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STEEL FOR HOT WORKING DIE HAVING ALLOYING ELEMENTS OF SILICON, CHROMIUM AND ALUMINUM

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ABSTRACT OF THE DISCLOSURE

A low alloy hot-working die steel is disclosed in which the thermal crack resistivity is substantially improved by the addition of aluminum to the steel. The steel consists essentially of 15 to .5 C, 10 to 3.0% Si, less than 1.2% Mn, 0.5 to 3% Cr, .01 to 1.5% Mo, .01 to 1% V, .01 to 1.7% Al, the rest Fe, and a total of less than 1% impurities taken from the group consisting of Cu, P and S.

This invention relates to low alloy hot-working die steels having had the thermal crack resistivity remarkably improved by the addition of aluminum.

For hot-working die steels SKT 4 (JIS) and others have been already used. As their improvements, there are low alloy die steels of a composition of 0.15 to 0.5% C, 1.0 to 3.0% Si, less than 1.2% Mn, 0.5 to 3.0% Cr, 0.01 to 1.5% Mo and 0.01 to 1.0% V, the rest being Fe, and a total of less than 1% of Cu, Al, P and S as impurities of said composition further containing less than 2.0% Ni as a secondary ingredient in the above mentioned alloy, of said composition further containing a total of less than 0.5% of one or more secondary ingredients of less than 0.5% W, less than 0.5% Ti, less than 0.5% Zr and less than 0.5% Nb and of said composition further containing a total of less than 0.5% of one or more of less than 0.5% W, less than 0.5% Ti, less than 0.5% Zr and less than 0.5% Nb and containing less than 2% Ni. The above mentioned improved die steels are high in the thermal crack resistivity and also have an impact resistance, wear resistance and high-temperature deformation resistance.

As a result of making various researches on hot-working die steels, the applicant has come to know that it is very effective to add Al in order to improve mostly the thermal crack resistivity and other properties required as of hot-working die steels. That is to say, when a proper amount of Al is added, there will be shown such remarkable effects as the further improvement of the thermal crack resistivity, rise of the transformation temperature, reduction of the volume variation at the time of transformation, increase of the resistance to softening by tempering and increase of the high temperature strength and specifically the resistivity to thermal crack produced when the surface part of a die is subjected to repeated thermal cycles will be very high.

The present invention is to further improve the characteristics of the above mentioned improved die steels by adding Al.

The present invention is a low-alloy hot-working die steel of a remarkably improved thermal crack resistivity of a composition of 0.15 to 0.5% C, 1.0 to 3.0% Si, less than 1.2% Mn, 0.5 to 3.0% Cr, 0.01 to 1.5% Mo, 0.01 to 1.0% V, 0.1 to 1.7% Al, the rest being Fe, and a total of less than 1% of Cu, P and S as impurities, of *c* composition having the above mentioned composition as main ingredients and containing less than 2.0% Ni as a secondary ingredient, of said composition further containing a total of less than 0.5% of one or more secondary ingredients of less than 0.5% W, less than 0.5% Ti, less than 0.5% Zr and less than 0.5% Nb or of said composition further containing a total of less than 0.5% of one or more of less than 0.5% W, less than 0.5% Ti, less than 0.5% Zr and less than 0.5% Nb and containing less than 2% Ni.

The reasons for defining the amounts of addition of the respective ingredient metals in the alloy steel of the present invention are as follows. If the content of C is less than 0.15%, its effect will not be sufficient for the required hardenability and strength. If it is more than 0.5%, no favorable impact resistance will be obtained. If Si is less than 1.0%, the effects of the rise of the transformation temperature and the reduction of the amount of the volume variation by transformation will be low. If it is more than 30%, there will be no effect of improving the impact resistance. If Cr is less than 0.5%, the rise of the hardenability and transformation temperature and the increase of the resistance to softening by tempering will not be able to be expected. In case more than 3.0% Cr is added, the wear-resistance will improve but no effect of the more remarkable rise of the transformation temperature will be able to be expected, the volume variation at the time of the transformation will increase and the effect of the improvement of the thermal crack resistivity will be low. Further, even if more than 1.5% Mo and more than 1.0% V are added, the effect of the reduction of the volume variation at the time of the transformation will not increase, the hardenability will rather reduce and thus no generally favorable effect will be obtained. In the same manner, the addition of less than 0.01% of each of Mo and V is meaningless in improving the thermal crack resistivity. Further, the addition of more than 1.2% Mn and more than 2.0% Ni is effective to the further improvement of the hardenability but will reduce the transformation temperature, increase the volume variation at the time of the transformation and lose the features of the present invention. In case less than 0.5% of each of Ti, W, Zr and Nb is added individually or simultaneously, favorable results will be obtained in the rise of the transformation temperature and the resistance to softening by tempering. However, with more than 0.5%, the hardenability will rather reduce and the price will be high. With the addition of less than 0.10% Al, no improvement of the heat-crack resistivity will be expected. Further, with more than 1.7%, the effect of the addition will be saturated and at the same time, the production will become difficult. Therefore, it is desirable that the amount of addition of Al is 0.10 to 1.70%.

The alloy steel of the present invention is of the above mentioned composition, is heated at a proper temperature above the transformation temperature for a proper time so as to be austenitized, is cooled by water-quenching, oil-quenching or air-cooling depending on the size of the product so as to be transformed and is heat-treated to be tempered at a proper temperature for a proper time so as to obtain a required hardness.

The heat-treated alloy steel of the present invention having such composition as is mentioned above is very high in the resistivity to thermal cracks produced when it is subjected to comparatively severe repeated thermal cycles, is very high also in the transformation temperature and can have the volume variation at time of the transformation remarkably reduced. Further, the alloy steel of the present invention is not seen to be very different in the mechanical properties at the room temperature from the above mentioned conventional die steels

to which no Al is added but has features that its resistance to softening by tempering is increased and that its high-temperature strength is improved.

