Feb. 12, 1963 P. R. BORNEMAN 3,077,397

LOW ALLOY-AIR HARDENING DIE STEEL

Filed May 9, 1961 2 Sheets-Sheet 1

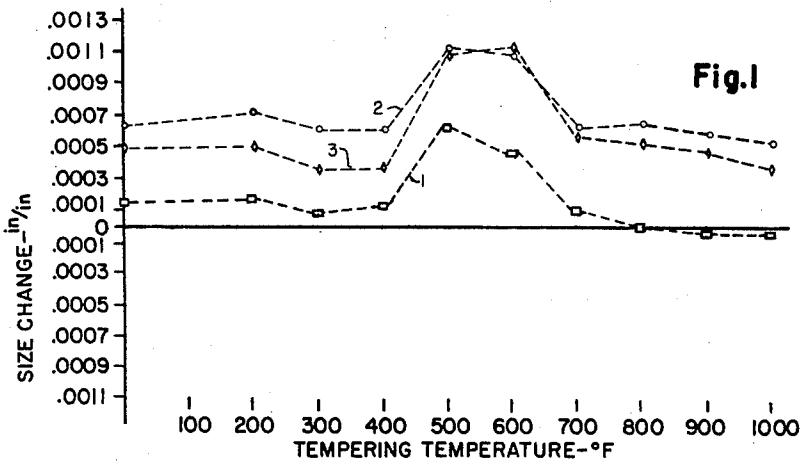

Fig.1

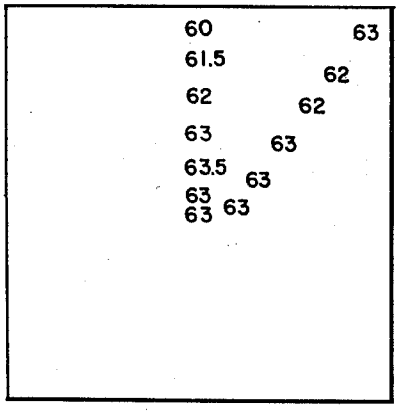

Fig.3

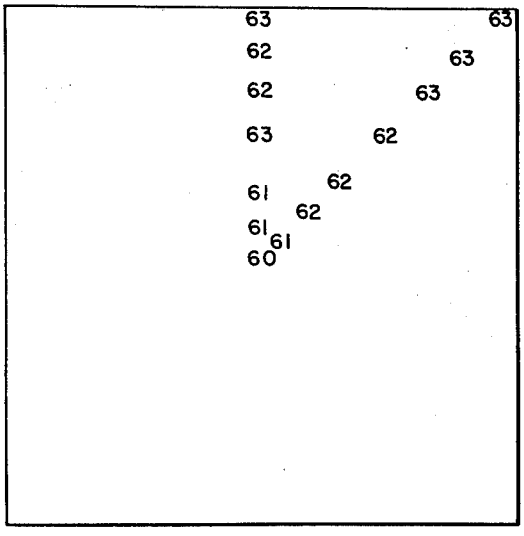

Fig.4

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LOW ALLOY-AIR HARDENING DIE STEEL

