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(54) **DIE STEEL HAVING SUPERIOR RUSTING RESISTANCE AND THERMAL CONDUCTIVITY, AND METHOD FOR PRODUCING SAME**

(57) Provided are: a mold steel which, in addition to satisfying the basic characteristics of mold steel, also combines superior rust resistance and superior thermal conductivity; and a method for producing the same. Steel having a composition containing, in terms of mass%: 0.07 to 0.15% C; between 0 and 0.8% Si, exclusive; between 0 and 1.5% Mn, exclusive; less than 0.05% P; less than 0.06% S; between 0 and 0.9% Ni, exclusive; 2.9 to 4.9% Cr; Mo and W either alone or in a complex such that (Mo + 1/2W) is between 0 and 0.8%, exclusive; between 0 and 0.15% V, exclusive; and 0.25 to 1.8% Cu, the remainder being composed of Fe and unavoidable impurities, wherein the mold steel has a hardness of 30 to 42 HRC. Preferably, Al, which is an unavoidable impurity, is restricted to less than 0.1%, N is restricted to less than 0.06%, and O is restricted to less than 0.005%. The aforementioned hardness can be obtained through quenching and through tempering at 530°C or higher.

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Description

TECHNICAL FIELD

[0001] The present invention relates to a mold steel having improved rusting resistance and thermal conductivity, and suitable mainly for the application of plastic molding. The invention also relates to a method for producing the steel.

Background Art

[0002] Conventionally, a mold steel particularly used for plastic molding is mainly required to have

(1) good mirror finishing properties, and low tendency of generation of pin holes or other micro pits,
(2) good texturing process properties,
(3) high strength, wear resistance and toughness,
(4) good machinability,
(5) high corrosion resistance and rust resistance,
(6) high thermal conductivity, or the like.

[0003] Among them, improvement of the rust resistance and thermal conductivity are particularly required for recent mold steel. When a mold is not in use, e.g. between productions or during maintenance, dew condensation may occur and cause rust on a mold surface. When the rust generates on the surface of the mold, removing of the rust, e.g. by scouring, is necessary for restarting the use, and thus productivity is reduced. Therefore, the mold steel is required to have a good rust resistance. Also, an improvement of thermal conductivity of the mold steel is important since it reduces a thermal cycle and increases productivity in a plastic molding process where heating and cooling are repeated.

[0004] As a mold steel for plastic molding, proposed is an alloy steel comprising, by mass% (hereinafter expressed as "%"): 0.075 to 0.15% C; up to 1.0% Si; 1 to 3% Mn; 2 to 5% Cr; 1 to 4% Ni wherein Mn+Cr+Ni≥6, Mo and W either alone or in a complex such that (Mo+1/2W) is 0.1 to 1.0%; up to 0.015% P; up to 0.02% S; and the balance of Fe and impurities (Patent Literature 1).

[0005] Also, a mold steel is proposed comprising: 0.10 to 0.25% C; up to 1.00% Si; up to 2.00% Mn; 0.60 to 1.50% Ni; more than 1.00 to 2.50% Cr; Mo and W either alone or in a complex such that (Mo+1/2W) is 1.00% or less; 0.03 to 0.15% V; 0.50 to 2.00% Cu; up to 0.05% S, wherein Al is restricted to 0.10% or less, N is restricted to 0.06% or less, and O is restricted to 0.005% or less, and the balance being Fe and inevitable impurities (Patent Literature 2).

Citation List

Patent Literature

[0006]

Patent Literature 1: JP-A-2001-505617
Patent Literature 2: JP-A-2007-146278

Summary of the Invention

[0007] The mold steel including 2 to 5% Cr of Patent Literature 1 has good rust resistance. However, since the steel has a low coefficient of thermal conductivity, a thermal cycle time may increase and productivity is reduced in some molding conditions. Meanwhile, the mold steel including 2.5% or less Cr of Patent Literature 2 has a high coefficient of thermal conductivity and can reduce the thermal cycle time. However, as compared to the steel of Patent Literature 1, it still leaves place for improving the rust resistance. Thus, the thermal conductivity and the rust resistance are conflicting properties, and a mold steel having both of the properties at high levels has been desired.

[0008] An object of the present invention is to provide a mold steel having both improved thermal conductivity and rust resistance, and to provide a preferable method for producing the mold steel.

[0009] The present inventors have studied compositions of mold steels, and thus found that many elements constituting conventional mold steels mutually act on the rust resistance and thermal conductivity in a complex manner. To achieve the both properties, the inventors have extracted factors having a particularly high influence among the elementals, and found an optimum relationship between the contents thereof. Thus, they reached the present invention.

[0010] Specifically, the present invention provides a mold steel having improved rust resistance and thermal conductivity. The steel comprises, by mass%:

0.07 to 0.15% C;
more than 0% and less than 0.8% Si;
more than 0% and less than 1.5% Mn;
less than 0.05% P;
less than 0.06% S;
more than 0% and less than 0.9% Ni;
2.9 to 4.9% Cr;
Mo and W either alone or in a complex such that (Mo+1/2W) is more than 0% and less than 0.8%;
more than 0% and less than 0.15% V;
0.25 to 1.8% Cu, and

the balance being Fe and inevitable impurities, wherein the mold steel has a hardness of 30 to 42 HRC. Preferably, inevitable impurities Al, N and O are restricted to less than 0.1% Al, less than 0.06% N, and less than 0.005% O.

