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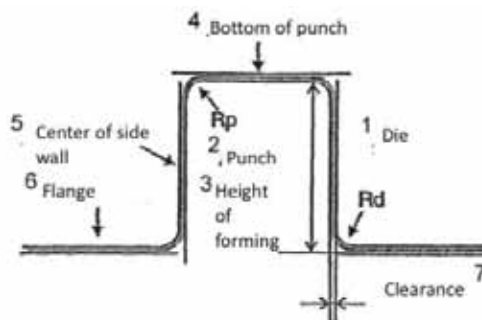
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[Continued]

(54) Title of the Invention: METHOD FOR HOT FORMING AND HOT-FORMED MEMBERS



1...DIE
2...PUNCH
3...HEIGHT OF FORMING
4...BOTTOM OF PUNCH
5...CENTER OF SIDE WALL
6...FLANGE
7...CLEARANCE

(57) **Abstract:** A method for hot forming, wherein in the cooling step of hot pressing, a formed product is first cooled at a rate of a critical cooling rate or higher down to the Ms point thereof and then cooled at a rate of 25 to 150°C/s from the Ms point to 200°C; and a hot pressed member which has been formed by the method and has a Vickers hardness of less than (the maximum quench hardness - 10) and (the maximum quench hardness - 100) or more. The hot pressed member is manufactured from a high strength steel sheet by means of hot pressing and exhibits a stable strength and toughness in combination.

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the "Guidance Notes for Codes and Abbreviations,"
which are published in the prefaces of the respective
PCT Gazettes that are issued periodically.

(57) Abstract: Hot-pressed members with both stable strength and toughness are manufactured from a high-strength steel sheet by means of hot pressing. In the cooling step of hot pressing, the formed product is first cooled to the Ms point at a rate of the critical cooling rate or higher and then cooled in the temperature range from the Ms point to 200°C at a cooling rate of 25–150°C/sec. The Vickers hardnesses of the hot-pressed members are less than the maximum quench hardness – 10 and equal to or greater than the maximum quench hardness – 100.

Specifications**Method for Hot Forming and Hot-Formed Members****Field of Technology**

This invention concerns hot-formed members, including mechanical structural parts, such as automobile body structural parts, suspension parts, etc., and a method for hot forming which is used in manufacturing them. More specifically, this invention concerns hot-pressed members and a hot-pressing method for that purpose.

Below, this invention will be explained by using hot-press forming as an example, but this invention can also be applied to hot-forming methods other than press forming, such as roll forming, forging, etc.

Prior Art

In recent years, in order to reduce the weights of automobiles, efforts have been made to increase the strengths of the steel materials by giving them tensile strengths of 590 MPa or higher, for example, and reducing their weights. In this kind of trend, as the strengths of the thin steel plates that are widely used in automobiles have been increased, their press-forming abilities have decreased, and it has been difficult to produce complex shapes. Specifically, as their strengths have increased, their ductilities have decreased and fractures are caused in places which have high degrees of working. The spring-back and wall camber have become larger, and the problem of worsening dimensional accuracy has arisen.

Therefore, in the case of steel plates with high strengths, especially ones with tensile strengths of 780 MPa or higher, it is not easy to produce parts by using press forming as a method of cold working. These high-strength steel plates can be worked by using roll forming instead of press forming, but roll forming can only be employed with parts which have uniform cross sections in the longitudinal direction, so that the shapes of the products to which it can be employed are limited.

On the other hand, as disclosed in UK Patent No. 1490535, in a hot press method in which heated steel plates are press formed, the steel plates are heated to high temperatures so that the steel plate material is softened and becomes highly ductile. As a result, complex shapes can be formed with good dimensional accuracy in the heated state. Furthermore, by the method of die cooling, that is, heating the steel plates to the austenitic temperature range and quenching them in dies, increasing the strengths of the plates by martensitic transformation, that is, hardening, can be accomplished at the same time.

However, when die cooling is used in the hot press method, the quench hardness of the material is in the range of Hv 400–490, which is insufficient, in the case of 0.2% C materials. In addition, there is the problem that the hardness of the material has an extremely large dispersion.

A hot press technique which was developed by the Swedish company Plunger was disclosed in Advanced Materials & Processes, Vol. 146, No. 6, 12/94, p. 16. In this technique, the die quenching is done starting from 980°C. The die temperature is assumed to be in the range of room temperature to several tens of °C, since it is not stated that the die is heated in that disclosure.

In the Japanese Unexamined Patent Application Heisei 8 [1996]-269615, rapid-quenching hot rolled steel plates are disclosed containing C: 0.18–0.30%, Si: 0.01–1.0%, Mn: 0.2–1.5%, P: $\leq 0.03\%$, S: $\leq 0.02\%$, sol. Al: $\leq 0.08\%$, Cr: 0.1–0.5%, B: 0.0006–0.0040%, and N: $\leq 0.01\%$, and in some cases also at least one of Cu: $\leq 0.5\%$, Ni: $\leq 0.3\%$, and Ti: 0.01–0.05%, with the remaining content being iron. These steel plates are given high strengths by high-frequency quenching after they have been cold worked.

Disclosure of the Invention

This invention provides hot-formed members which can be produced from high-strength steel plates by using a hot-forming method and which also have stabilized strengths and toughnesses, as well as a hot-forming method for producing them.

More specifically, this invention provides hot-pressed members, including mechanical structural parts, such as automobile body structural parts, suspension parts, etc., and a method for hot pressing which is used in manufacturing them.

By means of this method, it is possible to produce hot-formed members that also have stabilized strengths and toughnesses from hot forming; in this method, when the members are cooled after forming, for example, when they are die-cooled, the average cooling rate in the temperature range below the Ms point (the temperature at which martensite begins to be formed from austenite) is kept within a specific range.