Filed May 9, 1961 2 Sheets-Sheet 2

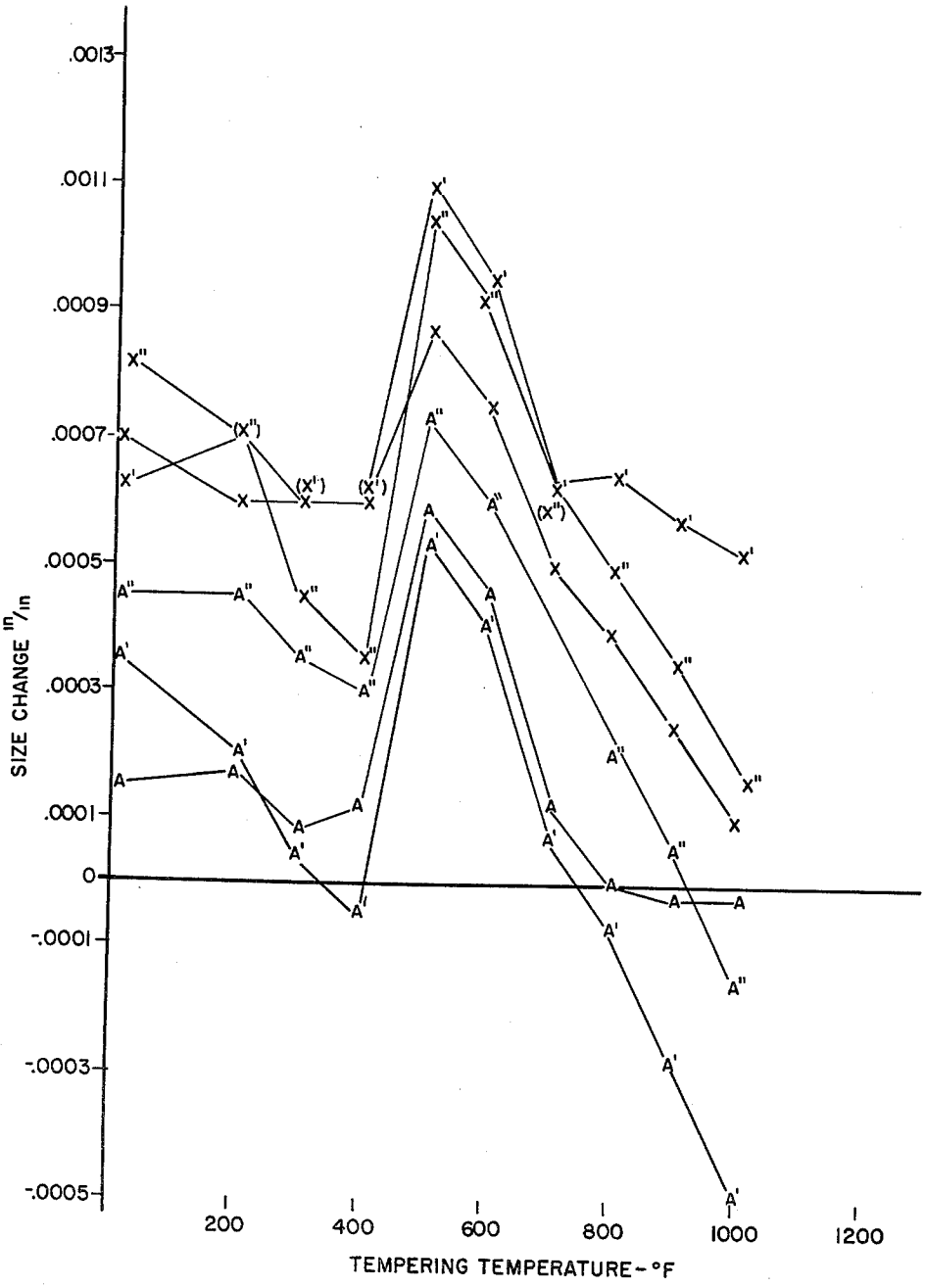

Fig.2

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LOW ALLOY-AIR HARDENING DIE STEEL

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4 Claims. (Cl. 75—126)

This invention relates to improvements in die steels, and relates in particular to a new and novel low alloy-air hardening die steel.

The low alloy-air hardening die steel to which the present invention is directed, is conventionally used for tools and dies having a design that prohibits the use of water hardening steels because of the hazard of distortion or cracking during hardening. The oil hardening steels generally hold their dimensions less closely than the air hardening compositions. The requirements of such steels are a combination or a balance of deep hardening characteristics, a wide hardening range, good impact resistance and good machinability in addition to dimensional stability during heat treatment. The aforementioned optimum properties are desired and required, particularly for the manufacture of dies used in punching, coining, piercing, blanking, stamping and trimming of metals and are also useful in the manufacture of hubs, bushings and master tools where high dimensional tolerances are of importance. The low alloy-air hardenable steels now available commercially satisfy several of the aforementioned properties; however, none satisfies all of the property requirements in good balance.

