# Newly Developed High Thermal Conductive Die Steel with Superior Performance for Hot Stamping

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## Abstract

The most common disadvantageous issue on hot stamping is low productivity. One of the reasons is the holding time at the bottom dead center of press because of quenching steel sheet. The heat transfer from steel sheet to die can be promoted by using high thermal conductive die steel and the holding time can be decreased. As the high thermal conductivite die steel for hot stamping, DHA-HS1 was developed. The characteristic of the developed steel is that it has high thermal conductivity while maintaining the high hardness required for tool steel. Moreover, the developed steel has high softening resistance so the hardness can be maintained high when it is exposed to high temperature for many hours.

In this study, subjects concerning the reduction in cycle time and prevention of the adhesion of plating have been examined using actual hot stamping equipment. As one example of the results, by applying the developed steel, the rise in temperature of the surface of die was suppressed and the temperature of the formed product immediately after opening the die was lower than that of 1.2344eq. steel. It was confirmed that the holding time of the developed steel die in order to get the same hardness of the forming product, was almost 3 s shorter than that of 1.2344eq. steel. Furthermore, it was confirmed that reduction of the die temperature by applying the developed steel made the adhesion of plating smaller by almost 24 %. Therefore, the developed steel can be expected to improve productivity and to reduce work time of die maintenance to remove adhesion of plating.

## 1 Introduction

One of the challenges of hot stamping methods is a low production efficiency. The reason is because the process needs a holding time at bottom dead center for heat transfer from heated steel sheets to dies. Therefore, in order to reduce the holding time by improving the heat transfer efficiency, dies with high thermal conductivity are required.

Moreover, wear and adhesion of plating are known as failure mode of hot stamping dies. Dies with high hardness and high wear resistance are required. On the other hand, when adhesion of plating occur on die surface, die maintenances have to be taken place and bring about low productivity.

Additionally, tailored tempering method has been suggested for making highly-functional parts.[1] This is a method to create low strength area partially on the ultra-high tensile strength parts by heating dies partially by electrical heater to prevent that part from hardening. In this case, since heated dies are exposed to high temperatures for a long time, wears progress by softening issue. Therefore, the high softening resistance is also required for those dies. However, up to now, there was no die

steel to fulfill high thermal conductivity and these strength required for hot stamping.
In this paper, the properties and applications of hot stamping die steel DHA-HS1 are explained. The developed steel is designed for high thermal conductivity, high hardness and high softening resistance to correspond to hot stamping die requirements.

## 2 Alloy Design of the Developed Steel

Figure 1 shows the positioning of the developed steel in comparison to hot and cold work die steel grades. The developed steel is alloy designed based on our study that the effect of each chemical component to thermal conductivity. It is a new concept steel grade that has both high thermal conductivity and high hardness.[2]
As for the effect of alloying elements on the thermal conductivity, 0.4% C steels with the hardness 46 HRC was already tested by varying Si and Cr contents.[3] Relationship between the amount of alloy elements and thermal conductivity is shown in Figure 2. It is found that increasing Si and Cr contents reduces thermal conductivity. About the developed steel, Si and Cr contents were reduced to attain high thermal conductivity, compared to 1.2344.
Moreover, in order to raise the hardness and to have high softening resistance, as to adjust carbide forming elements, C and Mo contents were increased and Cr content was reduced compared to 1.2344.