In one embodiment, this invention concerns a method of hot forming in which a steel plate that has a composition essentially containing C: 0.15–0.45%, Mn: 0.5–3.0%, Cr: 0.1–0.5%, Ti: 0.01–0.1%, B: 0.0002–0.004%, Si: $\leq 0.5\%$, P: $\leq 0.05\%$, S: $\leq 0.05\%$, Al: $\leq 1\%$, and N: $\leq 0.01\%$, as well as one or two or more of Ni: $\leq 2\%$, Cu: $\leq 1\%$, Mo: $\leq 1\%$, V: $\leq 1\%$, and Nb: $\leq 1\%$, with the remaining content being Fe and unavoidable impurities, is heated and kept at the Ac₃ point or

higher, after which it is formed to the final product shape. By means of this invention, during the forming or when the material is cooled from the forming temperature after forming, a quenching process is performed in which the cooling rate to the Ms point of the formed member is at or above the critical cooling rate, and the average cooling rate from the Ms point to 200°C is 25–150°C/sec. Furthermore, in this invention, the term “critical cooling rate” means the upper critical cooling rate.

In another embodiment, this invention concerns hot-formed members that have been formed from a steel plate which has the aforementioned steel composition. These hot-formed members have a hardness after the hot forming which is less than the maximum quench hardness – 10 and equal to or greater than the maximum quench hardness – 100.

In a favorable embodiment of this invention, the hot forming is hot-press forming which is performed by using a die for press forming.

By means of this invention, it is possible to make hot-press members which have both stabilized strength and toughness. Therefore, this invention contributes greatly to expanding the applications of high-strength steel plates as a material for press-formed members.

Simple Explanation of the Drawings

Fig. 1 is a schematic explanatory drawing of the hot-forming method.

Fig. 2 is a schematic drawing which shows the shape of a test piece for measuring the critical cooling rate.

Detailed Explanation of the Invention

The reasons for employing the aforementioned steel composition and forming conditions in this invention are as follows. In this invention, “%” in the steel composition, that is, the chemical composition of the steel, means “wt %.”

1. Composition of the base steel plate

C: 0.15–0.45%

Carbon (C) is an extremely important element which raises the hardening ability of the steel plate and principally determining its strength after hardening. Furthermore, it is an element which lowers the Ac₃ point and furthers the lowering of the hardening treatment temperature. However, if the C content is less than 0.15%, its effect will be insufficient, and if it exceeds 0.45%, there will be a deterioration in the toughness of the hardened parts. The lower limit of

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the desirable C content is 0.16% and its upper limit is 0.35%.

Mn: 0.5–3.0%

Manganese (Mn) is an extremely effective element for raising the hardening ability of the steel plate and stabilizing and maintaining its strength after hardening. Furthermore, it is an element which lowers the A_{c3} point and furthers the lowering of the hardening treatment temperature. However, if the Mn content is less than 0.5%, its effect will be insufficient, and if it exceeds 3.0%, there will be a deterioration in the toughness of the hardened parts. The range of the desirable Mn content is 0.8–2.0%.

Cr: 0.1–0.5%

Chromium (Cr) is an effective element for raising the hardening ability of the steel plate and stabilizing and maintaining its strength after hardening. However, if the Cr content is less than 0.1%, its effect will be insufficient, and if it exceeds 0.5%, its effectiveness will be saturated and a useless increase in cost will be invited. The range of the desirable Cr content is 0.15–0.30%.

Ti: 0.01–0.1%

Titanium (Ti) is an effective element for raising the hardening ability of the steel plate and stabilizing and maintaining its strength after hardening. However, if the Ti content is less than 0.01%, its effect will be insufficient, and if it exceeds 0.1%, its effectiveness will be saturated and a useless increase in cost will be invited. The range of the desirable Ti content is 0.015–0.03%.

B: 0.0002–0.004%

Boron (B) is an important element for raising the hardening ability of the steel plate and further raising the stabilizing and maintaining of its strength after hardening. However, if the B content is less than 0.0002%, its effect will be insufficient, and if it exceeds 0.004%, its effectiveness will be saturated and an increase in cost will be invited. The range of the desirable B content is 0.0005–0.0025%.

Si: $\leq 0.5\%$, P: $\leq 0.05\%$, S: $\leq 0.05\%$, Al: $\leq 1\%$, and N: $\leq 0.01\%$

All of these elements are also effective in raising the hardening ability of the steel plate and raising the stabilizing of its strength after hardening. However, if their contents are above the respective upper limits mentioned above, their effectiveness will be saturated and cost increases will be invited.

1 or 2 or more of Ni: $\leq 2\%$, Cu: $\leq 1\%$, Mo: $\leq 1\%$, V: $\leq 1\%$, and Nb: $\leq 1\%$

All of these elements are also effective in raising the hardening ability of the steel plate and raising the stabilizing of its strength after hardening; therefore, 1 or 2 or more of them are contained in the composition of the steel plate. However, even if their contents are above their respective upper limits, the effectiveness will be small and useless cost increases will be invited. Therefore, the contents of these alloy elements are made within the aforementioned ranges.

The steel plate which is used in this invention is heated to the austenite temperature range and an austenite transformation is caused when it is heated before the forming; therefore, its mechanical properties at room temperature before the heating are not important and its metal structure before the heating is not particularly limited. Consequently, the basic steel plate that is used may be a hot rolled steel plate, cold rolled steel plate, or plated sheet steel, and the method for producing it is not particularly limited. Examples of the plated sheet steels are aluminum-based plating steel sheet (that is, aluminized and aluminum alloy plating steel sheets) and zinc-based plating steel sheet (that is, zincified and zinc alloy plating steel sheets). The plated steel sheets may be electroplated steel sheets or molten plated sheet steels. Moreover, alloyed hot dip galvanized steel sheets may also be used.

2. Heating conditions and holding time

In the die cooling at the time of the hot pressing, in order to perform the hardening treatment after forming the formed members, that is, the hot-pressed members, the base steel plate must first be heated to the austenite temperature range and put into the austenite phase. For this, it is heated at or above the Ac_3 point and held for 1 minute or more at this temperature under the ordinary conditions. No particular upper limit is set for the holding time, but it is desirable for the upper limit to be about 10 minutes, considering the efficiency of the actual production.

3. Cooling rate at the time of the hot pressing

The cooling rate during the hot pressing (in the die) or after the hot pressing (after deforming) is a parameter which plays an extremely important role in obtaining stabilized strength and toughness in the hot-pressed members.

