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Technical Data

Die Material Evaluation Technology by Actual Hot Stamping Equipment

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1. Preface

In recent years, the application ratio of ultra-high strength automotive parts are increasing due to lightweight and collision safety requirements. Hot stamping methods are known as a production method of parts with higher tensile strength compared with current cold stamped parts. The process is to heat a steel sheet above the austenitizing temperature, then the heated steel sheet is quenched and formed by die pressing. One of the challenges of hot stamping methods is a low production efficiency[1)]. 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, hot stamping die damages have become an issue. Wear and adhesion of plating are known as failure mode. The wear is caused by the complex factor such as deformation resistances of supercooled austenite and oxide contamination generated by heating.

The die damage simulation by die materials changing is not enough to estimate by only comparison of the physical properties. It needs evaluation with stress loading conditions same as an actual die. Therefore, the die material evaluation technology by using the actual hot stamping equipment was needed. In this study, the evaluation method and die wear results that evaluated by die material changing are introduced.

2. Wear evaluation technology for die materials

2.1 Hot stamping equipment for test

The die damage on the mass production occurs in tens of thousands of shots at the earliest. Therefore, the test hot stamping equipment is designed to evaluate for tens of thousands of shots. And, it has the automatic transfer system by using two robot arms to reduce a workload of operator and operational variability of test conditions.

The furnace for heating steel sheets made by Daido Plant Industries. Co., Ltd. has the steel sheets rotation system to take heated sheets out continuously and automatically. The stamping press machine is the 110 tons electrical servo press machine made by AMADA PRESS SYSTEM CO., LTD. And, the two robot arms made by FANUC CORPORATION are installed at the front of the furnace and the press machine.

2.2 Test die and product

The test die and the product designs for wear evaluation are shown in Fig. 1. The test steel plate was a galvanized steel sheet, 22MnB5, and its size was 1.2 mm thickness x 50 mm width x 300 mm length. The plate was transferred into the furnace and heated. After that, it was transferred to the die, stamped (die closing), and cooled in the die by holding at the bottom dead center. As shown in Fig. 1, the test die has cooling lines on the upper punches and bottom die. The test was performed with internal water cooling. The product shape was the hat bending shape that simulated center pillar parts. As shown in Fig. 1, the upper punches were used as the evaluation parts and its wear volume was evaluated as explained in Chapter 3 below.

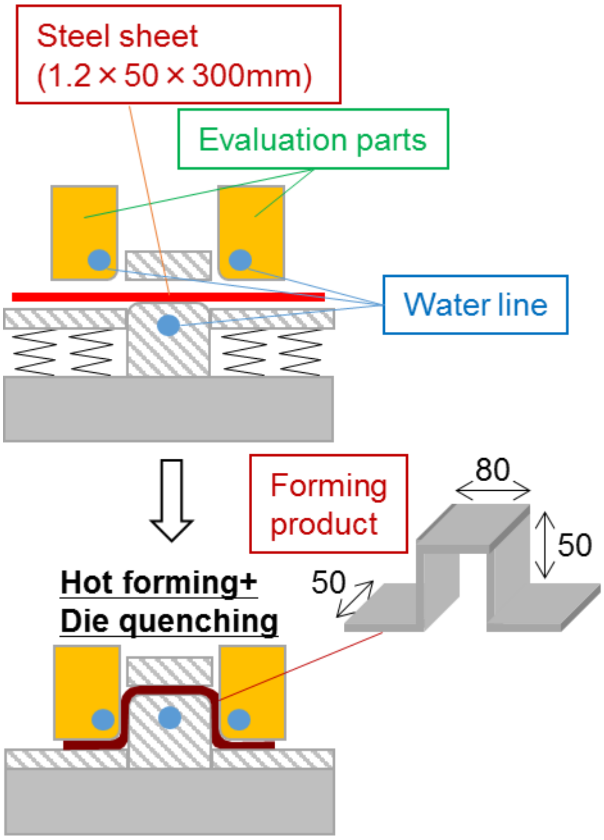

Fig. 1 Die and forming product.