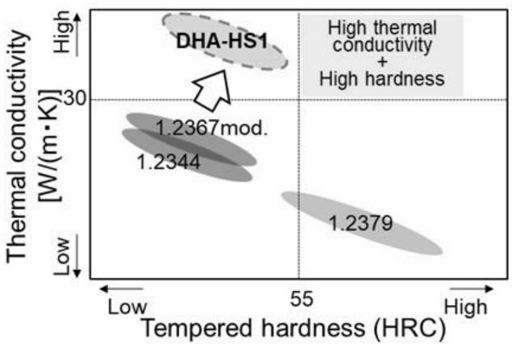


*Figure 1: Positioning diagram*

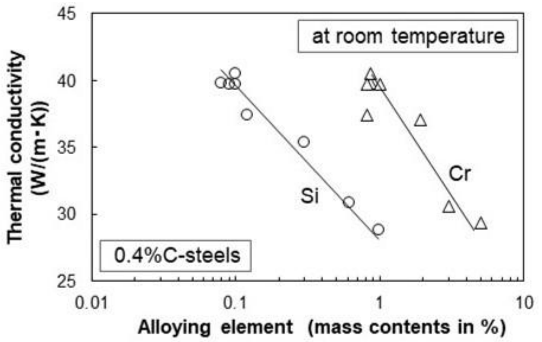


*Figure 2: Effects of alloying elements on thermal conductivity*

## 3 Fundamental Characteristics of the Developed Steel

Figure 3 shows the thermal conductivity of 1.2344eq. (JIS SKD61) and the developed steel in the temperature range between room temperature and 700 °C. The developed steel has higher thermal conductivity than 1.2344eq.. It contributes to increase of product efficiency of hot stamping and decrease of die damage, wear and adhesion of plating, because of its capability of suppression of the rise in die temperature.
Figure 4 shows the hardness after hardening and tempering of the developed steel. In the temperature

range between 500 ℃ and 600 ℃, the decreasing the hardness of the developed steel is less and it maintains high hardness even in case of surface treatment such as nitriding. Figure 5 shows the softening resistance of the developed steel. Hardness was tested at room temperature after 600 ℃ holding at the furnace. The initial hardness of specimens which were quenched from 1030 ℃ and tempered twice at 600 ℃ for 1 hour, was 54 HRC for the developed steel, and 50 HRC for 1.2344eq.. The holding time to be softened to 40 HRC were 200 hours for the developed steel and 16 hours for 1.2344eq., and the developed steel had more than 10 times higher softening resistance than 1.2344eq.. The developed steel will contribute to prevention of the die damage with softening problem because die inserts of tailored tempering parts and high stress parts were sometimes heated at high temperature in hot stamping methods.

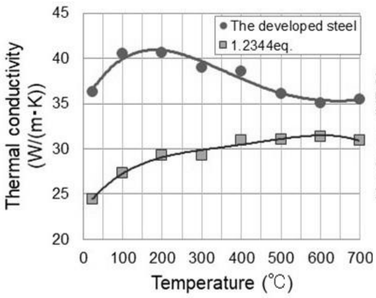

***Figure 3:*** *Thermal conductivity*

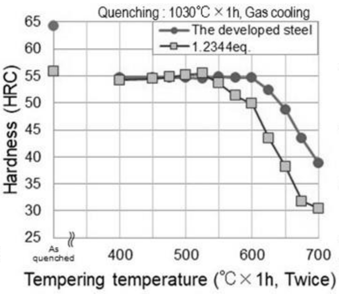

***Figure 4:*** *Tempering hardness curve*

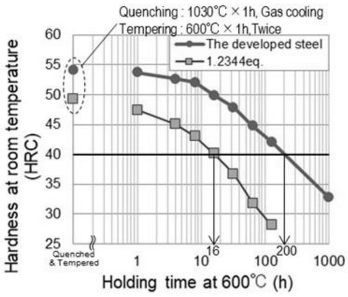

***Figure 5:*** *Softening resistance*

# *4 Case Study of the Developed Steel*

## 4.1 Reduction in Cycle Time

### *4.1.1 Evaluation Procedure*

As evaluation of reduction in cycle time, the decreasing the holding time at the bottom dead center of press by applying the high thermal conductivity steel to hot stamping die was investigated. In order to evaluate the decreasing of the holding time, the quality of the parts formed continuously by the actual press and die were investigated. Because there were effects to the quality of parts on the change of cooling capacity by the raise of the temperature of dies when forming the parts continuously.

To simulate the conditions of forming and cooling parts, the die material evaluation method by using the actual hot stamping equipment was introduced. To transfer steel sheets continuously and automatically, the equipment has the two robot for transportation and the furnace which has the steel sheets rotation system. The stamping press machine is the 110 tons electrical servo press machine.[4] The test die and the product designs are shown in Fig. 6. The test steel plate was aluminized steel sheet, 22MnB5, and its size was approximately 2 mm thickness x 50 mm width x 300 mm length. The product shape was the hat bending shape that simulated center pillar parts.