A die or tool steel has now been discovered which exhibits deep hardening characteristics, a wide hardening range, good impact resistance, and is easily machined in addition to exhibiting unusually good dimensional stability.

In general, the present invention is directed to a steel containing more than about .80% but less than .90% carbon, from 1.85% to 2.15% manganese, .25% to .50% silicon, .75% to 1.10% chromium, from 1.20% to 1.40% molybdenum and from about .45% to .85% vanadium, the balance being essentially all iron. The carbon content preferably falls within the range of from about .83% to .87%, and sulfur is optionally present within the range of from about .08% to .10% to impart improved machinability.

Consequently, it is an object of the present invention to provide a low alloy-air hardenable die or tool steel that exhibits good deep hardening characteristics, a wide hardening range, good impact resistance, good machinability in the annealed condition and good dimensional stability during heat treatment.

It is also an object of the present invention to provide a die or tool steel which exhibits superior dimensional stability during heat treatment to prior known low alloy deep hardening compositions.

It is a further object of the present invention to provide a die or tool steel which exhibits a wider hardening range than the prior known low alloy deep hardening compositions.

Other objects and advantageous features of the present invention will be obvious from the following description and the accompanying drawings wherein:

FIGURE 1 is a graphical representation of the dimensional distortion which occurs in the steel of the present invention as compared with similar prior known compositions;

FIG. 2 is a graphical representation of the comparative dimensional stability properties of analyses that constitute another embodiment of the present invention; and

FIGS. 3 and 4 are cross-sectional views of 4" and 6" cubes, respectively, showing hardness measurements taken from the center to the edge which illustrate the hardenability of the alloy of the present invention.

In quenching and tempering low alloy-air hardening compositions, it has been determined that the dimensional changes take place upon phase transformation and the dimensional changes are particularly noticeable during subsequent tempering heat treatments. The parts or dies are conventionally machined in the softer annealed condition and are then heated and quenched to effect maximum hardness for their ultimate use which demands such properties. During heating, transformation of the structure of the material to a phase known as austenite is accompanied by a decrease in size. Upon quenching the austenite is transformed to martensite; however, some of the austenite fails to transform and is referred to as "retained austenite." Tempering is conducted in order to complete the transformation of retained austenite into martensite or bainite and to relieve stresses that may result in subsequent cracking. This transformation is known to generally result in an expansion of the metal and unless the shrinkage which occurs during heating is equivalent to such expansion, a distortion of the die or tool occurs. The resulting die or tool steel part which has been shaped to close tolerances, is frequently found to be unacceptable. The tempering temperatures vary from room temperature to 1000° F., but generally occur between the temperature range of from about 400° F. to 650° F.

In the composition of the present invention, manganese, chromium and molybdenum are present as hardening agents within the usual and known ranges which are relatively critical in providing optimum deep hardening characteristics and impact resistance. The carbon content is also present as an essential hardening agent, since carbon, as is well known, is a necessary material for the formation of martensite which is the primary hardening phase. In the composition of the present invention, however, the carbon is present within critical limitations in that the amount of carbon present must exceed .80% (about .83%) in order to impart the necessary hardening and hardenable characteristics, while it must be below .90% (about .87%) in order to retain the excellent stability of the steel. Vanadium also must be within the critical range limitations of from about .45% to .85%. The function of the vanadium over and above about .20%, which is dissolved in the steel and acts as a hardening agent, is believed to be in combining with the carbon. If excessive amounts of vanadium are used, the effects are identical to that of insufficient amounts of carbon, in that insufficient amounts of available carbon caused either by excessive vanadium or too little carbon in the composition would result in insufficient hardening properties. On the other hand, the vanadium carbide precipitates at grain boundary junctions, and having a high solution temperature, controls grain growth and contributes to a wide hardening temperature range. This same vanadium carbide in some way appears to contribute to the dimensional stability, probably by controlling the amount of carbon which can be taken into solution during austenitizing. Consequently, if the vanadium is too low or below the critical range set forth, the dimensional stability properties are not obtained.

