reduce car body weight in response to ever stricter safety and environmental regulations. Hot stamping is a hot-forming method to obtain high-strength parts from steel sheets, but it has a problem of low productivity due to the long time required for cooling. Direct water quenching has been developed aiming at drastically improving the productivity of hot stamping. Die design applying fluid dynamics simulation and the forming performance of the developed process are presented herein based on some examples and test results.

1. Introduction

The automotive industry faces increasingly tightening safety and environmental regulations on cars. As a solution, the use of hot-stamped parts for body structural members is expanding as a measure to reduce car body weight.

This paper presents direct water quenching, which has been developed as a new method for greatly improving the productivity of the hot-stamping process by focusing on die design applying computational fluid dynamics and the verification results on forming performance based on examples.

2. Problems of Hot Stamping Process

Hot stamping is a forming method for manufacturing automotive structural parts from thin steel sheets whereby material sheets are heated, pressed into a desired shape while hot and low in strength, and rapidly cooled (quenched) so that the steel transforms into strong and stable martensite.[1, 2] The problem is, however, that the time for cooling a formed sheet between the dies (the holding time at the bottom dead center) is long and the productivity tends to be lower than that by cold stamping; the productivity of hot stamping including material transfer and other related processes is generally considered to be 2 to 3 strokes per minute (spm).

Direct water quenching is a method for raising the productivity of hot stamping to 10 spm or more, about three times what it has been, comparable to that of cold stamping. It originated from studies of the cooling process of hot material between dies and included measures to quicken the pressing operation and materials transfer.[3)]

3. Development of Direct Water Quenching

3.1 What is direct water quenching?

As shown in part (a) of **Fig. 1**, by conventional hot stamping, formed hot sheets are cooled by heat transfer to the cool-forming dies through direct contact. In this case, owing to the heat insulation by air, the cooling takes longer at portions where there is a gap between the sheet and the die than at portions that are in direct contact with each other. To shorten the cooling time, it is necessary to keep good contact of the two, but it depends on the forming accuracy of the dies and the thickness deviation of the sheet to form. In addition, the dies must be highly thermal conductive, but presently, materials that have both high strength and high heat resistance are not yet widely used for dies.

In consideration of the situation, the authors have worked out a method of thermal conduction by direct contact as well as a liquid medium: a direct cooling and quenching method by which a formed steel sheet is cooled by water injected into the gap between the sheet and the die, as illustrated in part (b) of Fig. 1.

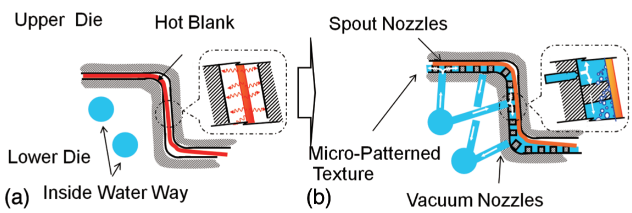

Fig. 1 Mechanism of the direct water quenching (a) Die-quenching process, (b) Direct water-quenching process

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3.2 Structure of dies for direct water quenching and optimum cooling

The basic structure of the dies for the present method is explained here. Depressions are engraved on the die surfaces that contact the sheets, forming a network of canals called the micro pattern (MP), which also connects to the holes for water supply and others for letting out the steam and excessive water through the dies. Aiming at improving and optimizing the die material quality, product dimensional accuracy, productivity, etc. by the conventional die-quenching hot stamping, various studies have been provided on thermal conduction and formability prediction by simulation.[4] For direct water quenching, it is necessary in addition to see to it that the cooling water is evenly distributed in the entire surface of the formed sheet to obtain homogeneous cooling.[5]

How to prevent thermal deformation of formed products in the design of forming dies is explained below: here the principal means is the prediction of temperature difference and dimensional accuracy based on computer-aided engineering (CAE) combining fluid mechanics simulation of the cooling water with hot forming analysis.

3.3 Design of dies for direct water quenching

Figure 2 shows a typical flow of the design work for direct water quenching dies. The arrangement of the water supply and discharge holes at the MP surface is optimally defined ① at the die design stage, based on the fluid analysis and hot-forming analysis, ② the dies are manufactured, and then ③ at trial forming, cooling characteristics and dimensional accuracy are verified based on the thermal image, the 3D shape, etc. of the formed parts. To enhance the hardenability and dimensional accuracy of the formed parts and attain target productivity, accurate analyses of fluid dynamics and shape accuracy are required at the die design stage (① above). At the die design stage, based on the theory of heat transfer from hot material to cooling water, the water flow rate distribution in the MP obtained using the fluid analysis was selected as the criterion for the cooling performance evaluation.