[0011] The invention also provides a method for producing a mold steel having improved rust resistance and thermal conductivity. The method comprises subjecting the steel to quenching and tempering at a temperature of not lower than 530°C so as to have a hardness of 30 to 42 HRC, wherein the steel comprising, by mass%:

0.07 to 0.15% C;
more than 0% and less than 0.8% Si;
more than 0% and less than 1.5% Mn;
less than 0.05% P;
less than 0.06% S;
more than 0% and less than 0.9% Ni;
2.9 to 4.9% Cr;
Mo and W either alone or in a complex such that (Mo+1/2W) is more than 0% and less than 0.8%;
more than 0% and less than 0.15% V;
0.25 to 1.8% Cu, and

the balance being Fe and inevitable impurities. Preferably, inevitable impurities Al, N and O are restricted to less than 0.1% Al, less than 0.06% N, and less than 0.005% O.

[0012] Preferably, in the mold steel and the method, following values of Expressions 1 and 2 are not less than 100,

$$\text{Expression 1: } 85-60.1\times[C\%]-115\times[S\%]+0.1\times[Ni\%]+7.17\times[Cr\%]+2.44\times[(Mo+1/2W)\%],$$

and

$$\text{Expression 2: } 140+30.9\times[C\%]-17.8\times[Si\%]-10.5\times[Mn\%]-12.4\times[Ni\%]-3.68\times[Cr\%]-1.26\times[(Mo+1/2W)\%]-3.68[Cu\%],$$

where the bracket [ ] indicates a mass percent of the element in the bracket.

[0013] According to the present invention, both improved rust resistance and thermal conductivity, that have been conventionally achieved only individually, can be simultaneously achieved with high reproducibility. Thus, this is effective for improvement in the art of a mold.

Description of Embodiments

[0014] The invention specifies the elements having a significant influence on rust resistance or thermal conductivity as constituting elements of the mold steel. Specifically, C, S, Ni, Cr, Mo and W have a significant influence on rust resistance, and C, Si, Mn, Ni, Cr, Mo, W, and Cu have a significant influence on thermal conductivity. Accordingly, the thermal conductivity can be increased by adjusting the contents of C, Si, Mn, Ni, Cr, Mo, W and Cu for a mold steel having a good rust resistance described in Patent Literature 1. The rusting resistance can be increased by adjusting the contents of C, S, Ni, Cr, Mo and W for a mold steel having superior thermal conductivity described in Patent Literature 2.

[0015] In another aspect, the invention quantifies a degree of influence of the elements on each of rust resistance and thermal conductivity. The quantification clarifies the composition of the mold steel to be adjusted, thereby improving the rust resistance and thermal conductivity. Now, each element will be described.

[0016] C: 0.07 to 0.15%

[0017] C is an element that increases a quenching property, and causes structural strengthening by precipitation of Cr, Mo(W), and V carbides by tempering. It is a basic element required for maintaining a hardness of 30 to 42 HRC described later by quenching and tempering. In order to suppress machining distortion that occurs during a cutting process or the like, it is desirable to reduce a residual stress in the steel, and this requires a high tempering temperature described above. Thus, for the steel of the invention, it is important to add an enough C amount to stably achieve a hardness of not lower than 30 HRC even through tempering at e.g. 530°C or higher is conducted.

[0018] However, as the C amount increases, Cr carbides are formed and solid-solved Cr in a matrix decreases, and thus the rust resistance is lowered. Thus, C is added not more than 0.15% according to the invention. Meanwhile, the solid-solved Cr is a major factor for reducing a coefficient of thermal conductivity of the mold steel. Thus, too little C, which forms Cr carbides, reduces thermal conductivity of the mold steel and prevents a required hardness. Thus, C is set to be not less than 0.07%. Preferably, the C content is not less than 0.08% and/or not more than 0.13%. More preferably, the C content is not less than 0.1% and/or not more than 0.12%. Further preferably, the C content is not more than 0.1%.

[0019] Si: more than 0% and less than 0.8%

[0020] Si is an element that increases corrosion resistance against atmosphere when the mold is in use, such as a gas generated from a material to be molded in plastic molding. However, too much Si significantly reduces a coefficient of thermal conductivity of the steel, and reduces thermal conductivity. Low Si content reduces anisotropy of a mechanical property and also reduces banded segregation to provide a good mirror finishing property. Thus, the Si content is less than 0.8% according to the invention. Preferably, the Si content is not less than 0.1% and/or not more than 0.6%. More preferably, the Si content is not less than 0.15% and/or not more than 0.5%. Further preferably, the Si content is not less than 0.2%. Particularly preferably, Si is not less than 0.25%.

[0021] Mn: more than 0% and less than 1.5%

[0022] Mn is an element that improves a quenching property, prevents generation of ferrite phase, and provides an appropriate hardness by quenching and tempering. However, too much Mn significantly reduces thermal conductivity, and is also combined with S described later to generate a non-metal inclusion MnS which causes rust or pin holes. Also, too much Mn increases viscosity of the matrix and reduces machinability. Thus, the Mn content is less than 1.5%. Preferably, the Mn content is not less than 0.1% and/or not more than 1.0%. More preferably, the Mn content is not less than 0.2% and/or not more than 0.8%. Further preferably, the Mn content is not less than 0.3%.

[0023] P: less than 0.05%

[0024] Too much P reduces hot workability and toughness. Thus, the P content is less than 0.05% according to the invention. Preferably, the P content is not more than 0.03%.

[0025] S: less than 0.06%

[0026] S in a form of non-metal inclusion MnS significantly improves machinability. However, much MnS promotes anisotropy of a mechanical property, particularly, toughness or the like, and reduces performance of the die itself. MnS becomes a starting point of rust or pin holes, which significantly reduce rust resistance and polish finish property that are important properties of the steel of the invention. Thus, even when added, S is limited to be less than 0.06%. Preferably, the S content is not more than 0.035%. A preferable lower limit is 0.005% or more.