In order to give the hot-pressed members stabilized strength and toughness, it is not essential to make the structure after the hot pressing a complete martensite structure, but rather to make it an auto-tempered martensite structure. In order to make this auto-tempered martensite structure, in the cooling step during or after the hot pressing, it is cooled to the M_s

point at a cooling rate at or above the critical cooling rate, so that a diffusion transformation does not occur, and in the temperature range from the Ms point to 200°C, it is cooled at a slow cooling rate, that is, an average cooling rate of 25–150°C/sec. By performing this kind of cooling, the tempering is performed at the same time that the martensite transformation occurs; therefore, there is little variation in strength and a martensite structure with excellent toughness is obtained. Desirable cooling rates from the Ms point to 200°C are in the range of 30–120°C/sec.

4. The method of forming in the hot-pressing method

Shapes of the forming in the hot-pressing method include bending, drawing, stretch forming, hole expansion, and flanging. Furthermore, if a means for cooling the steel plate simultaneously with or immediately after the forming is provided, this invention may also be applied to forming methods other than hot pressing, for example, roll forming.

5. Hot-pressed members

The members which are produced by the hot-pressing method described above have tempered martensite structures with little variation in strength and excellent toughness. Moreover, since the strength obtained is the strength of the tempered martensite structure, the hardness is lower than the hardness (Hv), that is, the maximum quench hardness – 10, and since they are not excessively tempered, it is equal to or greater than the maximum quench hardness – 100. If the value of Hv becomes higher than the maximum quench hardness – 10, the toughness will be lowered, and if it is less than the maximum quench hardness – 100, the strength will be lowered. Desirable values of Hv are in the range of less than the maximum quench hardness – 20 or lower and the maximum quench hardness – 80 or higher.

Here, the “maximum quench hardness” is the hardness that is obtained when a water-cooling treatment is performed after the material is kept for 10 minutes in a salt bath heated to 900°C.

6. The method of cooling at the time of the hot-press forming

Ordinarily, since steel dies are kept at room temperature or several tens of degrees Celsius, cooling of the formed members is accomplished by these steel dies when hot-press forming is done. Therefore, in order to change the cooling rate, it is understood that the die dimensions may be changed and the thermal capacity changed.

Moreover, the cooling rate can also be changed by changing the die material to a dissimilar metal (for example, copper, etc.). Moreover, if the die dimensions or material are not changed, the cooling rate can also be changed by changing the quantity of cooling water, when a water-

cooled die is used. In this case, also, the cooling rate of the press-formed members can also be changed by, for example, using a die which has a number of grooves cut in it beforehand and causing water to flow through the grooves during the pressing, or raising the pressing machine during the press formation and causing water to flow between the dies.

Therefore, the following means are considered for changing the cooling rate before and after the Ms point:

- (1) transferring to a die with a different thermal capacity or a room-temperature die immediately after the Ms point is reached;
- (2) in the case of using a water-cooled die, changing the quantity of water flowing in the die immediately after the Ms point is reached; and
- (3) changing the quantity of water flowing between the die and the member immediately after the Ms point is reached.

Working Examples

The following working examples are examples of this invention, but the invention is not limited in any way by them.

In these examples, steel plates (1.0 mm thick) with the composition shown in Table 1 are used as the base steel plates. These steel plates were made by hot or cold rolling slab ingots which were made in the laboratory. Furthermore, for steel No. 2, hot dip galvanizing (60 g/m² of Zn adhering per side) was performed, after which an alloying treatment was performed (Fe content in the plating film 15 mass %).

These steel plates were cut into pieces 40 W x 60 L (mm) and heated at 900°C x 5 minutes in a furnace with an air atmosphere, after which they were removed from the furnace and hot-press forming was performed immediately thereafter with a flat plate steel die. For steel No. 2, the hot-press forming was performed by changing the cooling conditions (tests Nos. 2, 5, and 6).

The Vickers hardnesses of the hot-pressed members that were obtained were measured (load 9.8 N, number of measurements: 5). Moreover, the cooling rates after the press forming were measured by attaching thermocouples to the steel plates. The cooling rates were primarily changed by changing the die dimensions.

Furthermore, for test No. 2, the cooling rate was adjusted by injecting water between the dies immediately after the steel plate temperature reached the Ms point.

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The maximum quench hardness was taken to be the hardness that was obtained when a water-cooling treatment was performed after the material was kept for 10 minutes in a salt bath heated to 900°C.

Table 2 shows the results that were obtained, in terms of the Ac₃ points, Ms points, and critical cooling rates of each kind of steel, which were measured by the following methods.

Cylindrical test pieces 3.0 mm in diameter and 10 mm long (Fig. 2) were cut from the hot-rolled plates and heated in air to 950°C at a temperature rise rate of 10°C/sec. After they were kept at this temperature for 5 minutes, they were cooled to room temperature at various cooling rates. The Ac₃ and Ms points were measured by measuring the changes in the thermal expansions of the test pieces during the heating and cooling. Moreover, the Vickers hardnesses (load 49 N, number of measurements: 5) of the test pieces that were obtained were measured, and their structures were observed, and the critical cooling rates were estimated from these results.

Table 1

Steel No.	Chemical composition (mass %; remainder: essentially Fe)														
	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Ti	Nb	Al	B	N
1	0.16	0.02	1.36	0.019	0.004	0.01	0.01	0.19	—	0.01	0.03	—	0.06	0.0013	0.008
2	0.21	0.25	1.20	0.008	0.002	0.01	0.02	0.20	—	0.01	0.02	0.01	0.05	0.0007	0.005
3	0.33	0.11	1.53	0.001	0.001	—	—	0.20	—	—	0.02	—	0.04	0.0015	0.001
4	0.42	0.11	1.51	0.001	0.001	—	—	0.20	0.01	—	0.02	—	0.04	0.0014	0.001

Table 2

Test No.	Steel No.	Ac ₃ point (°C)	Ms point (°C)	Critical cooling rate (°C/sec)	Measured cooling rate to Ms point (°C/sec)	Average cooling rate from Ms point to 200°C	Hardness after hot pressing (HV)	Maximum quench hardness (HV)	Die size (t x W x L mm)	Notes
1	1	860	450	25	60	40	418	461	50 x 400 x 400	Working Examples
2	2	823	410	17	60	100	451	501	50 x 400 x 400 ^{*1}	
3	3	823	390	10	60	40	560	652	50 x 400 x 400	
4	4	785	370	10	60	30	683	750	50 x 400 x 400	
5	2	823	410	17	60	22 ^{*3}	390	501	50 x 50 x 400	Comparison Examples
6	2	823	410	17	60	200 ^{*3}	500	501	50 x 50 x 400 ^{*2}	

*1 Water injected between dies immediately after the Ms point

*2 Pressing machine raised immediately after the Ms point and test pieces immediately put into a water bath

*3 Conditions outside the range of this invention

In Tests Nos. 1–4 in these examples of the invention, since the average cooling rate from the Ms point to 200°C was correct, the hardnesses obtained were lower than the maximum quench hardness – 10 and higher than the maximum quench hardness – 100.

