

[72] Inventors Tetsuro Ito
 Nagoya;
 Goshi Kato, Tsushima; Atsuyoshi Kimura,
 Chita-gun, all of Japan
[21] Appl. No. 781,520
[22] Filed Dec. 5, 1968
[45] Patented Jan. 11, 1972
[73] Assignee Daido Seiko Kabushiki Kaisha
 Minami-ku, Nagoya, Aichi, Japan
[32] Priority Apr. 3, 1968
[33] Japan
[31] 43/21947

[54] **FREE CUTTING STEELS**
 1 Claim, 24 Drawing Figs.
[52] U.S. Cl. 75/125,
 75/123 AA, 75/123 F, 75/126 C, 75/126 G,
 75/126 M

[51] Int. Cl. C22c 39/54
[50] Field of Search 75/123, 123
 R, 123 AA, 123 F, 125, 126 G, 126 M

[56] References Cited
 UNITED STATES PATENTS
2,258,604 10/1941 Gagnebin 75/123 X
Primary Examiner— L. Dewayne Rutledge
Assistant Examiner— Joseph E. Legru
Attorney— Wenderoth, Lind & Ponack

ABSTRACT: This invention relates to free cutting steels containing in combination calcium and at least one free cutting element selected from the group consisting of lead, sulfur and tellurium. Such free cutting steels are characterized by their cutting property.