[0027] Ni: more than 0% and less than 0.9%

[0028] Ni also improves a quenching property of the steel of the invention, and prevents generation of ferrite phase. Ni is an element that increases rust resistance of the steel of the invention. However, too much Ni reduces a coefficient of thermal conductivity, and also increases viscosity of the matrix to reduce machinability. Thus, the Ni content is less than 0.9%. Preferably, the Ni content is not less than 0.1% and/or not more than 0.6%. More preferably, Ni is not less than 0.15%, and further preferably not less than 0.2%.

[0029] Cr: 2.9 to 4.9%

[0030] Cr is an element that precipitates and coagulates as fine carbide by tempering to increase strength of the steel of the invention. Cr is also solid-solved in the matrix to increase the rust resistance of the steel of the invention. Furthermore, when the steel is subjected to nitriding treatment, Cr increases a hardness of the nitride layer. However, too much Cr increases an amount of the solid-solved Cr and significantly reduces a coefficient of thermal conductivity as well as reduces softening resistance. Thus, the Cr content according to the invention is 2.9 to 4.9%. Preferably, the Cr content is not less than 3.5% and/or not more than 4.8%. Further preferably, the Cr content is not less than 3.8%.

[0031] Mo and W either alone or in a complex (Mo+1/2W): more than 0% and less than 0.8%.

[0032] Mo and W precipitate and coagulate as fine carbides in the tempering process to increase strength of the steel of the invention. Mo and W also increase softening resistance in the tempering process. Mo and W are solid-solved, like Cr, in the matrix to increase rust resistance of the steel according to the invention. Thus, they are added either alone or in a complex. Furthermore, Mo and W are partially solid-solved in an oxide film on a mold surface, and thus have an effect of increasing corrosion resistance against a corrosive gas generated from e.g. plastic during the use of the mold. However, too much Mo and W reduce machinability. When the above amount of solid-solved Mo and W increases, a coefficient of thermal conductivity is significantly reduced. Thus, Mo and W either alone or in a complex defined by a relational expression of (Mo+1/2W) are set to less than 0.8% according to the invention. Preferably not less than 0.1% and/or not more than 0.6%, further preferably not less than 0.3% and/or not more than 0.5%.

[0033] V: more than 0% and less than 0.15%

[0034] V improves resistance to tempering softening, and prevents coarsening of grains and increases toughness. Also, V forms minute hard carbide to increase abrasive resistance. However, too much V reduces machinability, and thus the V content is less than 0.15%. Preferably, the V content is not less than 0.03% and/or not more than 0.10%. More preferably, the V content is not less than 0.05%, and further preferably, not less than 0.07%.

[0035] Cu: 0.25 to 1.8%

[0036] Cu is an element that precipitates and coagulates a Fe-Cu solid solution in the tempering process to increase strength of the steel according to the invention. However, too much Cu significantly reduces hot workability, and also reduces a coefficient of thermal conductivity, thereby reducing thermal conductivity of the steel according to the invention. Thus, the Cu content is 0.25 to 1.8% according to the invention. Preferably, the Cu content is not less than 0.4% and/or not more than 1.5%. More preferably, the Cu content is not less than 0.7%, and further preferably not less than 1.0%.

[0037] Al: less than 0.1%

[0038] Al is an inevitable impurity and is generally used as a deoxidizing element in a melting process. If much Al_2O_3 presents in the steel after hardness is adjusted, a mirror finishing property is reduced. Thus, the Al content is preferably restricted to less than 0.1% according to the invention. More preferably, the Al content is less than 0.05%.

[0039] N (nitrogen): less than 0.06%

[0040] N is an inevitable impurity and forms a nitride in the steel. If too much nitride is formed, toughness, machinability and a polishing property of the die are significantly reduced. Thus, the N content in the steel is preferably restricted to a low level. Thus, the N content is preferably restricted to less than 0.06% according to the invention. More preferably, the N content is less than 0.03%.

[0041] O (oxygen): less than 0.005%

[0042] O is an inevitable impurity and forms an oxide in the steel. If too much oxide is formed, cold plastic workability and a polishing property are significantly reduced. It is particularly important to prevent the formation of Al_2O_3 as described above according to the invention. Thus, an upper limit of the O content is preferably restricted to 0.005% according to the invention. More preferably, the O content is less than 0.003%.

[0043] Preferably, values of following Expressions 1 and 2 are not less than 100 (a value in the bracket indicates a content (mass%) of each element).

$$\text{Expression 1: } 85-60.1\times[C\%]-115\times[S\%]+0.1\times[Ni\%]+7.17\times[Cr\%]+2.44\times[(Mo+1/2W)\%]$$

$$\text{Expression 2: } 140+30.9\times[C\%]-17.8\times[Si\%]-10.5\times[Mn\%]-12.4\times[Ni\%]-3.68\times[Cr\%]-1.26\times[(Mo+1/2W)\%]-3.68[Cu\%]$$

[0044] The contents of elements constituting the steel need to be controlled within the above ranges to achieve improved rust resistance and thermal conductivity, on condition that basic properties such as strength, softening resistance and machinability are satisfied. However, the influence on the rust resistance and thermal conductivity differs depending on the individual elements. Thus, it is effective to mutually control the contents of the elements to achieve the rust resistance and thermal conductivity while maintaining the basic properties.