The improved properties of the alloy of the present invention are demonstrated by the following specific examples and by the drawings. Table I sets forth the analysis of the material tested which includes alloys possessing the composition of the present invention and known commercially available compositions for which comparative dimensional stability test data is given. Applicant's compositions are identified by the designations AL–123, AL–123(2) and AL–123EZ, while the commercially available materials are identified by their common tradenames Airloy, XT–028 and XT–028EZ (EZ meaning a high sulfur machining grade).

TABLE I

Designation	C	Mn	Si	Cr	Mo	V	S
AL–123	.85	2.08	.27	.77	1.36	.84	------
AL–123(2)	.81	2.00	.25	1.02	1.28	.50	------
AL–123EZ	.86	2.16	.26	.76	1.31	.80	.117
Airloy	1.04	2.92	.28	1.08	1.01	.01	.014
XT–028	.72	2.14	.36	1.06	1.35	.03	------
XT–028EZ	.69	2.02	.24	1.02	1.22	.02	.081

The superior dimensional stability of applicant's alloys as compared to the prior known similar compositions is particularly illustrated by the data shown by the following Tables II, III and IV and FIGS. 1 and 2 of the drawings. In Table II, there are shown the dimensional changes effected on ¾ inch round x 2.000" long specimens of the material designated in Table I as AL–123, Airloy and XT–028 when the material is hardened and hardened plus tempered at temperatures ranging up to 1000° F. Each of the commercial grades was hardened by air quenching from the temperature recommended for the specific grade to secure optimum mechanical properties and applicant's composition was quenched from 1525° F., which is within 25° F. of the quenching temperature of the other materials and which temperature gave applicant's composition equivalent or superior mechanical properties as well as superior dimensional properties. The dimensional changes were determined by measuring the length of the bars before and after heat treatment. The data of Table II is plotted graphically in FIG. 1 to more clearly show the advanages of applicant's analysis. In FIG. 1 dimensional changes are plotted against tempering temperatures and curve **1** represents applicant's alloy, while curve **2** shows the dimensional stability of the XT–028 analysis and the curve **3** the Airloy composition. The line **0** represents no dimensional change and the initial plots indicate the dimensional change occurring upon quenching.

TABLE II

Dimensional Stability

[Average change inches/inch of length ¾" round x 2.0000" long samples]

XT–028 .60–.80C No V	AL–123 .83–.87C .45–.85V	Airloy 1.00 C 3.00 Mn No V	Tempering temp., °F.
+.00062	+.00015	+.00049	(1)
+.00070	+.00017	+.00049	200
+.00060	+.00008	+.00035	300
+.00060	+.00012	+.00035	400
+.00110	+.00060	+.00097	500
+.00096	+.00045	+.00099	600
+.00062	+.00010	+.00057	700
+.00065	+.00000	+.00052	800
+.00058	−.00003	+.00047	900
+.00052	−.00003	+.00037	1,000

[1] As hardened, change from the finish machined size.

NOTE 1.—+ Denotes expansion, − denotes contraction.

NOTE 2.—XT–028—Hardened at 1550°F. for 8 minutes TAT—Air Quench. AL–123—Hardened at 1525°F for 8 minutes TAT—Air Quench. Airloy—Hardened at 1500°F for 8 minutes TAT—Air Quench.

It may be readily observed from either Table II or FIG. 1 that applicant's alloy exhibits less dimensional change either as quenched or as quenched and tempered at any tempering treatment up to 1000° F. Although greater dimensional change is experienced by all three alloys in the 450° F.–600° F. temperature range, applicant's alloy exhibits the least change or deviation from the original dimensions of the bars.

