Steel Sheets for Highly Productive Hot Stamping

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Rapid progress is being made in the application of hot-stamped, super-high strength parts to automobile bodies. Hot stamping is a technology that can solve the problems associated with high-strength steel sheet, e.g., an increased forming load and deterioration of dimensional accuracy; however, the method has suffered from low press productivity and limitation in the shapes of parts. In order to overcome these issues, a steel sheet for hot stamping has been developed via compositional design. This paper introduces the characteristics of the newly developed steel sheet and its practical applications, including a demonstration of the multi-step hot stamping.

Introduction

High-strength steel sheets have increasingly been used for automotive structural members to comply with strengthened collision safety standards and to decrease the weight for emission reduction purposes. Kobe Steel has been providing various kinds of high-strength steel sheets for cold forming. Recently, it put 1180 MPa grade steel sheets into practical use, and they were adopted for automotive body structures for the first time in the world[1), 2)]. However, high-strength steel sheets for cold forming have an issue that the forming load is increased and the dimensional accuracy is reduced as the steel sheet strength is increased[3)]; accordingly, a limited amount of 1180 MPa grade steel sheets have been put into practical use.

To solve such the issue, the application of hot stamping has been expanded[4), 5)]. Hot stamping is a process in which steel sheets are heated up to an austenite range, hot formed, and then die-quenched to form martensite structures, which can easily increase the strength up to 1500 MPa grade. In general, steel sheets for hot stamping use 22MnB5 steel (boron steel); however, it takes time to quench it to ensure the strength, and the productivity rate is about one tenth of that of steel sheets for cold forming[6)]. Accordingly, improvements in hot stamping productivity by means of compositional design[6), 7)] or improved die quenching method[8)] have been proposed.

Focusing on the issue of steel sheets for hot stamping as described above, Kobe Steel developed a steel sheet for high productivity hot stamping by means of optimized compositional design, which is introduced in this paper.

1. Concept of compositional design of developed steel

In a hot stamping process using 22MnB5 steel, steel sheets are austenitized, die quenched, and then die opened after holding until they are cooled to 200℃ or less to form the martensite structure required for achieving a strength of 1,500 MPa, as shown in **Fig. 1**.[9)] For example, if the required strength can be achieved with die opening at 600℃, the holding time for die quenching could be significantly shortened to about 3 seconds, while the conventional holding time is about 15 seconds, allowing press productivity to be improved. In conventional hot stamping, the strength to be obtained after die opening is 1,500 MPa; therefore, the subsequent piercing and trimming require laser processing for reasons of die durability and delayed fracture in a cutting area, causing an increased cost due to decreased productivity and additional investment in equipment.

Meanwhile, if the holding time for die quenching can be shortened, the steel sheet temperature after forming would still be high, and a low-strength state could be maintained. Then, multi-step hot stamping becomes possible, where piercing and trimming are performed in one press machine continuously after forming. This is expected to improve significantly the productivity of hot stamped parts.

Then, cold rolled steel sheets (thickness: 1.4 mm) with chemical compositions shown in **Table 1** were

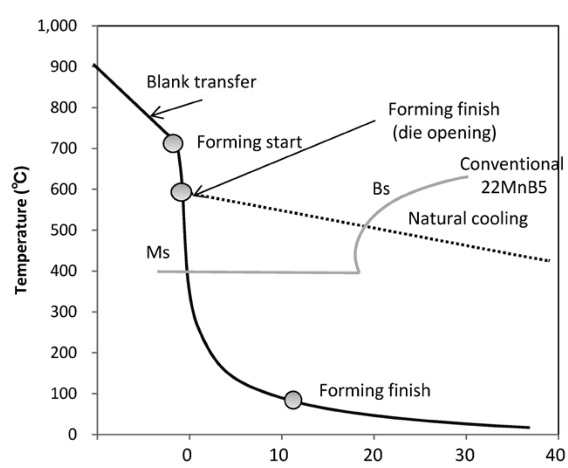

Fig. 1 Steel temperature change in conventional hot stamping

Table 1 Chemical composition of steels

(mass%)