2.3 Test conditions

Figure 2 shows the chemical analysis results by EPMA (Electron Probe Micro Analyzer) of the steel sheet surface after 950 °C heating for 300 sec for determination the heating condition. It indicated that Zinc oxide (ZnO) and Fe-Zn solid solution were generated in that order from the surface. It was similar to the report by Fujimoto et al.[3)]

Figure 3 shows the temperature of steel sheet and forming product measured by thermography during transportation from the furnace to the press machine and immediately after opening the die. Based on the CCT diagram (Continuous Cooling Transformation diagram) that has reported by Kojima et al.[4)], the steel sheet temperature before starting forming did not reach the range of ferrite and pearlite generation temperatures. Moreover, the average cooling rate of the steel sheet during holding at the bottom dead center was 52 ° C/sec. It had exceeded the cooling rate that generates only martensite, over 30 ° C/sec.

In addition, the martensite transformation of steel sheet starts from 400 ° C and ends around 200° C according to the CCT diagram[4)]. The holding at bottom dead center needs to be continued to be around

200 ° C[5]. As shown in Fig. 3, the holding time at bottom dead center is required to be more than 8 s to cool down until around 200 ° C. The product hardness after 8 sec of holding at the bottom dead center is shown in Fig. 4. The Vickers hardness was 450 to 500 HV that is equivalent to 1500 MPa tensile strength. As the results, the holding time was set to 8 sec for this wear evaluation test of die material as explained in Chapter 3 below. The other test conditions were shown in Table 1.

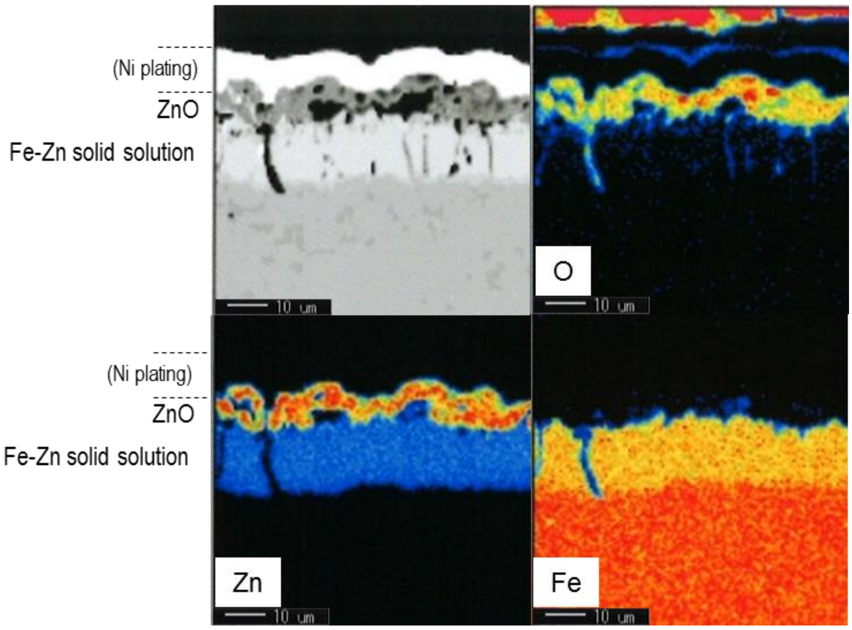

Fig. 2 EPMA analysis near surface of steel sheet after heating.

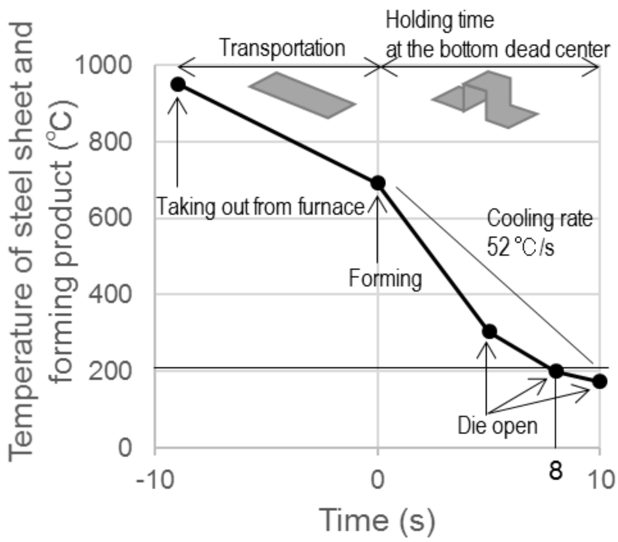

Fig. 3 Cooling curve of steel sheet.

