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HIGH SILICON-CARBON TOOL STEEL

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This invention pertains to a steel eminently adapted for use in tools employed for the forming of hot metal, such as die blocks, punches and the like, the steel being characterized in being relatively shallow hardening on quenching, and being hardenable to Rockwell "C" 60 or higher and in maintaining such high hardness after tempering for about two hours at 700° F., the steel containing as essential alloying constituents carbon, manganese, silicon and chromium in the proportions set forth hereinafter.

The invention also pertains to tools for forming hot metal made of this steel.

It is the object of this invention to provide a relatively shallow hardening steel for die blocks, punches, and the like, for forming hot metal. It is a further object of this invention to provide a steel which will harden to upward of Rockwell "C" 60 and which will retain this high hardness when tempered up to at least 700° F.

There are many hot forming operations in which the die, punch, mandrel, and the like, get quite hot, say over about 900° F., because of fairly long and intimate contact of the forming tool with the hot metal being formed. For these operations it is customary to use high alloy steels generally classified as hot work steels, which have appreciable resistance to softening at temperatures from about 900° to 1100° F. Prominent among these hot work steels are: 0.30/.40% C, 5% Cr steels with some V, Mo, and W; and 0.30% C, 9 W, 3% Cr steel with some V and Mo. Tools made from these steels must of necessity be tempered about 900° F. and consequently they are below Rockwell "C" 60 in hardness, and generally no higher than Rockwell "C" 50.

There are other operations such as the forging of flat objects, for example, knife blades, compressor blades, turbine buckets, and the like, particularly in the blocking stages, where contact between the hot metal and the die is of relatively short duration and the die surface does not get beyond about 700° F. in temperature. It is for the latter type of service that the steel of this invention is intended.

In order to avoid wear of the hot working tool, it is desirable to heat treat the die to high hardness, say

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over about Rockwell "C" 60. Furthermore, it is preferable in this type of service that the steel be shallow hardening, so that in sections about 1½" thick or larger, the steel when water quenched hardens to martensite only at the surface and to some distance below the surface, the core being of appreciably lower hardness. This provides the die with a good combination of wear resistance and toughness. There are many shallow hardened dies used for cold forming of metals but as yet no steel has been available for shallow hardened dies for hot forming because the known steels which are shallow hardening have little resistance to softening at temperatures beyond about 500° F., and the steels which have good resistance to softening are all very deep hardening steels.

Now I have invented a steel in which shallow hardening and high attainable hardness are combined with excellent resistance to softening at temperatures up to at least 700° F. I have discovered that silicon effectively causes resistance to softening in the tempering of martensite as discussed in the publication, "The Effect of Silicon on the Tempering of Martensite," by A. G. Allten and P. Payson, American Society for Metals, 1952, preprint No. 10. Therefore, silicon over 1.0%, and preferably over 1.5%, is an important constituent of my steel. In order to develop high hardness in the steel and partly also to provide residual carbides which are beneficial both for developing shallow hardening and to improve wear resistance of the martensite of the steel, I use upward of 0.90% carbon, and preferably over 1.0% carbon. Since the combination of high carbon and high silicon in the steel is conducive to the formation of graphite in the steel when it is annealed, and since for this application it is desired to avoid such formation, I maintain chromium in the steel at a level over about 0.75%. Manganese is also present in the steel up to about 0.60% for the usual purposes of deoxidation and desulfurization, but higher amounts are undesirable from the viewpoint of low hardenability. Also from the viewpoint of low hardenability, the elements nickel, molybdenum, coppers, etc., should be present in no more than residual amounts.

The composition of the steel of this invention is as follows:

	Broad	Preferred
Carbon	0.90/1.3	1.00/1.1.
Manganese	0.15/0.6	0.25/0.5.
Silicon	1.2/2.5	1.6/1.9.
Chromium	0.75/1.5	0.9/1.2.
Other elements such as nickel plus molybdenum plus copper, etc.	up to 0.5%	under 0.3%.
Balance	Fe	

The effect of silicon on the tempering of hardened steels containing about 1.0 carbon and 1.0 chromium is shown in Table I.

TABLE I

Effect of silicon on tempering of hardened 1.0 carbon, 1.0 chromium steels

Bar	C	Mn	Si	Cr	Rockwell "C" Hardness					
					As Quenched	After 2 hour cumulative tempering at—				
						400° F.	500° F.	600° F.	700° F.	800° F.
4140	.97	.50	.53	1.1	67	62	60	59	54	50
4141	.97	.52	1.03	1.1	66	61	61	60	56	51
4142	1.01	.45	1.74	1.1	66	63	61	61	60	55
4143	1.00	.51	2.10	1.1	66	62	62	61	60	55

It is clear from the above that to maintain a hardness of Rockwell "C" 60 with a temper over 600° F., it is desirable to hold the level of silicon over 1.0%. I have therefore set the low limit for silicon in the steel of this invention at 1.2%, and preferably 1.6%. Silicon has only a minor effect on increase of hardenability but it does increase the hardness of the annealed steel appreciably and therefore I limit the silicon to a maximum of 2.5%.

The shallow hardenability of the steel is best established by the conventional Jominy test, and data are given for several steels in Table II. Included in this table for comparison purposes are data on a conventional oil hardening tool steel.

TABLE II

Hardenability of high carbon-silicon steels

Bar	C	Si	Cr	Austenitizing Temperature, ° F.	Rockwell "C" Hardness at Indicated Position on Jominy Bar in 16ths of an inch						
					2	3	4	5	6	8	10
4140	0.97	0.53	1.1	1,475	65	64	61	49	49	39	35
4141	0.97	1.03	1.1	1,475	65	65	64	62	54	44	38
4142	1.01	1.74	1.1	1,550	66	66	65	63	59	45	42
4143	1.00	2.10	1.1	1,550	66	66	65	64	61	45	42
4144	0.99	2.22	2.2	1,600	67	67	66	66	65	61	46
Oil Hardening Tool Steel				1,475	66	----	65	----	64	63	60

It is clear from the above that the steels of this invention are definitely shallower hardening than the conventional oil hardening tool steel. Furthermore, these data show that chromium as high as 2% makes the steel much deeper hardening than the 1.0% chromium steels. For this reason, I limit the chromium in the steel of this invention to 1.5%.

In the appended claims, the expression a hot metal forming tool is meant to include such tools as die blocks, punches and the like.

What is claimed is:

1. An alloy steel consisting essentially of about: 1.6 to 1.9% silicon, 0.9 to 1.2% chromium, 1 to 1.1% carbon, 0.25 to 0.5% manganese, under 0.3% of other elements, balance iron, characterized in being relatively shallow hardening and in being hardenable to a minimum of about Rockwell "C" 60, and in maintaining such hardness after tempering for about two hours at 700° F.

2. A hot metal forming tool made of an alloy steel containing about: 1.6 to 1.9% silicon, 0.9 to 1.2% chromium, 1 to 1.1% carbon, 0.25 to 0.5% manganese, under 0.3% of other elements, balance iron, said steel being characterized in being relatively shallow hardening and in being hardenable to a minimum of about Rockwell "C" 60, and in maintaining such hardness after tempering for about two hours at 700° F.

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