	C	Si	Mn	Cr	Ti	B
Conventional 22MnB5	0.23	0.02	1.3	0.2	0.02	0.0029
Hi-Mn	0.23	0.20	2.1	–	0.02	0.0015
Hi-Si	0.22	1.19	1.3	0.2	0.03	0.0025
Developed steel	0.22	1.20	2.2	–	0.02	0.0015

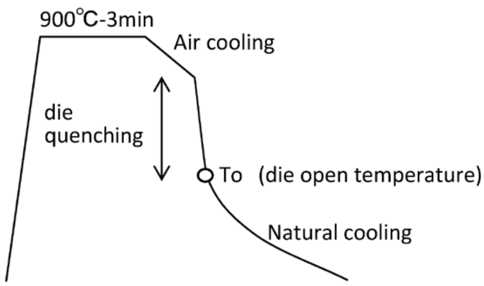

Fig. 2 Experimental method

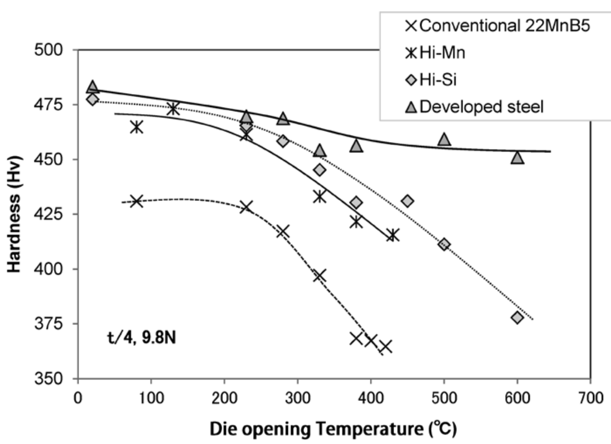

Fig. 3 Effect of die opening temperature on hardness

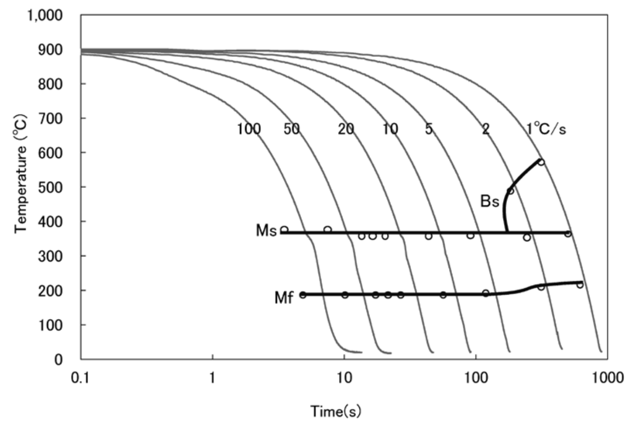

Fig. 4 CCT diagram of the developed steel

heat treated as shown in **Fig. 2**, and examined for the effect of die opening temperature (To) on hardness. **Fig. 3** shows the results. In this development, we focused on the addition of Mn and Si in order to inhibit the ferrite and bainite transformation. Si is also capable of increasing the temper softening resistance of martensite.

Hi-Mn steel with increased Mn, compared with 22MnB5 steel, is capable of increasing hardness at any die opening temperature. However, in order to obtain a reliable hardness of 450 HV or more, which is equivalent to a strength of 1,500 MPa, it is necessary to cool down to 200℃ or less. Hi-Si steel with increased Si gives the same results as Hi-Mn steel. By contrast, the developed steel sheet with increased Si and Mn shows excellent hardenability, with a hardness of 450 HV or more being obtained even at a die opening temperature of 600℃, with a small change in hardness depending on the die opening temperature. Thus, the developed steel sheet, which can ensure hardness without die quenching, allows the holding time for die quenching to be significantly shortened, and further processing to be added within one press machine.

Fig. 4 shows the CCT diagram of the developed steel sheet. With the developed steel sheet, the ferrite and bainite transformation is inhibited by the addition effect of Mn and Si, and the critical cooling rate is about 5℃/s, while it is about 30℃/s in the case of conventional 22MnB5 steel.