In Test No. 5, a comparison example, the cooling rate was above the critical cooling rate but the average cooling rate from the Ms point to 200°C was slow; therefore, sufficient hardness was not obtained. Moreover, in Test No. 6, another comparison example, the average cooling rate from the Ms point to 200°C was too rapid; therefore, it was too hard. Here, the meaning of “too hard” is not that the absolute value of the hardness was high, but that it was near the maximum quench hardness.

In the case of the steel plate of Test No. 2, an example of this invention, the plate was heated at 900°C x 5 minutes in a furnace with an air atmosphere, removed from the furnace and hat-type hot-press forming was performed [blank size: 1.0 T x 80 W x 320 L (mm)].

A schematic drawing of the hat-forming method used in this case is shown in Fig. 1. The hot-press forming conditions used were: forming height 70 mm, Rd (die shoulder R) 8 mm, Rp (punch shoulder R) 8 mm, clearance 1.0 mm, and blank holding force 12.7 kN.

Moreover, the Vickers hardnesses were measured in the bottom punch part, middle side wall part, and flange part of the hot-press formed member (load 9.8 N, number of measurements: 5). The cooling rates at these locations were measured by attaching thermocouples at each location. The results are shown in Table 3.

Table 3

	Average cooling rate from Ms point to 200°C (°C/sec)	Hardness after hot pressing (HV)
Bottom of punch	55	460
Center of side wall	100	471
Flange	120	480

Since the average cooling rate from the Ms point to 200°C was correct in each location, good hardnesses were obtained. Moreover, it can be seen that the variation in hardness within the same member was small.

Claims

1. A method of hot forming which is a method in which steel plates having essentially the steel compositions of C: 0.15–0.45%, Mn: 0.5–3.0%, Cr: 0.1–0.5%, Ti: 0.01–0.1%, B: 0.0002–0.004%, Si: $\leq 0.5\%$, P: $\leq 0.05\%$, S: $\leq 0.05\%$, Al: $\leq 1\%$, and N: $\leq 0.01\%$, as well as one or two or more of Ni: $\leq 2\%$, Cu: $\leq 1\%$, Mo: $\leq 1\%$, V: $\leq 1\%$, and Nb: $\leq 1\%$, with the remaining content being Fe and unavoidable impurities, are heated and kept at a temperature of the Ac_3 point or higher, after which they are formed to the final product shape; moreover, when they are cooled from the forming temperature during or after the forming, the cooling rate to the Ms point of the formed member is at or above the critical cooling rate and a quenching treatment is performed in which they are cooled at an average cooling rate from the Ms point to 200°C in the range of 25– $150^\circ\text{C}/\text{sec}$.

2. The method of hot forming in Claim 1 in which the aforementioned forming is performed by using a press-forming die.

3. The method of hot forming in Claim 1 or Claim 2 in which, after the aforementioned forming is performed by using a die for press forming, the cooling is performed by injecting water between the dies.

4. Hot-formed members, characterized in that they are constituted from steel plates which have essentially the steel compositions of C: 0.15–0.45%, Mn: 0.5–3.0%, Cr: 0.1–0.5%, Ti: 0.01–0.1%, B: 0.0002–0.004%, Si: $\leq 0.5\%$, P: $\leq 0.05\%$, S: $\leq 0.05\%$, Al: $\leq 1\%$, and N: $\leq 0.01\%$, as well as one or two or more of Ni: $\leq 2\%$, Cu: $\leq 1\%$, Mo: $\leq 1\%$, V: $\leq 1\%$, and Nb: $\leq 1\%$, with the remaining content being Fe and unavoidable impurities, and their hardnesses after the hot forming are Vickers hardnesses which are less than the maximum quench hardness – 10 and equal to or greater than the maximum quench hardness – 100.

5. Hot-formed members of Claim 4 in which the aforementioned hot forming is hot-press forming.

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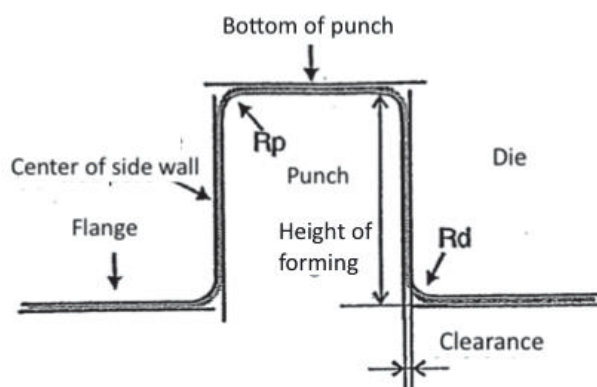


Fig. 1

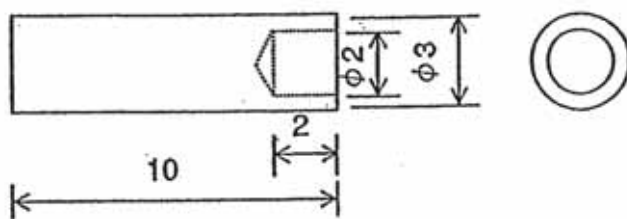


Fig. 2

DECLARATION OF JON JOHANNING

I, Jon Johanning, declare the following:

1. I am over 18 years of age and competent to make this declaration.
2. I am a qualified Japanese to English translator as certified by the American Translators Association.
3. I have translated the attached patent application regarding International Publication No. WO 2004/106573 A1 (PCT/JP2004/007654), bearing a publication date of December 9, 2004.
4. I affirm that the translated text has been translated and edited to the best of my ability and knowledge to accurately reflect the content, meaning, and style of the original text. I hereby certify under penalty of perjury under the laws of the United States of America that the foregoing constitutes, pursuant to my knowledge and belief, a true and correct translation of the original document.
5. I declare that all statements made herein of my knowledge are true, and that all statements made on information and belief are believed to be true, and that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.