Now, the various properties of the alloy steels of the present invention (represented by A in the table), a conventional improved alloy steel (represented by B in the table) and SKT4 (JIS) as a conventional die steel (represented by C in the table) shall be compared. The above mentioned respective alloy steels had such chemical compositions as are shown in Table 1. The results of their thermal fatigue tests are shown in Table 2.

TABLE 1

	C	Si	Mn	Cr	Mo	V	Al	Ni	Ti
AI	0.35	1.54	0.81	1.06	0.41	0.21	0.55		
AII	0.35	1.65	0.83	1.05	0.42	0.21	1.08		
AIII	0.37	1.52	0.90	1.02	0.40	0.21	1.07	1.08	
AIV	0.32	1.54	0.83	1.04	0.40	0.20	0.94		0.06
AV	0.35	1.51	0.81	1.05	0.41	0.20	0.92	0.92	0.06
B	0.33	1.51	0.73	1.01	0.41	0.21			
C	0.55	0.29	0.62	0.85	0.28	0.15		1.41	

TABLE 2

Steels	Cycles to failure by thermal fatigue
AI	1803
AII	2806
AIII	1955
AIV	2686
AV	1647
B	1100
C	280

The above mentioned respective steels were heated to a proper temperature above the transformation temperature, were oil-quenched, were tempered so as to be of the same hardness and were compared. The cycles to failure by thermal fatigue so called herein are the repeated thermal cycles until a test piece broke when it was tested in a thermal fatigue tester of a type in which a thermal stress was produced by applying thermal cycles to the test piece as locked.

The transformation temperatures at the time of heating and the rates of volume variation at the time of the transformation are shown in Table 3.

TABLE 3

Steels	Transformation temperature, ° C.		Volume variation at the time of transformation, percent
	Starting temperature	Finishing temperature	
AI	806	957	0.114
AII	819	1,000	0.021
AIII	809	978	0.028
AIV	820	1,030	0.025
AV	800	975	0.015
B	793	904	0.237
C	710	771	0.612

Table 4 shows comparisons of the mechanical properties at the room temperature of the steels of the present invention and the conventional steels as heated to a proper temperature above the transformation temperature, oil-quenched and then tempered. Table 5 shows their mechanical properties at high temperatures as they were also oil-quenched and tempered and had the hardness at the room temperture made the same. Further, Table 6 shows their Charpy U-notch impact values as they were heat-treated in the same manner as in the above.

TABLE 4

Steels	Tensile strength, kg./mm.²	Yield strength, kg./mm.²	Elongation Percent	Reduction of area, Percent	Tempering temperature, ° C.
AI	103.3	88.2	18.0	55.1	725
AII	107.2	92.1	16.0	53.4	725
AIII	104.4	90.0	15.0	56.6	725
AIV	98.1	83.6	15.0	62.6	725
AV	104.2	89.4	16.0	55.0	725
B	90.4	76.6	20.0	56.8	725
C	105.0	90.2	18.5	57.5	675

TABLE 5

Steels	Tensile strength, kg./mm.²	Yield strength, kg./mm.²	Elongation, Percent	Reduction of area, Percent
AI	19.3	15.4	60.0	87.6
AII	20.3	15.2	61.4	83.2
AIII	19.9	15.7	64.0	94.7
AIV	20.9	17.2	58.0	95.6
AV	18.8	14.6	74.0	96.8
B	17.0	12.4	65.9	90.6
C	8.5	5.3	125.4	94.7

TABLE 6

Steels	Hardness (HRC)	Impact values by U-notch, kg. m./cm.²
AI	32.8	11.0
AII	35.1	8.2
AIII	33.4	8.1
AIV	33.6	9.9
AV	35.3	7.8
B	30.7	16.9
C	35.2	10.6

As shown in Table 2, the hot-working die steels of the present invention are much higher in the cycles to failure by thermal fatigue than the conventional steels. It is also found from Table 3 that, in the steels of the present invention, the transformation temperature is very high and the volume variation at the time of the transformation is remarkably reduced. This shows that, even if the surface of the hot-working die is heated to a high temperature when it is used, the transformation temperature will be hardly reached and that, even in case the transformation temperature is exceeded, the volume variation by the transformation will be small. By avoiding the fluctuation of the internal stress in the steel caused by the transformation, the thermal crack resistivity will be improved. As shown in Tables 4 and 6, the mechanical properties at the normal temperature of the hot-working die steels of the present invention are not inferior to those of the conventional hot-working die steels. It is shown that the steels of the present invention are high in the resistance to softening by tempering. Further, their mechanical properties at high temperatures are as shown in Table 5. It is found that their strength at high temperatures is high.

As explained in the above, the hot-working die steels of the present invention are very high in the thermal crack resistivity and are high also in the various properties on the transformation and in the mechanical properties at the room temperature and high temperatures.

What is claimed is:

1. A hot-working die comprising a steel for thermal crack resistivity consisting essentially of 0.15 to 0.5% C, 1.0 to 3.0% Si, less than 1.2% Mn, 0.5 to 3.0% Cr, 0.01 to 1.5% Mo, 0.01 to 1.0% V, and 0.1 to 1.7% Al, the rest being Fe and a total of less than 1% impurities taken from the group consisting of Cu, P and S.

2. A hot-working die as claimed in claim 1 containing an effective amount up to 2.0% Ni.

3. A hot-working die as claimed in claim 1 containing an effective amount up to 0.5% of at least one secondary ingredient taken from the group consisting of W, Ti, Zr, and Nb.

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