In order to achieve a stable hardness in stamped parts, the dependency of the cooling rate below the Ms point (the secondary cooling rate) should be low. Accordingly, the effect of the secondary cooling rate on hardness was examined, using test material manufactured from a cold rolled steel sheet, which was heated up to 900℃, quenched to 380℃, and then cooled at different secondary cooling rates (CR_2) as shown in **Fig. 5**. **Fig. 6** shows the results. While hardness is significantly decreased by the effect of the secondary cooling rate in the case of 22MnB5 steel, the cooling rate dependency is small, and the hardness is stable in the case of the developed steel. This seems to be due to the fact that in the case of the developed steel the temper softening resistance is increased by the addition of Si and the hardness is stable, while in the case of 22MnB5 steel the self-tempering of martensite progresses as the cooling rate is decreased.

With the developed steel, strength can be ensured by adding Mn and Si appropriately under a wide range of cooling conditions after heating, and a stable hardness can be obtained in a practical cooling rate range (5℃/s or more) below 380℃.

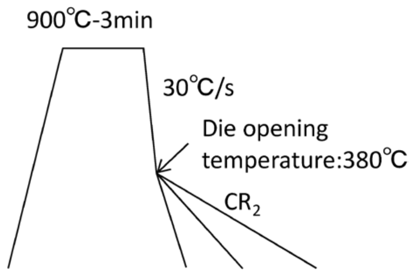

Fig. 5 Experimental method

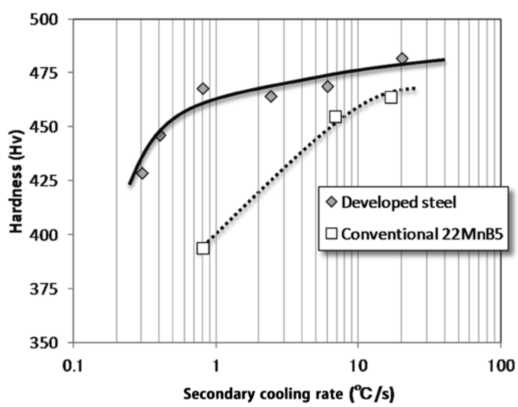

Fig. 6 Effect of secondary cooling rate on hardness

2. Characteristics of developed steel sheet

2.1 Basic characteristics after hot stamping

We manufactured the JIS No. 5 test pieces from a cold rolled steel sheet of 1.4 mm in thickness, by heating it up to 900℃, forming it into the shape shown in **Fig. 7** (b) using the die shown in (a), and then cutting out the test piece from the position shown in (b). The holding time for die quenching was set to 2 levels: 0 second (without holding) and 15 seconds. The tensile test results using these test pieces are shown in **Table 2**. While 22MnB5 steel showed a strength of 1,500 MPa or more with a holding time for die quenching after hot stamping of 15 seconds, the developed steel showed a strength of 1,500 MPa or more even without holding time for die quenching.

Fig. 8 shows the microstructures of 22MnB5 steel with holding time for die quenching for 15 seconds, and the developed steel without holding time for die quenching. Both steels have single phase structures of martensite; however, the developed steel produces less carbide compared to 22MnB5 steel. This seems to be due to the effect of Si inhibiting carbide. It presumably contributes to an increase in temper softening resistance, and makes it possible to obtain high-strength without holding time for die quenching.

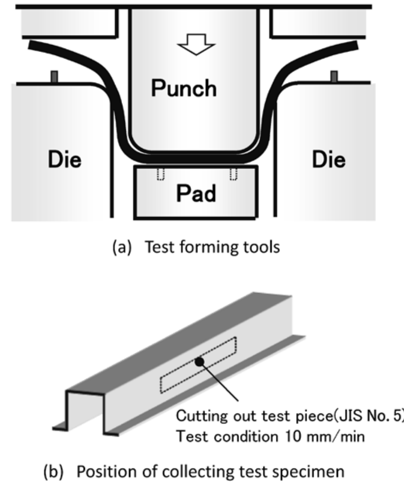

Fig. 7 Experimental methods for die pressing

Table 2 Effect of holding time for die quenching on mechanical properties

	Holding time at die quenching (s)	Die opening temperature (℃)	YS (MPa)	TS (MPa)	EL (%)
Developed steel	0	about 600	1,056	1,504	10
Conventional 22MnB5	15	about 200	1,149	1,512	8
	0	about 600	1,028	1,080	6