[0045] Thus, the degree of influence on rust resistance and thermal conductivity was searched for individual elements constituting the steel of the invention. As the result, the rust resistance is increase by Cr, Mo, W and Ni in this order, while S and C reduce rust resistance in this order. The result also showed that C has a higher effect of increasing thermal conductivity, and Si, Ni, Mn, Cr, Cu, Mo and W, in this order, reduce thermal conductivity. A multiple regression analysis using the contents of the elements as variables was performed to represent the above degree of influence as an appropriate mutual coefficient.

[0046] Specifically, the degree of influence of the elements on the rust resistance of the steel of the present invention can be mutually expressed by following Expression 1. At this time, a coefficient of an element increasing the property is represented by plus, while a coefficient of an element reducing the property is represented by minus, and a larger absolute value shows a higher degree of influence. For the steel of the present invention, a value by Expression 1 is preferably not less than 100 to further improve the rust resistance. Further preferably, the value is not less than 105.

$$\text{Expression 1: } 85-60.1\times[C\%]-115\times[S\%]+0.1\times[Ni\%]+7.17\times[Cr\%]+2.44\times[(Mo+1/2W)\%]$$

[0047] The degree of influence of the elements on the thermal conductivity of the steel of the present invention can be mutually expressed by following Expression 2. At this time, a coefficient of an element increasing the property is represented by plus, while a coefficient of an element reducing the property is represented by minus, and a larger absolute value shows a higher degree of influence. For the steel of the present invention, a value by Expression 2 is preferably not less than 100 to further improve the thermal conductivity. Further preferably, the value is not less than 105.

$$\text{Expression 2: } 140+30.9\times[C\%]-17.8\times[Si\%]-10.5\times[Mn\%]-12.4\times[Ni\%]-3.68\times[Cr\%]-1.26\times[(Mo+1/2W)\%]-3.68[Cu\%]$$

[0048] Hardness of the die steel being 30 to 42 HRC

[0049] Too low hardness reduces a mirror finishing property in producing a mold, and also reduces abrasive resistance as a mold product. On the other hand, too high hardness reduces machinability in producing the mold and also reduces toughness as the mold product. Thus, a hardness of the mold steel according to the invention is defined to be 30 to 42 HRC. Preferably, the hardness is not less than 35 HRC and/or not more than 40 HRC. The mold steel of the invention can be used as a so-called preharden steel, which is adjusted to the hardness through quenching and tempering heat treatment and then machined into a mold shape.

[0050] The steel of the invention can stably obtain the hardness of not lower than 30 HRC, further not lower than 35 HRC, even though it is subjected to hot tempering at not lower than 530°C, or even tempering at not lower than 540°C. In order to prevent machining distortion that occurs in the cutting process or the like, it is advantageous to conduct the tempering process at a high temperature to reduce residual stress in the steel as described above. The mold steel of the invention is adjusted to have an optimum composition having both improved rust resistance and thermal conductivity, as well as a tempering property as described above. Quenching temperature is not limited at this time. For example, quenching from a temperature of not lower than 900°C can be applied.

Example 1

[0051] A steel ingot of 10 kg adjusted to have a predetermined composition was melted in a vacuum melting furnace. The composition is shown in Table 1. Table 1 also shows values of Expressions 1 and 2 according to the invention. Conventional steels 1 and 2 correspond to those in Patent Literatures 1 and 2, respectively.

[Table 1]

No.	COMPOSITION (mass%)								
	C	Si	Mn	P	S	Ni	Cr	Mo	W
STEEL OF THE INVENTION 1	0.089	0.30	0.29	0.005	0.0540	0.21	3.07	0.50	<0.01
STEEL OF THE INVENTION 2	0.086	0.30	0.30	0.005	0.0290	0.21	3.02	0.49	<0.01
STEEL OF THE INVENTION 3	0.070	0.32	0.32	0.004	0.0055	0.21	2.99	0.30	<0.01
STEEL OF THE INVENTION 4	0.087	0.30	0.30	0.005	0.0567	0.22	4.80	0.50	<0.01
STEEL OF THE INVENTION 5	0.085	0.31	0.28	0.003	0.0087	0.21	4.88	0.51	<0.01
STEEL OF THE INVENTION 6	0.100	0.18	0.30	0.005	0.0007	0.20	4.54	0.40	<0.01
COMPARATIVE STEEL 1	0.100	1.01	1.07	0.004	0.0074	0.99	4.90	0.51	<0.01
COMPARATIVE STEEL 2	0.102	0.50	0.83	0.005	0.0070	0.99	3.97	0.31	<0.01
COMPARATIVE STEEL 3	0.104	0.48	0.79	0.007	0.0069	2.99	2.00	0.30	<0.01
CONVENTIONAL STEEL 1	0.163	0.28	1.46	0.007	0.0154	1.03	1.84	0.51	<0.01
CONVENTIONAL STEEL 2	0.134	0.25	2.47	0.008	0.0080	1.02	3.00	0.30	<0.01