Jon Johanning

Dated and signed on May 3,
2019.

(19) 世界知的所有権機関
国際事務局



(43) 国際公開日
2004 年 12 月 9 日 (09.12.2004)

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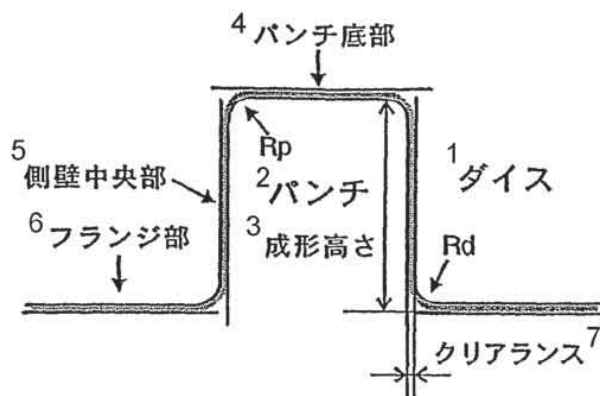
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[続葉有]

(54) Title: METHOD FOR HOT FORMING AND HOT FORMED MEMBER

(54) 発明の名称: 熱間成形法と熱間成形部材



- 1...DIE
2...PUNCH
3...HEIGHT OF FORMING
4...BOTTOM OF PUNCH

- 5...CENTER OF SIDE WALL
6...FLANGE
7...CLEARANCE

(57) Abstract: A method for hot forming, wherein in the cooling step of hot pressing, a formed product is first cooled at a rate of a critical cooling rate or higher down to the Ms point thereof and then cooled at a rate of 25 to 150°C/s from the Ms point to 200°C; and a hot pressed member which has been formed by the method and has a Vickers hardness of less than (the maximum quench hardness - 10) and (the maximum quench hardness - 100) or more. The hot pressed member is manufactured from a high strength steel sheet by means of hot pressing and exhibits a stable strength and toughness in combination.

[続葉有]

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(57) 要約: 高強度鋼板から、安定した強度と靱性を併せ持つ熱間プレス部材を熱間プレスにより作製する。熱間プレス時の冷却過程において、 M_s 点までは臨界冷却速度以上で冷却し、 M_s 点から 200°C までの温度範囲の冷却速度を $25\sim 150^{\circ}\text{C/s}$ とする。熱間プレス部材のビッカース硬さは、(最高焼入れ硬さ-10) 未満、かつ (最高焼入れ硬さ-100) 以上である。

明 細 書

熱間成形法と熱間成形部材

技術分野

本発明は、自動車のボディー構造部品、足回り部品等を初めとする機械構造部品等の熱間成形部材と、その製造に使用される熱間成形方法に関する。さらに詳述すれば、本発明は、熱間プレス部材とそのための熱間プレス方法に関する。

以下では、熱間プレス成形を例にとって本発明を説明するが、本発明はロール成形、鍛造等のプレス成形以外の熱間成形にも適用可能である。

背景技術

近年、自動車の軽量化のため、例えば引張強さ590 MPa 以上というように鋼材の高強度化を図り、使用重量を減ずる努力が進んでいる。自動車に広く使用される薄鋼板では、そのような傾向の下、鋼板強度の増加に伴って、プレス成形性が低下し、複雑な形状を製造することが困難になってきている。具体的には、強度増加に伴って延性が低下し、加工度が高い部位で破断が生じたり、スプリングバックや壁反りが大きくなり、寸法精度が劣化するという問題が発生する。

従って、高強度、特に引張強さ780 MPa 級以上の鋼板の場合、冷間加工手段としてプレス成形を利用して部品を製造することは容易ではない。プレス成形ではなくロール成形を利用すれば、上記の高強度鋼板の加工が可能であるが、ロール成形は長手方向に一樣な断面を有する部品にしか適用できず、適用できる製品の形状が限定される。

一方、英国特許第1490535 号に開示されているように、加熱した鋼板をプレス成形する熱間プレス法では、鋼板を高温で加熱することから、鋼板の材質は軟化して高延性になっているため、加熱状態で複雑な形状を寸法精度よく成形することが可能である。さらに、鋼板をオーステナイト域温度に加熱しておき、金型内で急冷するという金型冷却により、マルテンサイト変態による鋼板の高強度化、即ち、焼入れ、が同時に達成できる。

しかし、熱間プレス法における金型冷却では、部材の焼入れ硬さが、0.2 %C 材の場合でHv 400~490 と十分ではなく、しかも部材中の硬さのばらつきが非常に大きいという問題がある。

Advanced Materials & Processes, Vol. 146, No. 6, 12/94, p. 16 には、スウェーデンのプランジャ社により開発されたホットプレス技術が紹介されており、980 °C からダイクエンチ（金型内急冷）することが記載されている。金型温度は、加熱との記載がないので、常温~数十°C と推定される。

特開平 8-269615号には、C : 0.18~0.30%、Si : 0.01~1.0 %、Mn : 0.2~1.5 %、P : 0.03%以下、S : 0.02%以下、sol.Al : 0.08%以下、Cr : 0.1~0.5 %、B : 0.0006~0.0040%、N : 0.01%以下を含み、場合によりCu : 0.5 %以下、Ni : 0.3 %以下、Ti : 0.01~0.05%の少なくとも1種をさらに含み、残部鉄からなる、急速焼入れ用熱延鋼板が開示されている。この鋼板は、冷間加工した後、高周波焼入れにより高強度化させるものである。

発明の開示

本発明は、熱間成形法により高強度鋼板から製造でき、かつ安定した強度と靱性を併せ持つ熱間成形部材と、それを作製する熱間成形法を提供する。

より具体的には、本発明は、自動車のボディー構造部品、足回り部品等を初めとする機械構造部品等の熱間プレス部材と、その製造に使用される熱間プレス方法を提供する。

本発明によれば、成形後の冷却時、例えば金型冷却時に、Ms点（オーステナイトからマルテンサイトが生成し始める温度）以下の温度域での平均冷却速度を一定範囲内に収めることにより、熱間成形によって安定した強度および靱性を併せ持つ熱間成形部材を製造することができる。