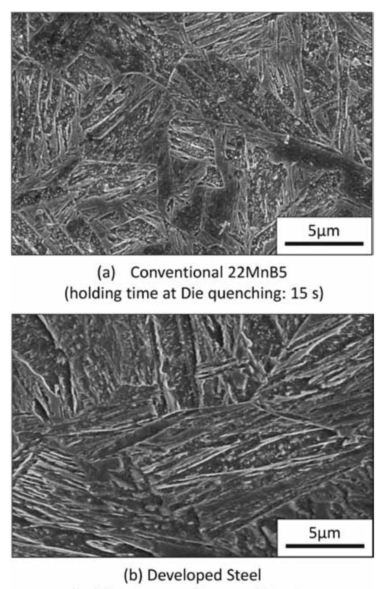

Fig. 8 Microstructure of die quenched steel

2.2 Practical characteristics

In order to evaluate spot weldability, chemical conversion treatability and low-temperature toughness, we heated the developed cold rolled steel sheet of 1.4 mm in thickness (t) up to 900℃, forcibly cooled it to 380℃, and then cooled it naturally. We prepared the test material by removing the surface scale by shot blasting using iron balls of 0.3 mm in diameter at an air pressure of 0.4 to 0.5 MPa. It has been proven that the tensile strength (TS) is of 1500 MPa grade.

We spot welded the test material in the conditions shown in **Table 3** to examine the effect of the current on the nugget diameter. **Fig. 9** shows the results. The welding current stands at 6.0 kA when the nugget diameter is $4\sqrt{t}$, and the welding current stands at 8.0 kA when expulsion is developed. This means that a suitable welding current range exists around 2.0 kA, which is comparable with that of conventional 22MnB5 steel and other high-tensile steels. **Fig.10** shows the effect of the welding current on cross tension strength. A stable cross tension strength of 7,000 N or more was obtained within the suitable welding current range, which is comparable with that of conventional 22MnB5 steel.

Chemical conversion treatability was evaluated using a commercial treatment solution (Surfdyne SD 6350 from Nippon Paint). **Fig.11** shows the phosphate film on the surface of the developed steel sheets. No lack of hiding (exposure of substrate) is observed, and the crystal grain size and form are also favorable.

Table 3 Spot welding conditions

Elctrode tip	Dome type Cu-Cr, tip diameter: 6 mm
Elctrode force	4,000 N
Welding time	20 cycles (60Hz)