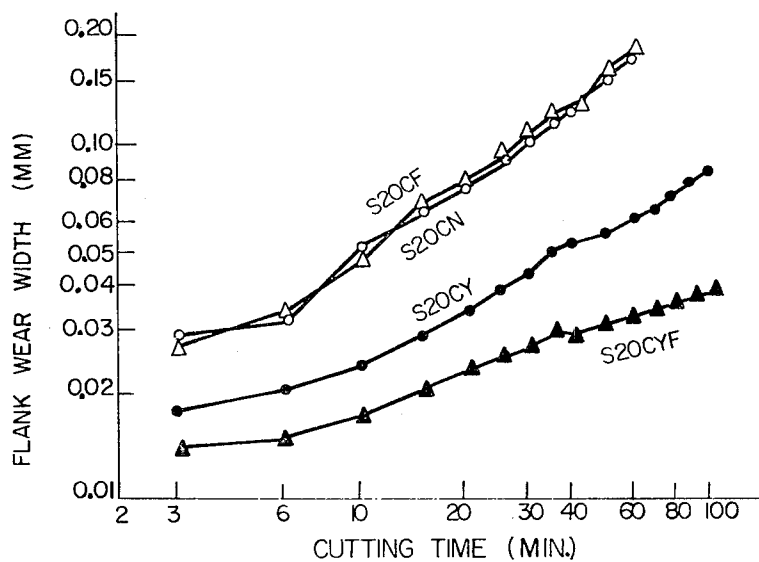


FIG. 1

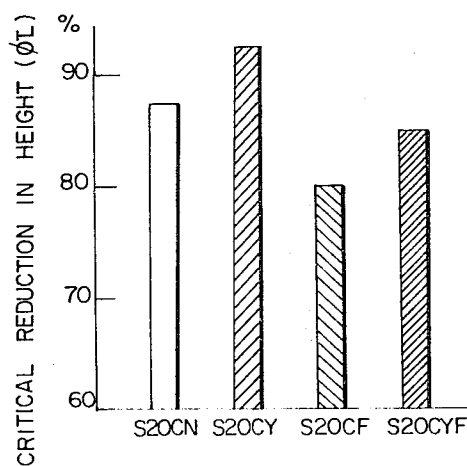


FIG. 2

INVENTORS

TETSURO ITO
GOSHI KATO
ATSUYOSHI KIMURA

BY *Wunderlich, Lind & Packer*
ATTORNEYS

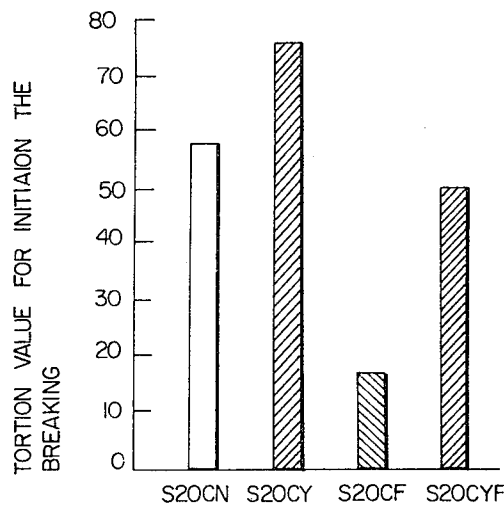


FIG. 3

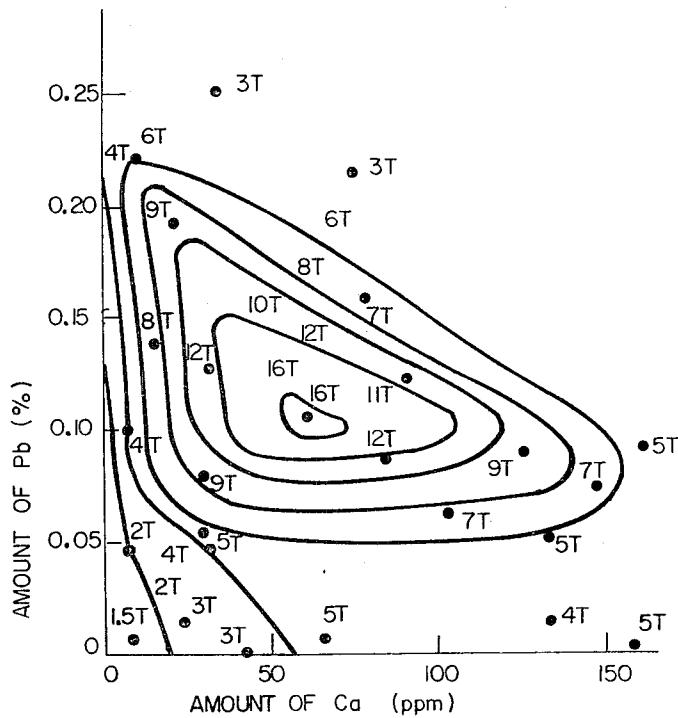


FIG. 4

INVENTORS
TETSURO ITO
GOSHI KATO
ATSUYOSHI KIMURA

BY *Wendroth, Lund & Ponack*
ATTORNEYS

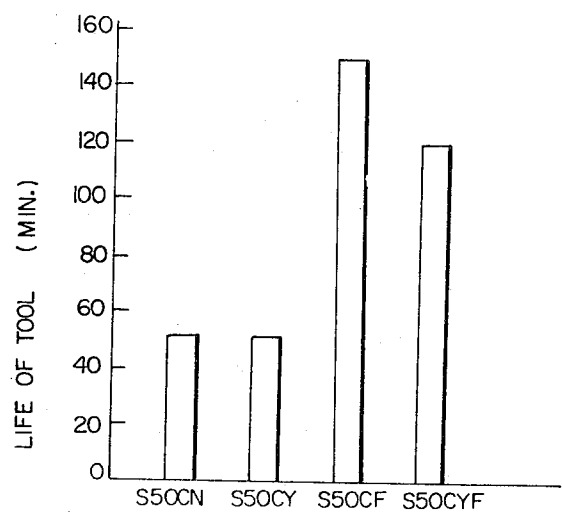


FIG. 5

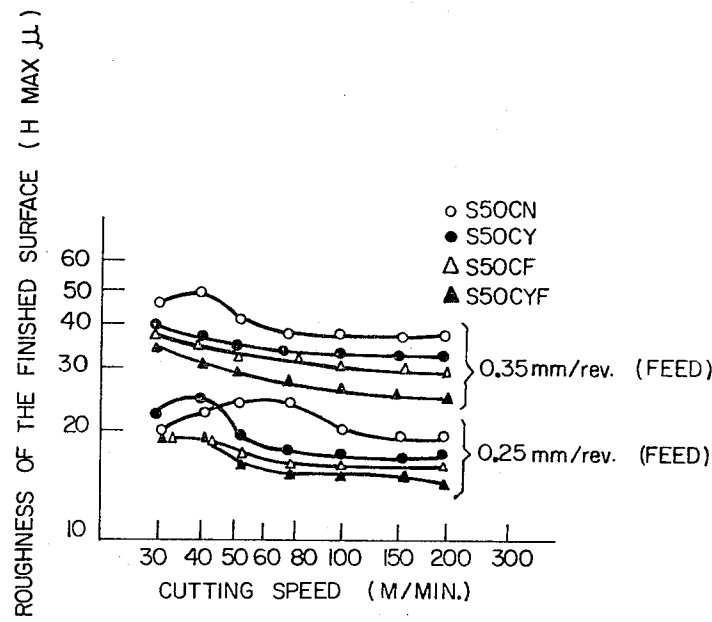


FIG. 6

INVENTORS

TETSURO ITO
GOSHI KATO
ATSUYOSHI KIMURA

BY *Wendert, Funder & Mack*
ATTORNEY

FIG.7
(1)