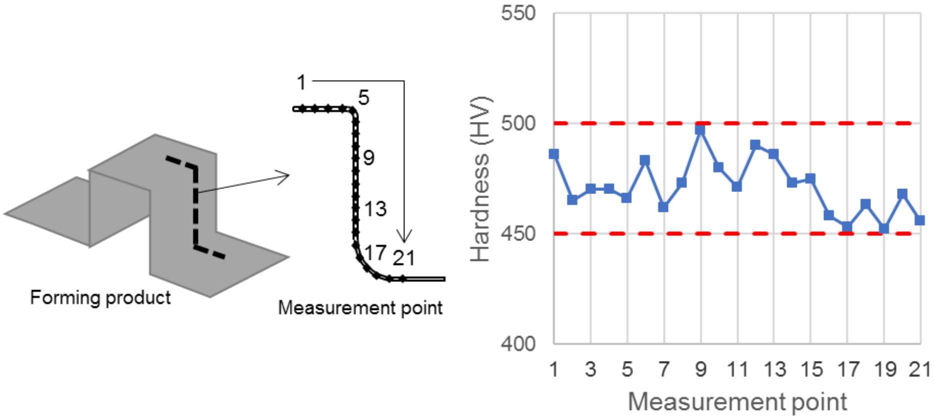

Fig. 4 Cross-section hardness of forming product.

3. Wear evaluation test

3.1 Die materials

As shown in Table 1, SKD61 (JIS G 4404), DH31-EX™ (Daido brand steel grade) and DHA™-HS1 (Daido special steel grade for hot stamping) [7), 8)] were used for the upper punches, which are the wear evaluation parts. Figure 5 shows the position of DHA-HS1 in the diagram that is showing the relationship between tempered hardness and thermal conductivity. DHA-HS1 has higher tempered hardness and thermal conductivity than SKD61. Figure 6 shows the thermal conductivity. DHA-HS1 has higher thermal conductivity than SKD61 and DH31-EX. It is possible to improve the productive efficiency of hot stamping method because of decreasing of the die surface temperature.

The heat treatment conditions for making test dies and tempered hardness are shown in Table 2.

Table 1 Test conditions.

Steel sheet	*Steel*		*Zn coated steel sheet (22MnB5)*
	Shape		*1.2×50×300 mm*
Die	*Steel*		*DHA-HS1, JIS-SKD61, DH31-EX*
	Volume of cooling water	*Upper die*	*7 L/min*
		Lower die	*4 L/min*
	Temperature of cooling water		*25 ℃*
	Clearance		*+8 %*
Furnace	*Temperature*		*950 ℃*
	Holding time		*5 min*
Press	*Load*		*20 ton*
Cycle time	*Transportation from furnace to press*		*9 sec*
	Descending and ascending of press		*3.5 sec*
	Holding time at the bottom dead center		*8 sec*
	Other transportation		*9.5 sec*
	Total time each 1 shot		*30 sec(2 spm)*

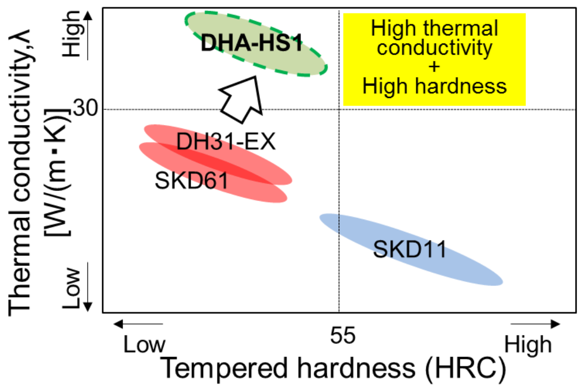

Fig. 5 Position diagram of DHA-HS1.

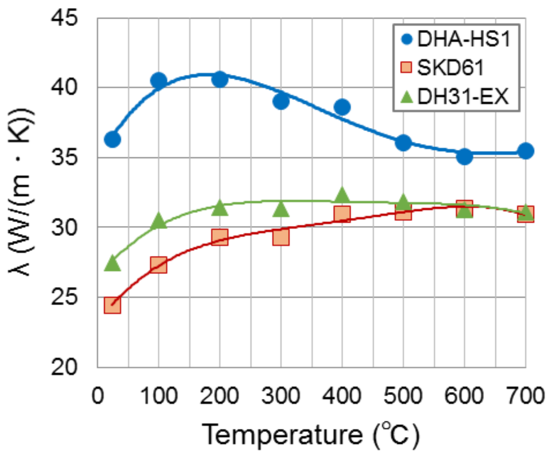

Fig. 6 Thermal conductivity of DHA-HS1.