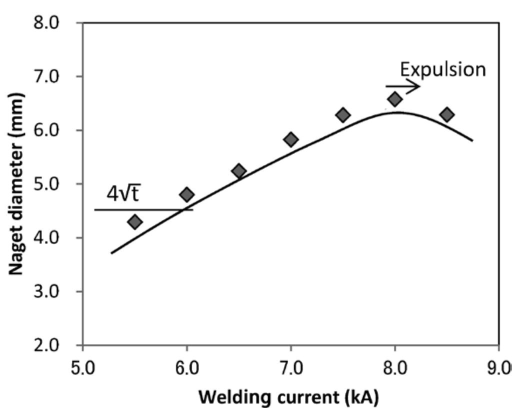

Fig. 9 Relationship between spot welding current and nugget diameter

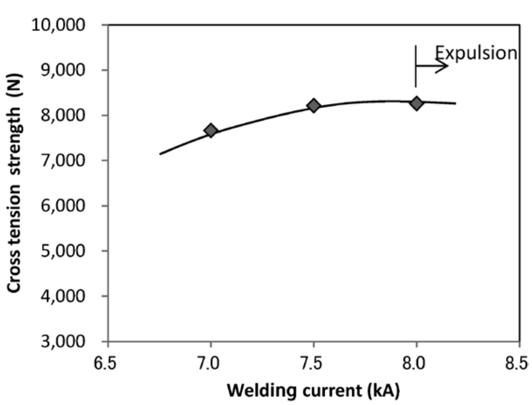

Fig.10 Relationship between spot welding current and cross tension strength

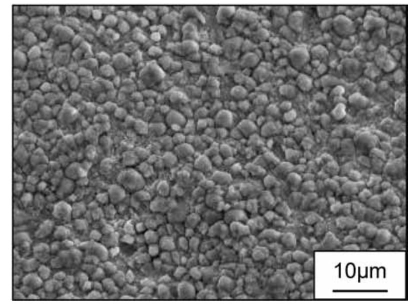

Fig.11 Micrograph of phosphate crystal on developed steel

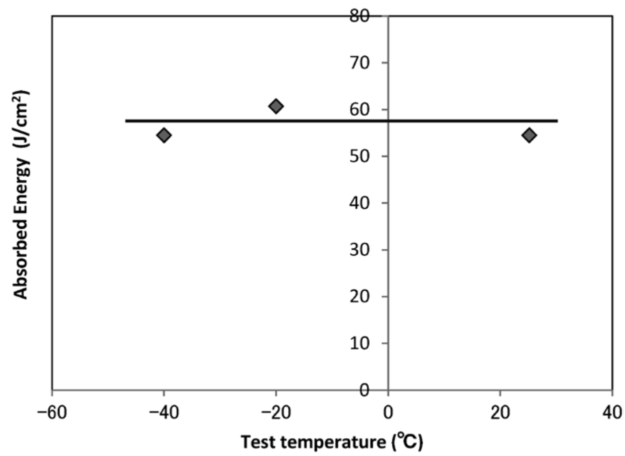

Fig.12 Results of Charpy test of developed steel

Fig.12 shows the evaluation results on the JIS No. 4 Charpy test pieces manufactured. No brittle fracture surface is observed at any test temperature, and a comparable absorbed energy is shown at -40℃ and room temperature; accordingly, the practical characteristics of the low-temperature toughness are satisfied.

3. Evaluation of usefulness of developed steel sheet

3.1 Verification of multi-step hot stamping

It was expected that the excellent hardenability and hardness stability of the developed steel would also be effective in hot stamping where the contact with the die tends to be insufficient[10], including multi-step hot stamping and different-thickness welded parts in tailored blanks.

Accordingly, we conducted a verification experiment for multi-step hot stamping. In this verification, multiple die sets were manufactured to form into the part shape as shown in **Fig.13** - Stage #3 in 3 steps, which seems to be difficult to form in the conventional single step. Piercing and trimming were included in Stage #2 and Stage #3,