1 態様において、本発明は、質量%で、C : 0.15~0.45%、Mn : 0.5~3.0 %、Cr : 0.1~0.5 %、Ti : 0.01~0.1 %、B : 0.0002~0.004 %、Si : 0.5 %以下、P : 0.05%以下、S : 0.05%以下、Al : 1 %以下、N : 0.01%以下を含有し、かつNi : 2 %以下、Cu : 1 %以下、Mo : 1 %以下、V : 1 %以下、およびNb : 1 %以下の1種または2種以上を含有し、残部Feおよび不可避免の不純物から本質

的になる鋼組成を有する鋼板を、 A_{c3} 点以上に加熱・保持した後、最終製品形状への成形を行う熱間成形方法に関する。本発明によれば、成形中または成形後の成形温度からの冷却に際して、成形部材の M_s 点までの冷却速度が臨界冷却速度以上で、かつ、 M_s 点から200℃までの平均冷却速度が25～150℃/sで冷却して焼入れ処理を行う。なお、本発明では、臨界冷却速度は上部臨界冷却速度の意味である。

別の態様において、本発明は、上記鋼組成を有する鋼板から構成された熱間成形部材に関する。この熱間成形部材は、熱間成形後の硬さが、ビッカース硬さで、（最高焼入れ硬さ－10）未満、かつ（最高焼入れ硬さ－100）以上、である。

本発明の好適態様において、熱間成形は、プレス成形用金型を用いて行う熱間プレス成形である。

本発明によれば、安定した強度と靱性を併せ持つ熱間プレス部材の作製が可能となる。従って、本発明は、高強度鋼板のプレス成形部材としての用途拡大に大きく寄与する。

図面の簡単な説明

図1はハット成形法の模式的説明図である。

図2は臨界冷却速度の測定用試験片の形状を示す模式図である。

発明の詳細な説明

本発明において前述した鋼組成および成形条件を採用する理由は次の通りである。本発明において、鋼組成、つまり鋼の化学組成を示す「%」は「質量%」を表す。

1. 素地鋼板の組成

C : 0.15～0.45%

炭素（C）は、鋼板の焼入れ性を高め、かつ焼入れ後、強度を主に決定する非常に重要な元素である。さらに A_{c3} 点を下げ、焼入れ処理温度の低温化を促進する元素である。しかし、C含有量が0.15%未満ではその効果は十分ではなく、一方でC含有量が0.45%を超えると、焼入れ部の靱性劣化が著しくなる。好ましい

C含有量の下限は0.16%、上限は0.35%である。

Mn : 0.5~3.0 %

マンガン (Mn) は、鋼板の焼入れ性を高め、かつ焼入れ後に強度を安定して確保するために非常に効果のある元素である。さらに、Ac₃点を下げ、焼入れ処理温度の低温化を促進する元素である。しかし、Mn含有量が0.5 %未満ではその効果は十分ではなく、一方でMn含有量が3.0 %を超えるとその効果は飽和し、さらに焼入れ部の靱性劣化を招く。好ましいMn含有量は 0.8~2.0 %である。

Cr : 0.1~0.5 %

クロム (Cr) は、鋼板の焼入れ性を高め、かつ焼入れ後、強度を安定して確保するために効果のある元素である。しかし、Cr含有量が0.1 %未満ではその効果は十分ではなく、一方でCr含有量が0.5 %をこえるとその効果は飽和し、いたずらにコスト増を招く。好ましいCr含有量は0.15~0.30%である。

Ti : 0.01~0.1 %

チタン (Ti) は、鋼板の焼入れ性を高め、かつ焼入れ後、強度を安定して確保するために効果のある元素である。さらに焼入れ部の靱性も向上させる効果を有する。しかし、Ti含有量が0.01%未満ではその効果は十分ではなく、一方でTi含有量が0.1 %を超えるとその効果は飽和し、いたずらにコスト増を招く。好ましいTi含有量は 0.015~0.03%である。

B : 0.0002~0.004 %

ホウ素 (B) は、鋼板の焼入れ性を高め、かつ焼入れ後、強度の安定確保効果をさらに高める重要な元素である。しかし、B含有量が0.0002%未満ではその効果は十分ではなく、一方でB含有量が0.004 %を超えるとその効果は飽和し、かつコスト増を招く。好ましいB含有量は0.0005~0.0025%である。

Si : 0.5 %以下、P : 0.05%以下、S : 0.05%以下、Al : 1 %以下、N : 0.01 %以下

これらの元素も、いずれも鋼板の焼入れ性を高め、かつ焼入れ後の強度の安定化を高める効果を有する。しかし、それらの含有量が上記のそれぞれの上限を超えると、その効果は飽和し、かえってコスト増を招く。

Ni : 2 %以下、Cu : 1 %以下、Mo : 1 %以下、V : 1 %以下、Nb : 1 %以下の

1種または2種以上

これらの元素も、鋼板の焼入れ性を高め、かつ焼入れ後、強度の安定確保に効果のある元素であるので、1種または2種以上を含有させる。しかし、それぞれ上限値を越えて含有させてもその効果は小さく、かついたずらにコスト増を招くため、各合金元素の含有量は上述の範囲とする。

本発明で使用する鋼板については、成形に先立つ加熱の際にオーステナイト温度域に加熱し、オーステナイト変態をさせるため、加熱前の室温での機械的性質は重要ではなく、加熱前の金属組織については特に制限されない。従って、素地鋼板としては、熱延鋼板、冷延鋼板、めっき鋼板のいずれを使用してもよく、その製造方法については特に限定はしない。めっき鋼板としては、アルミ系めっき鋼板（即ち、アルミめっきおよびアルミ合金めっき鋼板）と亜鉛系めっき鋼板（即ち、亜鉛めっきおよび亜鉛合金めっき鋼板）が例示される。めっき鋼板は、電気めっき鋼板でも、溶融めっき鋼板でもよい。また、合金化溶融亜鉛めっき鋼板も使用できる。

2. 加熱条件および保持時間

熱間プレス時の金型冷却において、成形部材、つまり熱間プレス部材に成形後焼入れ処理を行うためには、まず素地鋼板をオーステナイト温度域まで加熱し、素地鋼板を一度、オーステナイト相にする必要がある。そのためには、 A_{c3} 点以上に加熱し、その温度で通常の場合では1分以上保持する。保持時間の上限は特に設けないが、実際の生産上の効率を考えると、保持時間の上限を10分程度にするのが望ましい。