No.	COMPOSITION (mass%) (ppm for [ ])						VALUE OF EXPRESSION (1)*2	VALUE OF EXPRESSION (2)*3
	V	Cu	Al	[N]	[O]	Fe*1		
STEEL OF THE INVENTION 1	0.09	1.36	0.005	6	6	Bal.	96.7	114.8
STEEL OF THE INVENTION 2	0.11	1.44	0.007	7	27	Bal.	99.4	114.5
STEEL OF THE INVENTION 3	0.09	1.44	0.004	8	29	Bal.	102.4	113.8
STEEL OF THE INVENTION 4	0.10	1.45	0.005	7	30	Bal.	108.9	107.9
STEEL OF THE INVENTION 5	0.08	1.38	0.008	7	31	Bal.	115.1	107.9
STEEL OF THE INVENTION 6	0.09	1.32	0.003	6	69	Bal.	112.5	112.2
COMPARATIVE STEEL 1	0.12	0.40	0.001	9	34	Bal.	114.6	81.5
COMPARATIVE STEEL 2	0.09	0.79	0.003	8	22	Bal.	107.4	95.3
COMPARATIVE STEEL 3	0.09	0.79	0.003	5	31	Bal.	93.3	78.6
CONVENTIONAL STEEL 1	0.08	0.73	0.003	9	9	Bal.	88.0	101.8
CONVENTIONAL STEEL 2	0.03	0.11	0.003	9	21	Bal.	98.4	89.2

*1: impurities are included

*2: 85-60.1[C%]-115[S%]+0.1[Ni%]+7.17[Cr%]+2.44[(Mo+1/2W)%]

*3: 140+30.9[C%]-17.8[Si%]-10.5[Mn%]-12.4[Ni%]-3.68[Cr%]-1.26[(Mo+1/2W)%]-3.68[Cu%]

[0052] Next, the steel ingot was forged at 1150°C to obtain a steel material having a thickness of 30 mm and a width of 30 mm, and the steel material was annealed at 860°C. From each annealed material, three steel pieces having following different sizes and shapes were processed: a piece of 10 mm × 10 mm × 10 mm for measuring hardness, a piece of 5 mm × 8 mm × 15 mm for evaluating rust resistance, and a piece having a diameter of 10 mm and a thickness of 1 mm for evaluating thermal conductivity. The pieces were subjected to predetermined quenching and tempering and then following tests were conducted.

(Hardness evaluation)

[0053] The steel piece of 10 mm × 10 mm × 10 mm was quenched from 950°C by gas cooling. Tempering was performed at 550°C for two hours since the high temperature tempering is advantageous for reducing residual stress in the steel. The results of hardness are shown in Table 2. The steel of the invention achieved a hardness of not less than 30 HRC even tempered at 550°C, and achieved a hardness of not lower than 35 HRC in a preferable case.

[Table 2]

No.	HARDNESS (HRC)
STEEL OF THE INVENTION 1	35.6
STEEL OF THE INVENTION 2	36.0
STEEL OF THE INVENTION 3	32.7

(continued)

No.	HARDNESS (HRC)
STEEL OF THE INVENTION 4	38.7
STEEL OF THE INVENTION 5	37.8
STEEL OF THE INVENTION 6	37.4
COMPARATIVE STEEL 1	38.8
COMPARATIVE STEEL 2	38.1
COMPARATIVE STEEL 3	36.9
CONVENTIONAL STEEL 1	38.7
CONVENTIONAL STEEL 2	34.5

(rust resistance evaluation)

[0054] The steel piece of 5 mm × 8 mm × 15 mm was quenched as described above. Tempering was performed at an appropriate temperature of 540°C to 580°C for two hours so that the hardness was adjusted to 34 to 36 HRC (target hardness: 35 HRC). An exposure test of the tempered piece was performed at a temperature of 80°C and a humidity of 90% for 24 hours, and an area ratio of rust on a surface of 8 mm × 15 mm was calculated (100 × rust area (mm^2)/ surface area of the test piece (mm^2)). The results are shown in Table 3.

(Thermal conductivity evaluation)

[0055] The steel piece having a diameter of 10 mm and a thickness of 1 mm was used and quenched as described above. Tempering was performed at an appropriate temperature of 540°C to 580°C for two hours so as to obtain a hardness of 34 to 36 HRC (target hardness: 35 HRC) as described above, together with a test piece for rust resistance evaluation. A coefficient of thermal conductivity of the tempered test piece was measured by a laser flash method. The results are shown in Table 3.

[Table 3]

No.	RUST AREA RATIO (%)	COEFFICIENT OF THERMAL CONDUCTIVITY (W/mk)
STEEL OF THE INVENTION 1	4	32.7
STEEL OF THE INVENTION 2	3	32.6
STEEL OF THE INVENTION 3	0	33.6
STEEL OF THE INVENTION 4	0	31.5
STEEL OF THE INVENTION 5	0	31.1
STEEL OF THE INVENTION 6	0	31.9
COMPARATIVE STEEL 1	0	21.1
COMPARATIVE STEEL 2	0	24.4
COMPARATIVE STEEL 3	17	22.5
CONVENTIONAL STEEL 1	22	29.1
CONVENTIONAL STEEL 2	4	27.0

[0056] From the results in Table 3, steels 1 to 6 of the invention having adjusted compositions achieved both rust resistance and coefficient of thermal conductivity superior compared to the conventional steels 1 and 2. The steels 3 to 6 of the invention which have not less than 100 of the value of Expression 1 are not confirmed of generation of the rust. On the other hand, for the comparative steel 1 having high Si and the comparative steel 3 having high Ni, a coefficient of thermal conductivity was significantly reduced. Although the comparative steel 2 has a composition close to that of the steel of the invention, a coefficient of thermal conductivity is low since it has high Ni. Since the comparative steel 3 has a low Cr content, rust resistance is also reduced.

Example 2

[0057] A steel ingot of 10 kg was melted in the same manner as in Example 1 described above, although a composition is changed. The composition is shown in Table 4. Table 4 also shows values of Expressions 1 and 2 according to the invention as in Table 1.