Table III shows the dimensional properties of ¼" round samples of the same materials employed to obtain the data shown by Table II and FIG. 1. This data confirms the data of Table II in that in nearly every instance, applicant's alloy shows far greater dimensional stability than the other grades.

TABLE III

[¼" round x 2.0000" long samples—Heat treatment identical to ¾" rd. samples]

XT–028	AL–123	Airloy	Tempering temp., ° F.
+.00005	−.00005	+.00050	(1)
−.00018	−.00005	+.00048	200
−.00051	−.00005	+.00037	300
−.00066	−.00008	+.00020	400
−.00033	+.00020	.00000	500
−.00007	+.00051	+.00080	600
−.00060	−.00012	+.00110	700
−.00081	−.00031	+.00090	800
−.00089	−.00045	+.00070	900
−.00103	−.00055	+.00060	1,000

[1] As hardened.

In Table IV and FIG. 2, there is shown dimensional stability of applicant's alloy AL–123EZ for different quenching temperatures. FIG. 2 and Table IV also show the comparative dimensional stability of a similar grade identified as XT–028EZ (see Table I). These analyses contain sulfur that has been added to improve machinability. ¾-inch round x 2.000" long samples were hardened at the recommended temperatures for the respective materials and at temperatures 50° F. above and 50° F. below these temperatures for 8 minutes and air quenched. The specimens were measured (lengthwise) to the fourth decimal place before hardening, after hardening and after each temper. The results were as follows:

TABLE IV

Dimensional Stability Average Change

[Inches/inch of length ¾" round x 2.000" long samples]

Tempering temp., ° F.	AL–123EZ			XT–028EZ		
	Austenitizing temperatures, ° F.					
	1,475	1,525	1,575	1,500	1,550	1,600
As hardened	[1]+.00045	[1]+.00015	[1]+.00035	[1]+.00070	[1]+.00062	[1]+.00082
200	+.00045	+.00017	+.00020	+.00060	+.00070	+.00070
300	+.00035	+.00008	+.00005	+.00060	+.00060	+.00045
400	+.00030	+.00012	−.00005	+.00060	+.00060	+.00035
500	+.00075	+.00060	+.00055	+.00090	+.00110	+.00105
600	+.00060	+.00045	+.00042	+.00075	+.00096	+.00092
700	+.00030	+.00010	+.00007	+.00050	+.00062	+.00062
800	+.00020	.00000	−.00008	+.00040	+.00065	+.00050
900	+.00005	−.00003	−.00028	+.00025	+.00058	+.00032
1,000	−.00015	−.00003	−.00050	+.00010	+.00052	+.00015

[1] Dimentional changes are in inches/in.

In FIG. 2 the plots represent the actual dimensional changes as set forth in Table IV. The graph more clearly

shows the advantages of applicant's analyses. All plots designated A, A' or A" are plots of analyses reported in Table I above (AL–123EZ), which are within the scope of the present invention, while all plots designated X, X' or X" are plots of the XT–028EZ material. The temperatures from which the samples were quenched varied, each material being air quenched from the temperature from which optimum die steel properties are obtained and at 50° F. above and below such optimum temperatures. The precise quenching temperatures were as follows:

AL–123EZ:	XT–028EZ:
A—1525° F.	X—1500° F.
A'—1575° F.	X'—1550° F.
A"—1475° F.	X"—1600° F.

As may be readily seen from the data of Table IV and from FIG. 2 at any given temper applicant's analysis exhibits far less distortion than the presently available compositions. This data shows that the degree of stability of applicant's alloy varies to some extent in accordance with the hardening treatment, but that similar compositions also vary, but are generally less dimensionally stable regardless of the exact head treatment given.

As may be observed from the data of Tables II–IV and FIGURES 1 and 2, applicant's compositions exhibit a closer relation to the theoretical zero limit of dimensional change than other low alloy-air hardening die steels now being used. This holds true for both large and small sample size showing that the vanadium addition in combination with the proper level of carbon produces close dimensional stability.