3. 熱間プレス時の冷却速度

熱間プレス中（金型内）または熱間プレス後（脱型後）の冷却速度は、熱間プレス部材において安定した強度および靱性を得るために非常に重要な役割を果たすパラメータである。

安定した強度および靱性を熱間プレス部材に付与するためには、熱間プレス後の組織を、完全マルテンサイト組織とするのではなく、自動焼き戻しマルテンサイト組織とすることが肝要である。この自動焼き戻しマルテンサイト組織にするためには、熱間プレス時または熱間プレス後の冷却段階で M_s 点までは拡散変態が

起きないように臨界冷却速度以上で冷却し、かつMs点から200℃までの温度範囲は平均冷却速度25～150℃/sという、遅い冷却速度で冷却する。このような冷却により、マルテンサイト変態が起こると同時に焼き戻しされるため、強度のばらつきが少なく、かつ靱性に優れたマルテンサイト組織が得られる。Ms点から200℃までの好ましい平均冷却速度は30～120℃/sである。

4. 熱間プレス法における成形方法

熱間プレス法における成形の形態としては、曲げ加工、絞り成形、張出し成形、穴拡げ成形、フランジ成形等がある。また、成形と同時またはその直後に鋼板を冷却する手段を備えていれば、プレス成形以外の成形法、例えばロール成形に本発明を適用してもよい。

5. 熱間プレス部材

前述の熱間プレス法にて作製された部材は、強度のばらつきが少なく、かつ靱性に優れた焼き戻しマルテンサイト組織を有する部材となる。また、得られる強度は、焼き戻しマルテンサイト組織の強度であるため、硬さ(Hv)で言い換えると、(最高焼入れ硬さ-10)よりも低い、過度に焼き戻されていないため、(最高焼入れ硬さ-100)以上の硬さを有する。Hvの値が(最高焼入れ硬さ-10)より高くなると靱性が低下し、(最高焼入れ硬さ-100)より低くなると強度が低下する。好ましいHvの値は、(最高焼入れ硬さ-20)以下、(最高焼入れ硬さ-80)以上である。

ここに「最高焼入れ硬さ」とは、900℃に加熱した塩浴中でその材料を10分間保持後、水冷処理を施した時に得られる硬さである。

6. 熱間プレス成形時の冷却方法

通常、鋼製金型は常温または数十℃程度の温度に保持されているから、熱間プレス成形に際して、この鋼製金型によりプレス成形部材の冷却が達成される。従って、冷却速度を変化させるためには、金型寸法を変え熱容量を変化させればよいことが分かる。

また、金型材質を異種金属（例えば銅など）に変えることでも冷却速度を変化させることができる。金型寸法も、材質も変えられない場合、水冷型の金型を用いてそのときの冷却水量を変えることによっても、冷却速度を変えることができ

る。その場合でも、例えば、予め溝を数カ所切った金型を用い、プレス中に水を溝に通すことによって冷却速度を変えたり、プレス成形途中でプレス機を上げ、その間に水を流すことでもプレス成形部材の冷却速度を変えることができる。

従って、Ms点の前後で冷却速度を変化させる手段には次のような手段が考えられる。

- (1) MS点到達直後に、熱容量の異なる金型または室温状態の金型に移動させて、冷却速度を変える。
- (2) 水冷金型の場合、MS点到達直後に、金型中を流れる水量を変化させて、冷却速度を変える。
- (3) Ms点到達直後に金型と部材の間に水を流し、その水量を変化させることで、冷却速度を変える。

実施例

以下の実施例は本発明を例示するものであるが、本発明はそれによりいかなる制限も受けない。

本例では、表1に示した組成を有する鋼板（板厚：1.0 mm）を素地鋼板とした。これらの鋼板は、実験室にて溶製したスラブを、熱間圧延、冷間圧延により製造した鋼板である。さらに鋼種No. 2には、めっきシミュレータを用いて溶融亜鉛めっき（片面あたりのZn付着量は60 g/m²）を施し、その後、合金化処理（めっき皮膜中のFe含有量は15質量%）を行った。

これらの鋼板を40 W×60 L（mm）の寸法に切断し、大気雰囲気の中、加熱炉内で、900℃×5分の加熱を行ってから、加熱炉より取り出し、その直後に、平板の鋼製金型を用いて、熱間プレス成形を行った。鋼種No. 2については、冷却条件を変化させて熱間プレス成形を行った（試験No. 2, 5, 6）。

得られた熱間プレス部材について、ビッカース硬さ測定（荷重9.8 N、測定数：5）を行った。また鋼板に熱電対を貼付し、プレス成形後の冷却速度の測定も行った。冷却速度については、主に金型寸法を変えて冷却速度を変化させた。

なお、試験No. 2については、鋼板温度がMs点に到達した直後に金型間に水を注入し冷却速度を調節した。

最高焼入れ硬さについては、900℃に加熱した塩浴中でその材料を10分間保持後、水冷処理を施した時に得られる硬さを最高焼入れ硬さとした。

得られた結果を、次の方法で測定した各鋼種のAc₃点、Ms点、および臨界冷却速度と共に表2にまとめて示す。

熱延鋼板から直径3.0 mm、長さ10 mmの円柱試験片（図2）を切り出し、大気中で950℃まで10℃/sの昇温速度にて加熱し、その温度で5分間保持したのち、種々の冷却速度で室温まで冷却した。そのときの加熱、冷却中の試験片の熱膨張変化を測定することにより、Ac₃点、Ms点を測定した。また、得られた試験片のビッカース硬度測定（荷重49N、測定数：5）および組織観察を行い、それらの結果から臨界冷却速度を見積もった。

表1

鋼種 No.	化学組成（質量%、残部：実質的にFe）														
	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Ti	Nb	Al	B	N
1	0.16	0.02	1.36	0.019	0.004	0.01	0.01	0.19	—	0.01	0.03	—	0.06	0.0013	0.008
2	0.21	0.25	1.20	0.008	0.002	0.01	0.02	0.20	—	0.01	0.02	0.01	0.05	0.0007	0.005
3	0.33	0.11	1.53	0.001	0.001	—	—	0.20	—	—	0.02	—	0.04	0.0015	0.001
4	0.42	0.11	1.51	0.001	0.001	—	—	0.20	0.01	—	0.02	—	0.04	0.0014	0.001