[Table 4]

No.	COMPOSITION (mass%)								
	C	Si	Mn	P	S	Ni	Cr	Mo	W
STEEL OF THE INVENTION 7	0.099	0.21	0.80	0.007	0.0310	0.20	3.99	0.41	<0.01
STEEL OF THE INVENTION 8	0.119	0.21	0.31	0.004	0.0061	0.21	4.53	0.41	<0.01
STEEL OF THE INVENTION 9	0.119	0.23	0.30	0.008	0.0096	0.20	4.50	0.40	<0.01
STEEL OF THE INVENTION 10	0.150	0.31	0.31	0.003	0.0089	0.21	4.87	0.51	<0.01
STEEL OF THE INVENTION 11	0.092	0.19	0.30	0.004	0.0079	0.21	4.47	0.40	<0.01
STEEL OF THE INVENTION 12	0.089	0.19	0.31	0.005	0.0054	0.21	3.85	0.04	<0.01
STEEL OF THE INVENTION 13	0.101	0.23	0.30	0.008	0.0091	0.20	4.11	0.30	<0.01
STEEL OF THE INVENTION 14	0.130	0.22	0.29	0.008	0.0050	0.20	4.66	0.20	<0.01
STEEL OF THE INVENTION 15	0.111	0.23	0.28	0.007	0.0047	0.20	4.61	0.20	<0.01
STEEL OF THE INVENTION 16	0.135	0.23	0.30	0.008	0.0054	0.15	4.61	0.25	<0.01
STEEL OF THE INVENTION 17	0.140	0.23	0.32	0.007	0.0054	0.60	4.60	0.25	<0.01
STEEL OF THE INVENTION 18	0.104	0.23	0.31	0.007	0.0048	0.20	4.60	0.10	0.41
STEEL OF THE INVENTION 19	0.121	0.23	0.29	0.007	0.0052	0.20	4.62	0.20	0.21
STEEL OF THE INVENTION 20	0.123	0.23	0.28	0.007	0.0049	0.20	4.63	0.10	<0.01
STEEL OF THE INVENTION 21	0.124	0.23	0.29	0.007	0.0049	0.20	4.61	0.10	<0.01
STEEL OF THE INVENTION 22	0.088	0.19	0.19	0.005	0.0069	0.21	4.49	0.40	<0.01
COMPARATIVE STEEL 4	0.062	0.31	0.30	0.005	0.0090	0.21	2.83	0.51	<0.01
COMPARATIVE STEEL 5	0.103	1.52	0.31	0.005	0.0105	0.20	4.49	0.39	<0.01
COMPARATIVE STEEL 6	0.056	0.84	0.82	0.004	0.0089	0.21	2.87	0.80	<0.01
COMPARATIVE STEEL 7	0.163	0.14	1.80	0.007	0.0272	0.10	1.79	0.30	<0.01

No.	COMPOSITION (mass%) (ppm for [ ])						EXPRESSION (1) VALUE	EXPRESSION (2) VALUE
	V	Cu	Al	[N]	[O]	Fe*1		
STEEL OF THE INVENTION 7	0.08	1.35	0.010	8	18	Bal.	105.1	108.2
STEEL OF THE INVENTION 8	0.08	1.36	0.008	10	21	Bal.	110.6	111.9
STEEL OF THE INVENTION 9	0.08	0.91	0.002	8	58	Bal.	110.0	113.5
STEEL OF THE INVENTION 10	0.09	0.88	0.008	10	18	Bal.	111.1	111.4
STEEL OF THE INVENTION 11	0.09	0.76	0.009	9	22	Bal.	111.6	113.9
STEEL OF THE INVENTION 12	0.09	1.34	0.009	8	32	Bal.	107.6	113.9
STEEL OF THE INVENTION 13	0.07	0.93	0.005	10	27	Bal.	108.1	114.5
STEEL OF THE INVENTION 14	0.08	0.66	0.003	10	55	Bal.	110.5	114.7
STEEL OF THE INVENTION 15	0.08	0.29	0.003	10	29	Bal.	111.4	115.6
STEEL OF THE INVENTION 16	0.14	0.29	0.004	11	27	Bal.	109.9	116.7
STEEL OF THE INVENTION 17	0.05	0.29	0.003	8	24	Bal.	109.6	111.1
STEEL OF THE INVENTION 18	0.08	0.29	0.003	8	25	Bal.	111.4	115.2
STEEL OF THE INVENTION 19	0.08	0.29	0.003	9	25	Bal.	110.8	115.8
STEEL OF THE INVENTION 20	0.08	0.66	0.003	11	22	Bal.	110.5	114.7
STEEL OF THE INVENTION 21	0.08	0.29	0.003	9	24	Bal.	110.3	116.0
STEEL OF THE INVENTION 22	0.01	1.33	0.010	7	31	Bal.	112.1	112.8
COMPARATIVE STEEL 4	0.08	0.57	0.002	9	22	Bal.	101.8	117.5
COMPARATIVE STEEL 5	0.08	0.90	0.008	9	19	Bal.	110.8	90.1
COMPARATIVE STEEL 6	0.08	1.67	0.008	7	22	Bal.	103.2	97.9
COMPARATIVE STEEL 7	0.08	0.25	0.001	10	30	Bal.	85.7	114.5

*1: impurities are included

[0058] Next, the steel ingot was forged and annealed under the same conditions as those in Example 1 described above. From each annealed material, three steel pieces having following different sizes and shapes were machined: a piece of 10 mm × 10 mm × 10 mm for evaluating hardness, a piece of 5 mm × 8 mm × 15 mm for evaluating rust resistance, and a piece of a diameter of 10 mm and a thickness of 1 mm for evaluating thermal conductivity. Then, the following tests were conducted on the pieces having been subjected to predetermined quenching and tempering.