As shown in Figure 6, the upper punches were used as the evaluation parts made by the developed steel and 1.2344eq. for comparison. The test die has cooling lines on the upper punches and bottom

die. The test was performed with internal water cooling. The forming conditions are shown in Table 1. For the evaluation of the deceasing the holding time, the holding time was changed from 0 s to 10 s.
After 15 shots continuously, the temperature of the dies and products and the hardness of the products were evaluated. The die temperature was measured by the thermocouple installed at 2 mm depth from the die surface.[5] The temperature of forming product was measured by thermography immediately after opening the die.

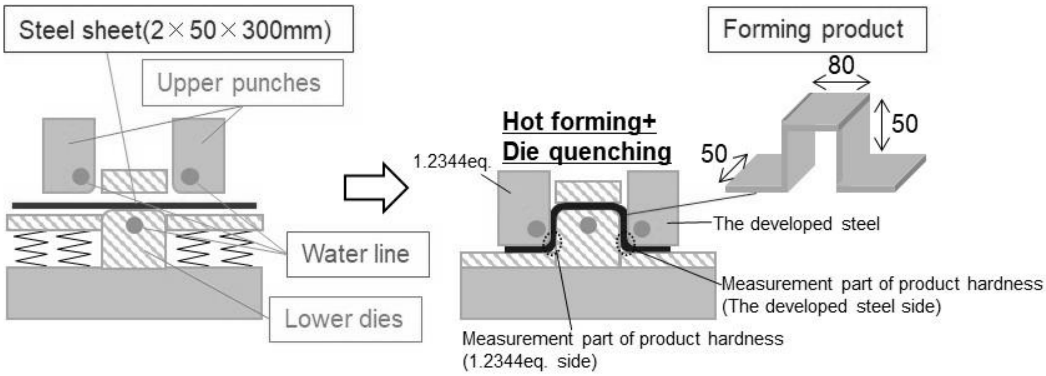


***Figure 6:*** *Die and forming product (evaluation of reduction in cycle time)*

***Table 1:*** *Forming conditions*

| | | | | **4.1 Reduction in Cycle Time** | **4.2 Prevention of the adhesion of plating** |
|---|---|---|---|---|---|
| Die | Cooling water | Volume | Upper die | 5 L/min | 0～5.6 L/min |
| | | | Lower die | 3.5 L/min | 0～8.0 L/min |
| | | Temperature | | 25 ℃ | 3～25 ℃ |
| | | Pressure | | 0.35 MPa | 0.35 MPa |
| | | Number of water line | | 1 (in the lower die) | 1 or 2 (in the lower die) |
| | | Clearance | | 0 % | +6 % |
| Furnace | Temperature | | | 950 ℃ | 950 ℃ |
| | Holding time | | | 5 min | 170 s |
| Press | Load | | | 40 ton | 40 ton |
| Cycle time | Transportation from furnace to press | | | 9 s | 9 s |
| | Holding time at the bottom dead center | | | 0～10 s | 10 s |
| | Total time each 1 shot | | | 22～32 s | 32 s |

### *4.1.2 Evaluation Results*

Figure 7 shows the die temperatures during hot stamping and the temperature at 15 shots. The temperature of the developed steel reaches maximum temperature in 1 s earlier than 1.2344eq. and the temperature of the developed steel is almost 15 °C lower than that of 1.2344eq., and it was the effects produced by the high thermal conductivity of the developed steel.
Figure 8 shows the relationship between the holding time and the maximum surface temperatures of the products. In case of the holding time 10 s, the temperature of contacted part with the developed steel was almost 40 °C lower than 1.2344eq. ones. Additionally, at 400 - 420°C which is the temperature where the martensite transformation starts, it generates the latent heat of phase transformation. By the application of the developed steel, heat transfer of steel sheet can be faster and the forming product can be transformed to martensite in shorter time than 1.2344eq..
The die temperatures changes by holding time are shown in Figure 9. In Figure 9, contour lines show the hardness of the products. The lower the die temperatures are, the more narrow the spaces of the lines are, and it is expressed that the product hardness is harder at shorter holding time due to the lower die temperature. In this evaluation condition, compared with the hardness of 1.2344eq. at the 10 s holding time, the holding time where the hardness of the developed steel is the same is 7 s, so it can be shorter by 3 s.