表2

試験 No.	鋼種 No.	Ac ₃ 点 (℃)	Ms 点 (℃)	臨界冷却 速度 (℃/s)	Ms点迄の 実測冷却 速度 (℃/s)	Ms点~200 ℃の平均 冷却速度 (℃/s)	熱間プレス 後の硬さ (HV)	最高焼入 れ硬さ (HV)	金型サイズ (t×W×Lmm)	備考
1	1	860	450	25	60	40	418	461	50×400×400	発 明 例
2	2	823	410	17	60	100	451	501	50×400×400 ^{*1}	
3	3	823	390	10	60	40	560	652	50×400×400	
4	4	785	370	10	60	30	683	750	50×400×400	
5	2	823	410	17	60	22 ^{*3}	390	501	50×50×400	比 較 例
6	2	823	410	17	60	200 ^{*3}	500	501	50×50×400 ^{*2}	

*1 Ms点直後に金型間へ水を注入。

*2 Ms点直後にプレス機を上昇させ、試験片を直ちに水槽へ投入。

*3 本発明の範囲外の条件

本発明例である試験No. 1～4では、Ms点から200℃までの平均冷却速度が適正であるため、得られた硬さは（最高焼入れ硬さ－10）よりも低く、また（最高焼入れ硬さ－100）よりも高い。

比較例である試験No. 5は、臨界冷却速度以上で冷却しているが、Ms点から200℃までの平均冷却速度が遅いため、十分な硬さが得られていない。また、やはり比較例である試験No. 6は、Ms点から200℃までの平均冷却速度が速すぎるため、硬くなりすぎている。ここに、「硬すぎる」との意味は、硬さの絶対値が高いということではなく、最高焼き入れ硬さに近いということである。

本発明例である試験No. 2の鋼板について、大気雰囲気加熱炉内で900℃×5分加熱して、加熱炉より取り出し、ハット型の熱間プレス成形〔blankサイズ：1.0 t×80 W×320 L (mm)〕を行った。

このときのハット成形法の模式図を図1に示す。採用した熱間プレス成形条件は、成形高さ70 mm、Rd（ダイス肩部R）8 mm、Rp（パンチ肩部R）8 mm、クリアランス1.0 mm、しわ押さえ力12.7 kNであった。

また、熱間プレス成形品のパンチ底部、側壁中央部、フランジ部について、ビッカース硬さ測定（荷重9.8 N、測定数：5）を行った。さらに、各部位に熱電対を貼付し、その部位の冷却速度も測定した。結果を表3にまとめて示す。

表 3

	Ms点～200℃ までの平均 冷却速度 (℃/s)	熱間プレス 後の硬さ (HV)
パンチ底部	55	460
側壁中央部	100	471
フランジ部	120	480

各部位でのMs点から200℃までの平均冷却速度が適正であるため、良好な硬さが得られている。また同じ部材中での硬さのばらつきも小さいことがわかる。

請 求 の 範 囲

1. 質量%で、C : 0.15~0.45%、Mn : 0.5~3.0 %、Cr : 0.1~0.5 %、Ti : 0.01~0.1 %、B : 0.0002~0.004 %、Si : 0.5 %以下、P : 0.05%以下、S : 0.05%以下、Al : 1 %以下、N : 0.01%以下を含有し、かつNi : 2 %以下、Cu : 1 %以下、Mo : 1 %以下、V : 1 %以下、およびNb : 1 %以下の1種または2種以上を含有し、残部Feおよび不可避免の不純物から本質的になる鋼組成を有する鋼板を、Ac₃ 点以上の温度に加熱・保持した後、最終製品形状への成形を行う方法であって、成形中または成形後の成形温度からの冷却に際して、成形部材のMs点までの冷却速度が臨界冷却速度以上で、かつMs点から200 °Cまでの平均冷却速度が25~150 °C/sで冷却して焼入れ処理を行う、熱間成形法。

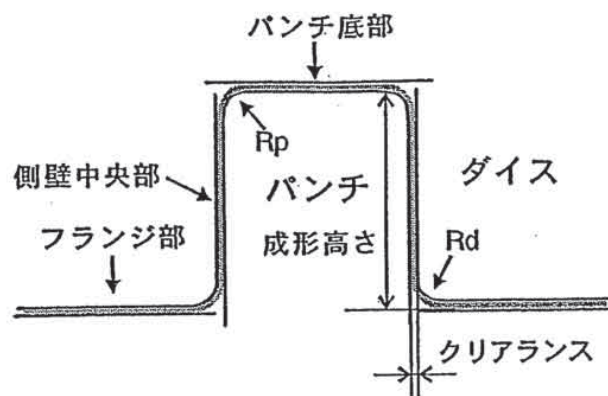
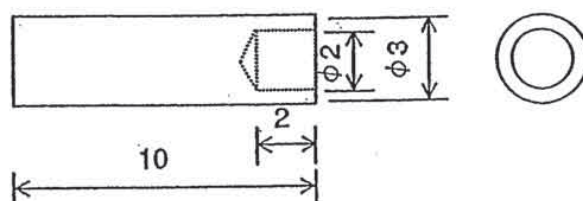
2. 前記成形をプレス成形用金型を用いて行う請求項1記載の熱間成形法。

3. 前記成形をプレス成形用金型を用いて成形後、金型間に水を注入して冷却する請求項1または2記載の熱間成形法。

4. 質量%で、C : 0.15~0.45%、Mn : 0.5~3.0 %、Cr : 0.1~0.5 %、Ti : 0.01~0.1 %、B : 0.0002~0.004 %、Si : 0.5 %以下、P : 0.05%以下、S : 0.05%以下、Al : 1 %以下、N : 0.01%以下を含有し、かつNi : 2 %以下、Cu : 1 %以下、Mo : 1 %以下、V : 1 %以下、およびNb : 1 %以下の1種または2種以上を含有し、残部Feおよび不可避免の不純物から本質的になる鋼組成を有する鋼板から構成され、熱間成形後の硬さが、ビッカース硬さで、(最高焼入れ硬さ-10)未満、かつ(最高焼入れ硬さ-100)以上であることを特徴とする、熱間成形部材。

5. 前記熱間成形が熱間プレス成形である請求項4記載の熱間成形部材。

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**Fig. 1****Fig. 2**