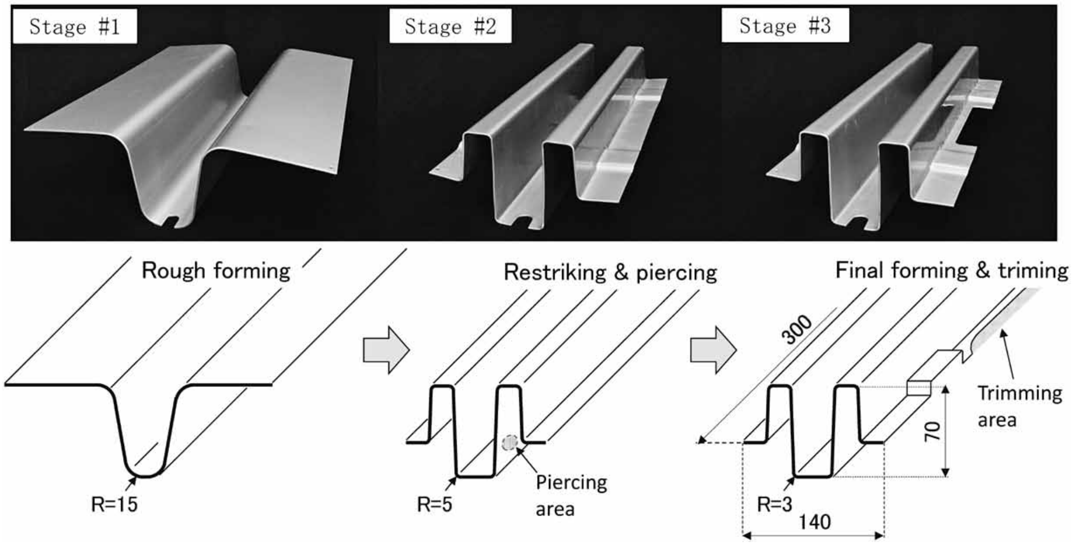

Fig.13 Changes in shape of member in multi-step hot stamping

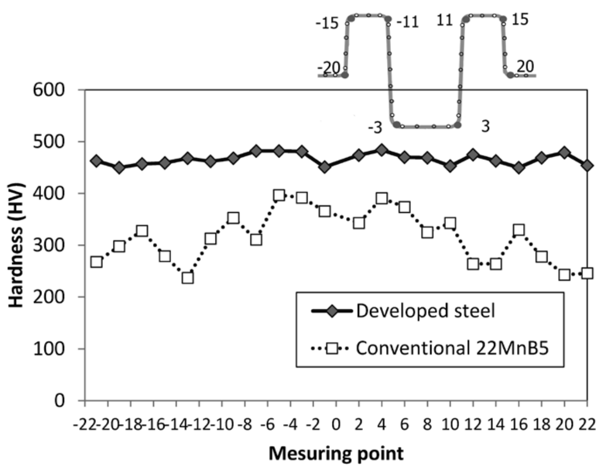

Fig.14 Hardness distributions of specimens

respectively. These die sets were mounted to a crank press machine. A blank of developed steel (1.4 mm in thickness) was heated to 900℃, and then transferred to the die in Stage #1. It was conveyed among the die sets using a robot, while the cycle time of the crank press machine was set to 20 shots per minute. The die opening temperature in Stage #3 was about 300℃, and the dimensional accuracy was favorable.

Fig.14 shows the hardness distribution measured at various points on the parts obtained. The 22MnB5 steel formed in the same process as above did not satisfy the hardness of 450 HV at any measuring point, with a large variation in hardness within the part. Meanwhile, the developed steel showed a stable hardness of 450 HV or more throughout the part. This indicates that the developed steel sheet makes possible such multi-step hot stamping, and that not only complicated shapes but also piercing and trimming can be processed in a single press machine.

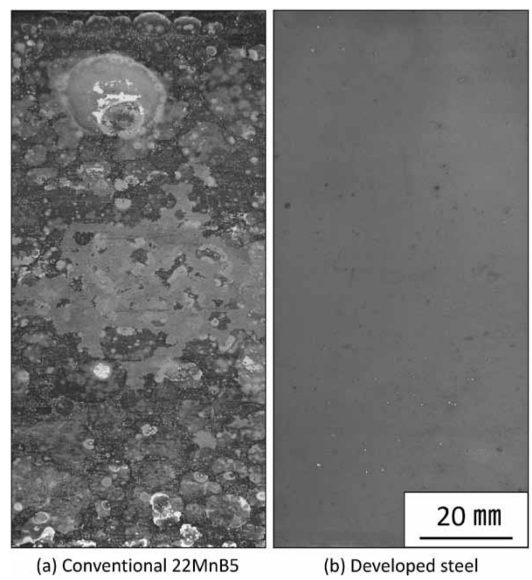

Fig.15 Sheet surface after die quenching

3.2 Surface characteristics of developed steel

Cold rolled steel sheets of 22MnB5 steel and the development steel were heated to 900℃ in an atmospheric furnace, air cooled, and then die quenched from 700℃ to room temperature. **Fig.15** shows the appearance of the surface of each steel sheet. While a large amount of scale is peeled off in the case of 22MnB5 steel, the developed steel is excellent in scale adhesion, which shows almost no peeling off. It is known that Si increases the high-temperature oxidation resistance of steel[11), and inhibits the production of oxidized scale. The developed steel sheet seems to have increased the adhesion, because scale was thinned by adding Si by 1.0% or more.

Such characteristics of the developed steel sheets are expected to prevent scale from peeling off in the die in an actual press, and prevent any surface defects in stamped parts caused by scale inclusion.

Conclusions

Kobe steel has developed a new steel sheet for highly productive hot stamping, and this paper has introduced its main characteristics. The developed steel sheet shows not only high productivity but also excellent hardness stability. In addition, it has also characteristics that satisfy customers' requirements, in terms of spot weldability, chemical conversion treatability and low-temperature toughness; therefore, it is expected to be used for multi-step hot stamping. Furthermore, it contributes to stabilizing the hot stamping process, because its excellent scale adhesion prevents scale from peeling off in the die.

Kobe Steel will continue striving to develop the steel sheets that satisfy its customers and contributes to expanding the application of high-strength steel sheets.

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