FIGS. 3 and 4 demonstrate the hardening properties of applicant's alloy. These figures show the results obtained when 4" and 6" cubes of applicant's alloy (AL–123) were heated to 1550° F., air cooled and cut in half, then tested for Rockwell "C" hardness from the edge and corner of each to the center of the former cubes. The results, as shown, clearly illustrate the good deep hardening characteristics of the material. These characteristics are known to be prevalent over a hardening range of 1500° F. to 1800° F. Such a wide band of acceptable hardening temperatures is greatly advantageous to a fabricator, since he can use a variety of equipment which may be available to him for such heat treatment and, additionally, can heat treat the material for purposes of quenching with other steels of various grades.

Table V shows the wide hardening range of the AL–123 analysis. Samples which were air quenched at temperatures of from 1500° F. to 1800° F. are shown to possess uniformly high hardnesses which are substantially retained upon subsequent tempering. Over this hardening range a fine grain size is maintained as shown by the Shepherd Fracture grain size ratings of 9½ or higher.

TABLE V

Hardening and Tempering Data

[Samples 2" long x 1⅛" rd. of steel having the analysis shown by Table I, were hardened for 5 minutes at the indicated temperature and air cooled. They were fractured and tested for hardness. The samples were then tempered cumulatively for 1hour at the indicated temperatures with the Rockwell "C" hardness checked after each temper]

Hardening temp., °F	Hardness as quenched	Grain size Shepherd rating	Cumulative 1-hour draw at—							
			300° F.	400° F.	500° F.	600° F.	700° F.	800° F.	900° F.	1,000° F.
1,350	26.5	5	27	29	28	28	27	23	25	26
1,400	52.5	7½	54	54	54	53	52	52	50.5	49
1,450	57	9½	58	57	56	56	53.5	54	53	51
1,500	59.5	10	61	59	57	56.5	53.5	54.5	54	52
1,550	59.5	10	60.5	59	56	55.5	55	56	55.5	52
1,600	62.5	10	62	60	59	57	57	56	55	52.5
1,650	63.5	9½	62.5	60.5	57	57.5	55.5	56	55	54
1,700	63	10	62	60	57	56.5	56.5	55	55	54
1,750	63	10	63	60.5	58	57	56	55.5	55	53.5
1,800	63.5	10	63	62	57	57	56	55	55	54
1,850	62.5	9	62.5	60.5	57.5	57	56	55.5	55	54
1,900	63	9	63.5	60	57	57	55	55	56	54.5
1,950	63	9	63	59.5	57.5	56.5	56	55	55	54
2,000	62.5	8	62.5	59.5	58	57	57	56	54	55

Table VI below, shows the Izod impact properties of the hardened and quenched AL–123 analysis. These properties are shown to be equivalent or superior to those possessed by the known commercially available materials.

TABLE VI

Izod Impact Tests at Room Temperature

[Unnotched Izod samples 3" long x .425" square were hardened at the indicated temperatures and air quenched. Tempering for 1 hour at the indicated temperature preceded finish grinding to .394" squares. The samples were then tested in a 120 ft. lb. Izod machine]

Hardening temp., ° F	Tempering temp., ° F	Hardness Rockwell "C"	Average impact value, ft. lbs.
1,500	(1)	43	51.75
1,500	300	42	62
1,500	400	39 –40	74
1,500	500	42	82
1,500	600	40	96
1,600	(1)	63	27.50
1,600	300	61 –62	55
1,600	400	59	68.25
1,600	500	56.5–57.5	82
1,600	600	55 –56	76.50
1,800	(1)	62 –63	23.25
1,800	300	60 –61	57.25
1,800	400	58 –59	89.50
1,800	500	56 –57	(2)
1,800	600	54 –56	(2)

[1] As quenched.
[2] Beyond capacity of machine.