Table 2. Die materials.

Steel	*Heat treatment conditions*		*Hardness after heat treatment*
	Quenching	*Tempering*	
DHA-HS1	*1030 ℃×1 h Gas cooling*	*560 ℃×1 h Air cooling ,Twice*	*54 HRC*
SKD61	*1030 ℃×1 h Gas cooling*	*600 ℃×1 h Air cooling ,Twice*	*49 HRC*
DH31-EX	*1030 ℃×1 h Gas cooling*	*500 ℃×1 h Air cooling ,Twice*	*53 HRC*

3.2 Wear volume measurement conditions

The appearance observation and measurement of wear volume were conducted at every 1,000 shots. The surface profiles of wear part on the upper punches were measured by a non-contact 3D dimension measuring machine made by KEYENCE, and the total volume of dent area from original shape was defined as the wear volume[9)].

3.3 Test results and Discussion

Figure 7 shows the appearance of evaluation parts that is the corner radius part on the upper punches after each shot. Figure 8 shows the wear volume at the evaluation parts at each number of shots. These results show that the wear volume has increased as the number of shots has increased, and the wear volume of DHA-HS1 was smaller than those of SKD61 and DH31-EX.

The wear volume difference among the die materials is explained below. The following equation which considers yield strength of the die is known as the wear volume simulation model on the forging method [10), 11)].

$$W = k \int \frac{PV}{YS} \, dt$$

W: Wear depth	YS: Yield strength of the die	P: Surface pressure
V: Relative sliding speed	dt: Dot time	k: Const

The influential factors by the die material properties are *YS* and *k*[11]. *YS* is defined as the die strength at forming temperature because the die temperature is raised by forming. The die strength at elevated temperature depends on the initial strength at room temperature. And, it is improved by increasing hardness[12]. Figure 9 shows the 0.2% proof strength at 500 and 600 °C of the die material used for this test. The 0.2% proof strength of DHA-HS1 is higher than that of SKD61 because DHA-HS1 can obtain higher hardness than SKD61. This is one of reasons why DHA-HS1 has less wear volume than SKD61.

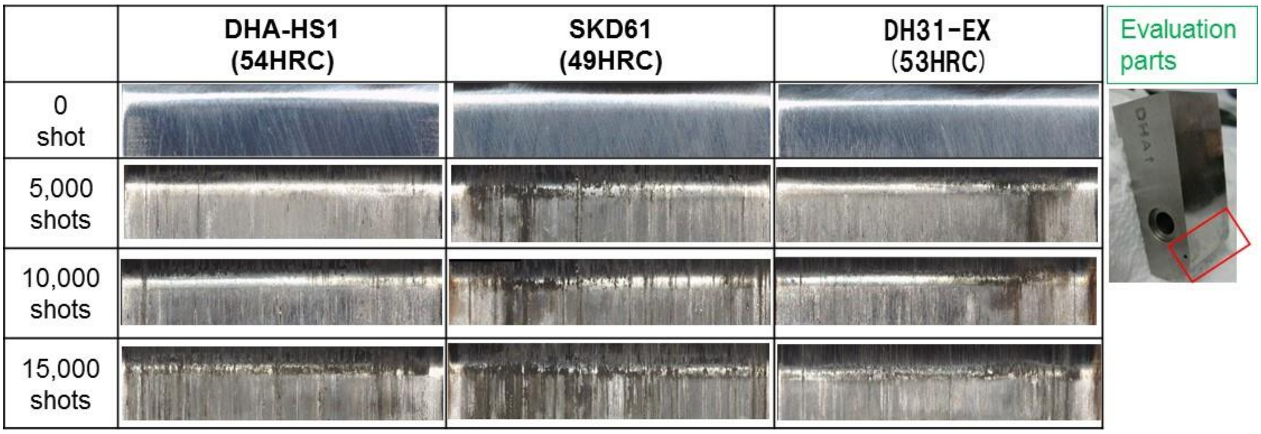

Fig. 7 Surface condition of upper evaluation parts after each shot.