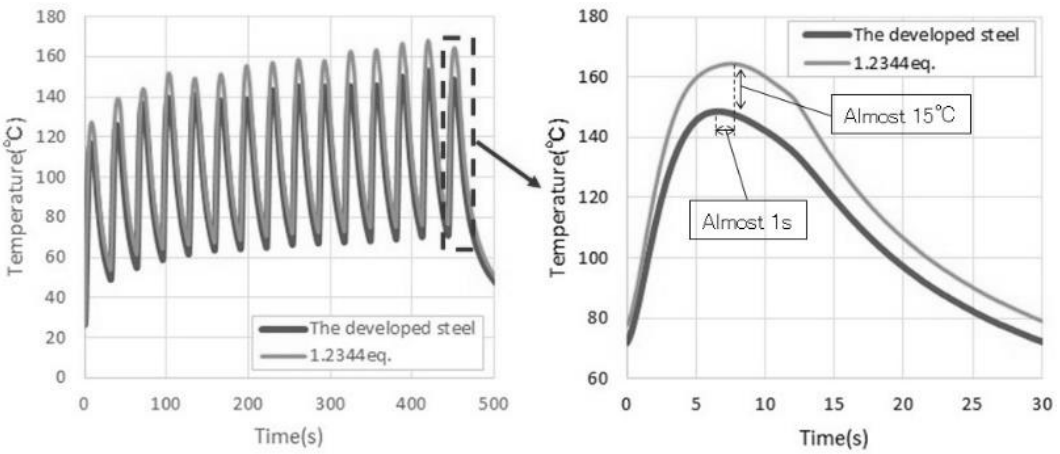


***Figure 7:*** *Die temperature during hot stamping*

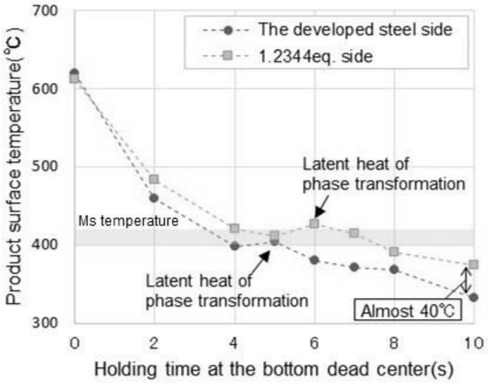


*Figure 8: The relationship between maximum temperature of products surface immediately after opening die and the holding time*

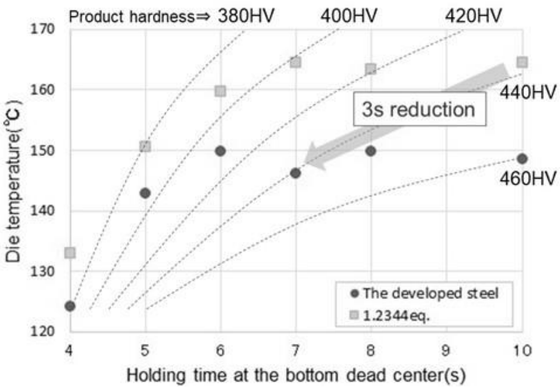


*Figure 9: The relationship between die temperature, product hardness and the holding time*

## 4.2 Prevention of the adhesion of plating

### *4.2.1 Evaluation Procedure*

As evaluation of prevention of the adhesion of plating, the effect of lowering die temperature by applying the high thermal conductivity steel on the adhesion of plating was investigated using the previously described hot stamping equipment.

The test die and the product designs are shown in Figure 10. The test steel plate was aluminized steel sheet, 22MnB5, and its size was approximately 2 mm thickness x 50 mm width x 300 mm length.

As shown in Figure 10, the lower dies were used as the evaluation parts made by the developed steel and 1.2344eq. steel for comparison. The forming conditions are shown in Table 1. In order to lower the die temperature, the volume and temperature of cooling water and the number of water line in the lower dies are changed as mentioned in Table 1. The die temperature was measured by the thermocouple installed at 2 mm depth from the die surface. The adhesion amount of plating on the R part of the lower dies after 50 shots was evaluated by the non-contact 3D dimension measuring machine, and the total volume of the convex area from original shape line was defined as adhesion amounts.[6]