From FIGS. 3 and 4 and Tables V and VI, it is shown that applicant's alloy exhibits good deep hardening characteristics (FIGS. 3 and 4 and Table V) and good impact resistance (Table VI), in addition to unusually good dimensional stability (FIGS. 1 and 2 and Tables II, III and IV).

The following data shown by Table VII also illustrates the wide hardening range and fine grain size of the alloy of the present invention. The material tested had the analysis reported as AL–123(2) in Table I above.

Samples 2" long were cut from 1" round annealed bar stock. They were hardened by holding for 5 minutes at the indicated temperatures and air cooling. Samples were fractured and Shepherd fracture grain size ratings obtained. Hardness measurements were obtained as quenched and after tempering cumulatively at tempera-

tures of 300° F., 400° F., 500° F., 600° F., 700° F., 800° F., 900° F. and 1000° F. Results are tabulated below:

TABLE VII

Hardening temperature, ° F.	Shepherd fracture grain size	Hardness, Rockwell C								
		As Quenched	Tempering temperatures							
			300° F.	400° F.	500° F.	600° F.	700° F.	800° F.	900° F.	1,000° F.
1,350	3	25.5	26.5	26.5	25	25	24	23	22	21
1,400	8	53	53.5	53	51	51	48.5	45	44	41
1,450	8½	59	59	58	57	56	53	50	47	42
1,500	9½	61	61	59	56	54	51	47	47.5	46
1,550	9½	63	63	60.5	58	57	54	52	50	47.5
1,600	10	63	62	60	58.5	57	56	54.5	53	52
1,650	9½	63.5	63	60	57.5	57	56	55	53.5	52.5
1,700	9½	64	62	60	57.5	57	56	55	54	51
1,750	9½	64	63	60	58	57	56	55	54	53
1,800	9½	64	62	59	58	57	56	55	53	51.5
1,850	8¾	63.5	62	59.5	58.5	57	56	55.5	54.5	54.5
1,900	8½	63.5	61	59.5	58	57	56	55.5	55	55
1,950	8	63.5	61	59	58	57	56	55.5	55	55
2,000	7	63-63.5	61	59	57.5	57	56	55.5	55	55

The above specific examples are given to illustrate the properties of applicant's novel composition and in no way limit the scope of applicant's invention or claims to the exact analyses set forth.

I claim:

1. An iron base alloy consisting essentially of greater than .80% and less than .90% carbon, 1.85% to 2.15% manganese, .25% to .50% silicon, .75% to 1.10% chromium, 1.20% to 1.40% molybdenum, .45% to .85% vanadium, the balance iron plus incidental impurities, said alloy being characterized by good deep hardening characteristics, a wide hardening range, good impact resistance, good machinability in the annealed condition and good dimensional stability during heat treatment.

2. An iron base alloy consisting of greater than .80% and less than .90% carbon, 1.85% to 2.15% manganese, .25% to .50% silicon, .75% to 1.10% chromium, 1.20% to 1.40% molybdenum, .45% to .85% vanadium, the balance iron plus incidental impurities, said alloy being characterized by good deep hardening characteristics, a wide hardening range, good impact resistance, good machinability in the annealed condition and good dimensional stability during heat treatment.

3. An iron base alloy consisting essentially of .83% to .87% carbon, 1.85% to 2.15% manganese, .25% to .50% silicon, .75% to 1.10% chromium, 1.20% to 1.40% molybdenum, .45% to .85% vanadium, the balance iron plus incidental impurities, said alloy being characterized by good deep hardening characteristics, a wide hardening range, good impact resistance, good machinability in the annealed condition and good dimensional stability during heat treatment.

4. An iron base alloy consisting of .83% to .87% carbon, 1.85% to 2.15% manganese, .25% to .50% silicon, .75% to 1.10% chromium, 1.20% to 1.40% molybdenum, .45% to .85% vanadium, the balance iron plus incidental impurities, said alloy being characterized by good deep hardening characteristics, a wide hardening range, good impact resistance, good machinability in the annealed condition and good dimensional stability during heat treatment.

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