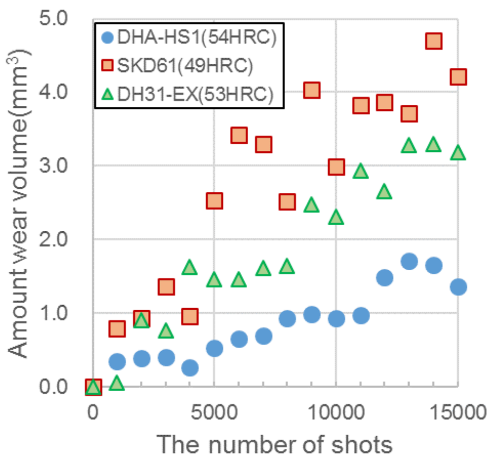

Fig. 8 Wear volume of upper evaluation parts after each shot.

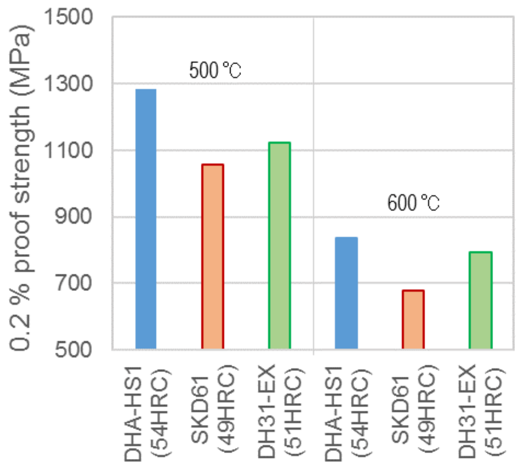

Fig. 9 0.2 % proof strength of DHA-HS1.

The die temperature is also the influential factor for wear volume. The change in die temperature during test is shown in Fig. 10. It was measured by 1 mm diameter thermocouple at 2 mm depth from the upper punch surface. The die temperatures during forming by high thermal conductivity grade DHA-HS1 were about 20 °C lower compared with SKD61 and DH31-EX. Therefore, the die strength at the surface of DHA-HS1 was maintained high because raise of the die temperature during forming was restrained. As the results, it was possible to evaluate the difference in wear volume when changing the die material because the order of die strength has matched the order of wear volume.

It is necessary to incorporate precisely the factor of thermal conductivity for wear analysis of high thermal conductivity grade such as DHA-HS1 to improve the accuracy of simulation model in the future. On the equation mentioned this paper, the wear depth depends on YS (Yield strength of the die) per dot time. The die temperature of the outermost layer that wear occurred was estimated higher than the results shown in Fig. 10. Because the YS depends on the maximum die temperature, it is important to measure the die temperature of the outermost layer during forming.

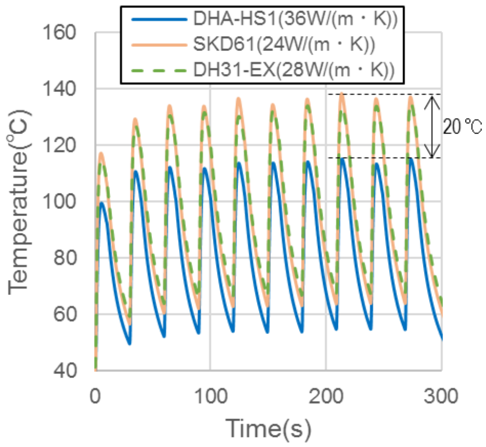

Fig. 10 Temperature of evaluation parts at 2 mm depth from the surface.

4. Summary

The die material evaluation technology by using the actual hot stamping equipment was investigated. Also, the influential factors for die wear affected by the die material properties were introduced in this study. Findings of this study are summarized as follows:

1. This test successfully evaluated die wear difference by material change because the test results using the actual hot stamping equipment showed wear volume difference between several die material properties. Therefore this evaluation technology will contribute to clarify the die wear mechanism affected by the die material properties.
2. The reason why DHA-HS1 which was developed by Daido Steel improves the die wear resistance of hot stamping is because it obtains higher hardness (≦54 HRC) than SKD61 and restrains the raising die surface temperature during forming.

This evaluation technology will be used for study of actual die wear mechanism and adhesion of plating from steel sheet mechanism and so on in the future.

DH31-EX and **DHA** are trademarks or registered trademarks of Daido Steel Co., Ltd.

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