(Hardness evaluation)

[0059] The steel piece of 10 mm × 10 mm × 10 mm was quenched under the same conditions as Example 1. Tempering was conducted under two conditions at 550°C for two hours in Example 1, and at 580°C for two hours. The results of hardness are shown in Table 5. Table 5 also shows the results of the steels 2, 3, 5 and 6 of the invention, the comparative steels 1 to 3, and the conventional steels 1 and 2 in Example 1. The steel of the invention achieved a hardness of 30 HRC or more through tempering at 580°C as well as at 550°C. A hardness of 35 HRC or more was obtained in a preferable case. A steel 22 of the invention having a low V content had a hardness of less than 30 HRC through tempering at 580°C. A comparative steel 4 having a low C content did not achieve 30 HRC through tempering both at 550°C and 580°C.

[Table 5]

No.	HARDNESS (HRC)	
	550°C TEMPERING	580°C TEMPERING
STEEL OF THE INVENTION 2	36.0	34.1
STEEL OF THE INVENTION 3	32.7	30.5
STEEL OF THE INVENTION 5	37.8	31.9
STEEL OF THE INVENTION 6	37.4	32.0
STEEL OF THE INVENTION 7	37.6	32.8
STEEL OF THE INVENTION 8	39.5	34.3
STEEL OF THE INVENTION 9	39.0	34.4
STEEL OF THE INVENTION 10	43.5	37.7
STEEL OF THE INVENTION 11	36.0	32.8
STEEL OF THE INVENTION 12	36.1	33.5
STEEL OF THE INVENTION 13	37.4	33.3
STEEL OF THE INVENTION 14	38.9	34.4
STEEL OF THE INVENTION 15	38.4	34.4
STEEL OF THE INVENTION 16	39.4	36.7
STEEL OF THE INVENTION 17	38.3	32.7
STEEL OF THE INVENTION 18	37.1	33.0
STEEL OF THE INVENTION 19	38.6	35.0
STEEL OF THE INVENTION 20	38.0	32.2
STEEL OF THE INVENTION 21	37.4	33.1
STEEL OF THE INVENTION 22	36.0	26.2
COMPARATIVE STEEL 1	38.8	30.5
COMPARATIVE STEEL 2	38.1	32.5
COMPARATIVE STEEL 3	36.9	33.5
COMPARATIVE STEEL 4	27.8	27.8
COMPARATIVE STEEL 5	36.9	27.9
COMPARATIVE STEEL 6	36.5	34.8
COMPARATIVE STEEL 7	33.9	32.8
CONVENTIONAL STEEL 1	38.7	31.5
CONVENTIONAL STEEL 2	34.5	28.0

(rust resistance evaluation)

[0060] The steel piece of 5 mm × 8 mm × 15 mm was quenched and tempered, and it was subjected to an exposure test under the same condition as the rust resistance evaluation in Example 1. A mass of the test piece after the rust generated through the test was removed and compared with a mass of the piece before the test. Thus, a mass reduction rate (100 × reduction amount (g) of test piece/mass (g) of test piece before test) was calculated. The results are shown in Table 6. Table 6 also shows the results of the conventional steel 2 in Example 1.

(Thermal conductivity evaluation)

[0061] The steel piece having a diameter of 10 mm and a thickness of 1 mm was quenched and tempered under the same conditions as the thermal conductivity evaluation in Example 1, and a coefficient of thermal conductivity was measured. The results are shown in Table 6. Table 6 also shows the results of the conventional steel 2 in Example 1.

[Table 6]

No.	MASS REDUCTION RATE (%)	COEFFICIENT OF THERMAL CONDUCTIVITY (W/mk)
STEEL OF THE INVENTION 7	0.055	33.1
STEEL OF THE INVENTION 8	0.049	32.8
STEEL OF THE INVENTION 9	0.044	29.9
STEEL OF THE INVENTION 10	0.060	30.8
STEEL OF THE INVENTION 11	0.053	31.4
STEEL OF THE INVENTION 12	0.057	31.9
STEEL OF THE INVENTION 13	0.054	32.2
STEEL OF THE INVENTION 14	0.055	30.8
STEEL OF THE INVENTION 15	0.050	32.6
STEEL OF THE INVENTION 16	0.057	32.0
STEEL OF THE INVENTION 17	0.050	31.5
STEEL OF THE INVENTION 18	0.054	31.4
STEEL OF THE INVENTION 19	0.057	31.1
STEEL OF THE INVENTION 20	0.056	31.6
STEEL OF THE INVENTION 21	0.048	32.3
STEEL OF THE INVENTION 22	0.052	31.3
COMPARATIVE STEEL 4	0.067	30.5
COMPARATIVE STEEL 5	0.055	20.8
COMPARATIVE STEEL 6	0.071	26.0
COMPARATIVE STEEL 7	0.092	35.0
CONVENTIONAL STEEL 2	0.060	27.0

[0062] From the results in Table 6, steels 7 to 22 of the invention have superior rust resistance and coefficient of thermal conductivity. Thus, both properties are achieved. Although the steel 10 of the invention has a high C content, it has a high value of Expression 1 and thus good rust resistance is obtained. Comparative steels 5 and 6 have a high Si content and a coefficient of thermal conductivity is low. Comparative steel 7 has a low Cr content and has a large mass reduction due to rust generation, and thus rust resistance is low.

Example 3

[0063] A steel ingot of 10 tons adjusted to have a composition in Table 7 was melted in an arc melting furnace. Like Table 1, Table 7 also shows values of Expressions 1 and 2 according to the invention.