As seen in **Fig. 3**, the cooling water flow rate distribution at the MP surface based on the fluid dynamics simulation of steady flow agrees well with the cooling performance of formed parts at trial pressing, and actually, good dimensional accuracy has been obtained by keeping the cooling water flow rate above a certain figure all over the MP surface. **Tables 1** and **2** show the conditions and results of the trial pressing, respectively. The result was satisfactory in terms of product shape and productivity, which indicates that the cooling water flow rate distribution is an important criterion in evaluating die performance. It has to be noted, in addition, that the control of the amount of cooling water is important for obtaining good results by the direct water quenching process, but further details are omitted here.

Figure 4 shows the hot-stamping test facilities of Nippon Steel

Table 1 Trial condition and die specification

Material	Aluminized steel for hot stamping (1.4 mm)
Formed shape	Hat (400 mm long × 140 mm wide × 30 mm high)
Dies	Upper die: Conventional die quenching Lower die: Direct water quenching (MP: 0.5 mm height cylindrical)

Table 2 Experimental results

Quench quality	Same as conventional
Shape accuracy	< ±0.5 mm
Productivity	Die stop at bottom 2.5 s Total tact time 5.5 s (approx. 11 spm)

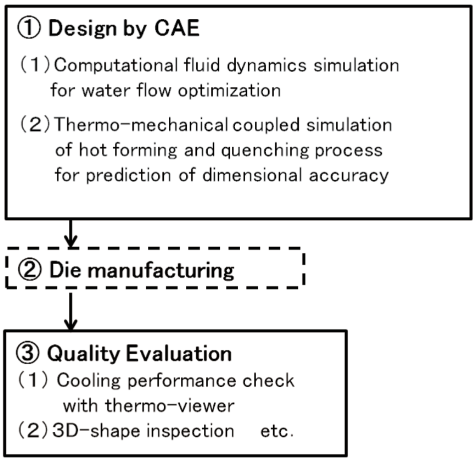

Fig. 2 Engineering flow of the direct water quenching die

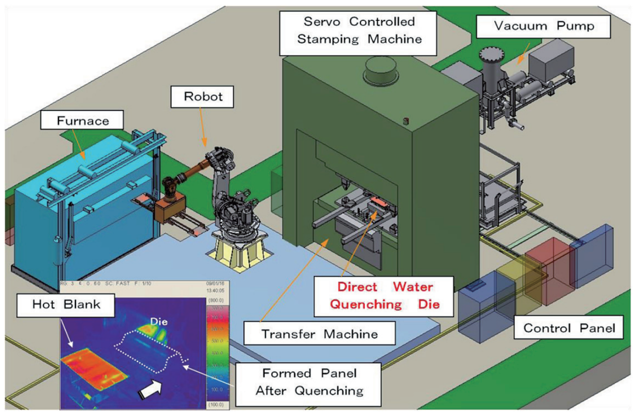

Fig. 4 Test facilities for hot stamping

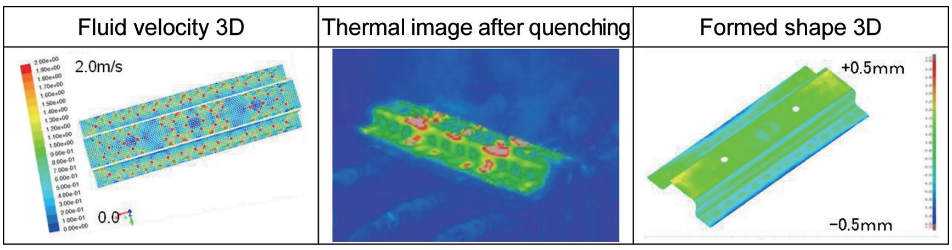

Fig. 3 Optimization by flow dynamics simulation and trial results

& Sumitomo Metal Corporation. The system is used openly for material development as well as for clarifying the characteristics of an automotive part that a customer (car builder) considers manufacturing by hot stamping and the like. Besides this, the company and its group are capable of proposing to customers forming methods for different sheet products and engineering vertically integrated forming systems for manufacturing parts of different shapes in large quantities.[6)]

4. Closing

Direct water quenching has been developed as an improvement of hot stamping aiming at enhancing the hardenability and dimensional accuracy of the formed products and achieving high productivity. The present paper has described the design technology for forming dies for direct water quenching using computational fluid dynamics of cooling water at the die surface contacting the formed piece. Based on some test examples, it was demonstrated that the developed method could achieve high productivity (approximately 11 spm). Further studies are being conducted to clarify complicated process phenomena and work out adequate measures to cope with them.

After the development of the basic technology of direct water quenching by Nippon Steel & Sumitomo Metal, the process has been brought to commercial practice through field tests and evaluation jointly by customers and the company. New steel materials of higher strength are being developed in the meantime for use for car parts,[7)] and in view of this, the company will continue looking for optimum structures of car parts and their manufacturing methods making the most of the advantages of such steel materials and propose solutions to enhance the performance of light-weight steel car bodies.

The authors would like to express their sincere gratitude to the members of the CAE and the test teams who cooperated in the die design development, and the people of the parties to the joint development who pointed out problems and gave directions during the studies for the commercial application of the developed process.

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