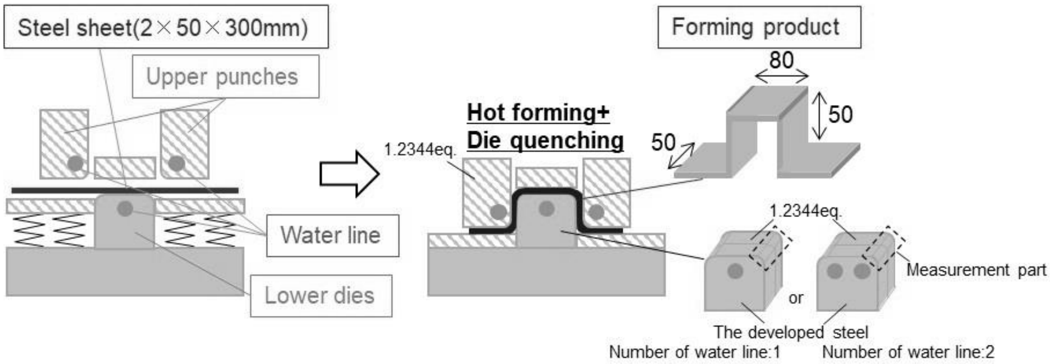


***Figure 10:*** *Die and forming product (evaluation of prevent of the adhesion of plating)*

### 4.2.2 Evaluation Results

Figure 11 shows the relationship between the maximum die temperature in the each conditions indicated in Table 2 and the adhesion amount of plating. Due to high thermal conductivity, when the cooling condition was the same, the maximum die temperature of the developed steel was about 20 ℃ lower than that of 1.2344eq. and the die temperature of the developed steel was less than 100 ℃. Also, the adhesion amount of plating decreased as a result of die temperature being lower, and the relationship between the maximum die temperature and adhesion amount of plating was found out. In addition, the adhesion amount of plating of the developed steel was smaller than that of 1.2344eq. and applying the developed steel had an effect on the prevention of plating adhesion.
Additionally, Figure 11 shows that the increase rate in the adhesion amount along with increasing the maximum die temperature of the developed steel was smaller than that of 1.2344eq., and it indicates the developed steel has a better adhesion resistance based on its chemical property compared with 1.2344eq.. Further factor analysis of the developed steel on the adhesion resistance must be done in the future.

***Table 2:*** *The relationship between graph legends and cooling conditions in Figure 11*

| The developed steel | | | ● | ▲ | ■ | ◆ |
|---|---|---|---|---|---|---|
| 1.2344eq. | | | ● | ▲ | ■ | ◆ |
| Cooling water | Volume | Upper die | 0L/min | 5.0L/min | 5.0L/min | 5.6L/min |
| | | Lower die | 0L/min | 3.5L/min | 6.2L/min | 8.0L/min |
| | Temperature | | - | 25℃ | 3℃ | 3℃ |
| | Number of water line | | - | 1 | 1 | 2 |

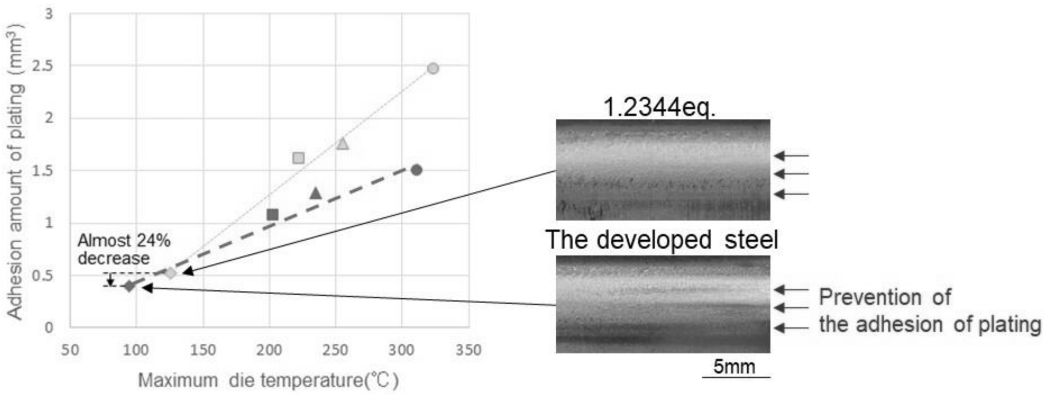


***Figure 11:*** *The relationship between the maximum die temperature and the adhesion amount of plating*

## 5 Summary

This paper has introduced the case study of high thermal conductivity steel developed for hot stamping die material. Due to high thermal conductivity, the die temperature can be lower, and the developed steel has shown its features such as improvement of internal cooling efficiency and prevention of plating adhesion.

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