[Table 7]

No.	COMPOSITON (mass%)								
	C	Si	Mn	P	S	Ni	Cr	Mo	w
STEEL OF THE INVENTION 23	0.110	0.32	0.30	0.021	0.0132	0.20	4.55	0.24	<0.01

	COMPOSITION (mass%) (ppm for [ ])						EXPRESSION (1) VALUE	EXPRESSION (2) VALUE
	V	Cu	Al	[N]	[O]	Fe*1		
	0.08	0.85	0.001	88	22	Bal.	110.1	111.9

* 1: impurities are included

[0064] Next, the steel ingots were forged and extended to obtain a square bar having a sectional area of 6500 cm^2. From the bar, two pieces of following different sizes and shapes were taken: a piece of 5 mm × 8 mm × 15 mm for evaluating rust resistance, and a piece having a diameter of 10 mm and a thickness of 1 mm for evaluating thermal conductivity. The rust resistance evaluation and the thermal conductivity evaluation were conducted under the same conditions as those in Example 2. The results are shown in Table 8.

[Table 8]

No.	MASS REDUCTION RATE (%)	COEFFICIENT OF THERMAL CONDUCTIVITY (W/mk)
STEEL OF THE INVENTION 23	0.053	30.6

[0065] The results in Table 8 show that steel 23 of the invention achieves both superior rust resistance and thermal conductivity.

Industrial Applicability

[0066] The steel of the invention satisfies the basic properties for a die. Thus, it can be applied to a die for rubber molding, for hot working used in a small lot production, for die-casting, or the like, besides a die for plastic molding.

Claims

1. A mold steel having improved rust resistance and thermal conductivity, the steel comprising, by mass%:

0.07 to 0.15% C;
more than 0% and less than 0.8% Si;
more than 0% and less than 1.5% Mn;
less than 0.05% P;
less than 0.06% S;
more than 0% and less than 0.9% Ni;
2.9 to 4.9% Cr;
Mo and W either alone or in a complex such that (Mo+1/2W) is more than 0% and less than 0.8%;
more than 0% and less than 0.15% V;
0.25 to 1.8% Cu, and

the balance being Fe and inevitable impurities,
wherein the mold steel has a hardness of 30 to 42 HRC.

2. The mold steel according to claim 1, wherein following values of Expressions 1 and 2 are not less than 100,

$$\text{Expression 1: } 85-60.1\times[C\%]-115\times[S\%]+0.1\times[Ni\%]+7.17\times[Cr\%]+2.44\times[(Mo+1/2W)\%],$$

and

$$\text{Expression 2: } 140+30.9\times[C\%]-17.8\times[Si\%]-10.5\times[Mn\%]-12.4\times[Ni\%]-3.68\times[Cr\%]-1.26\times[(Mo+1/2W)\%]-3.68[Cu\%],$$

where the bracket [ ] indicates a mass percent of the element in the bracket.

3. The mold steel according to claim 1 or 2, wherein the impurities include less than 0.1% Al, less than 0.06% N, and less than 0.005% O.

4. A method for producing a mold steel having improved rust resistance and thermal conductivity, the method comprising subjecting the steel to quenching and tempering at a temperature of not lower than 530°C so as to have a hardness of 30 to 42 HRC, wherein the steel comprises, by mass%:

0.07 to 0.15% C;
more than 0% and less than 0.8% Si;
more than 0% and less than 1.5% Mn;
less than 0.05% P;
less than 0.06% S;
more than 0% and less than 0.9% Ni;
2.9 to 4.9% Cr;
Mo and W either alone or in a complex such that (Mo+1/2W) is more than 0% and less than 0.8%;
more than 0% and less than 0.15% V;
0.25 to 1.8% Cu, and

the balance being Fe and inevitable impurities.

5. The method according to claim 4, wherein following values of Expressions 1 and 2 are not less than 100,

$$\text{Expression 1: } 85-60.1\times[C\%]-115\times[S\%]+0.1\times[Ni\%]+7.17\times[Cr\%]+2.44\times[(Mo+1/2W)\%],$$

and

$$\text{Expression 2: } 140+30.9\times[C\%]-17.8\times[Si\%]-10.5\times[Mn\%]-12.4\times[Ni\%]-3.68\times[Cr\%]-1.26\times[(Mo+1/2W)\%]-3.68[Cu\%],$$

where the bracket [ ] indicate a mass percent of the element in the bracket.

6. The method according to claim 4 or 5 wherein the impurities include less than 0.1% Al, less than 0.06% N, and less than 0.005% O.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/072317

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D6/00*(2006.01)i, *C22C38/60*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00, C21D6/00, C22C38/60

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2011
Kokai Jitsuyo Shinan Koho	1971-2011	Toroku Jitsuyo Shinan Koho	1994-2011

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2005-187899 A (Daido Steel Co., Ltd.), 14 July 2005 (14.07.2005), (Family: none)	1-6
A	JP 2004-2951 A (Daido Steel Co., Ltd.), 08 January 2004 (08.01.2004), (Family: none)	1-6
A	JP 11-179407 A (NKK Corp.), 06 July 1999 (06.07.1999), (Family: none)	1-6
A	JP 8-164465 A (Daido Steel Co., Ltd.), 25 June 1996 (25.06.1996), (Family: none)	1-6

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
15 November, 2011 (15.11.11)	22 November, 2011 (22.11.11)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
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INTERNATIONAL SEARCH REPORT

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 62-230955 A (Nippon Steel Corp.), 09 October 1987 (09.10.1987), (Family: none)	1-6

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2007146278 A **[0006]**