RAKE FACE OF TOOL AFTER THE
S50CN STEEL WAS CUT

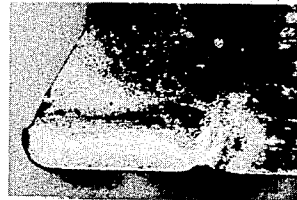
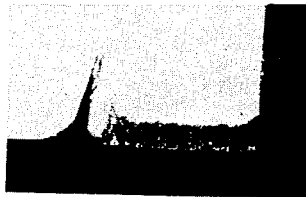


FIG.7
(3)

RAKE FACE OF TOOL AFTER
THE S50CY STEEL WAS CUT

FIG.7
(2)



RELIEF FACE OF TOOL AFTER
THE S50CN STEEL WAS CUT

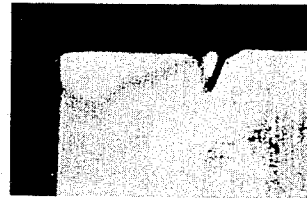
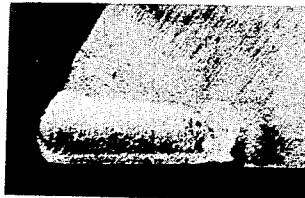


FIG.7
(4)

RELIEF FACE OF TOOL AFTER
THE S50CY STEEL WAS CUT

FIG.7
(5)



RAKE FACE OF TOOL AFTER
THE S50CF STEEL WAS CUT

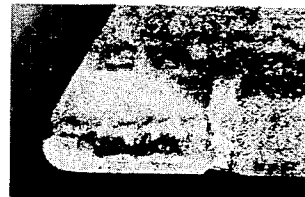
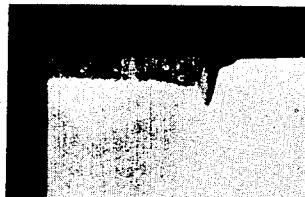


FIG.7
(7)

RAKE FACE OF TOOL AFTER
THE S50CYF STEEL WAS CUT

FIG.7
(6)



RELIEF FACE OF TOOL AFTER
THE S50CF STEEL WAS CUT

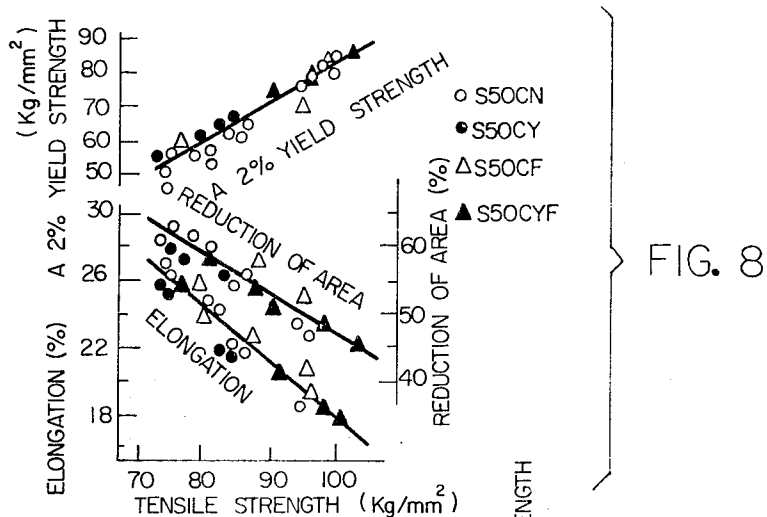
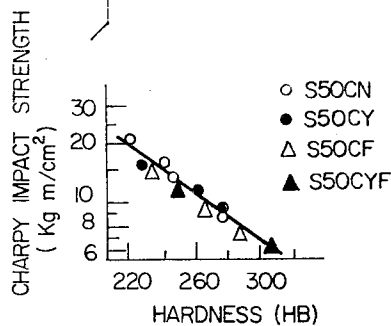
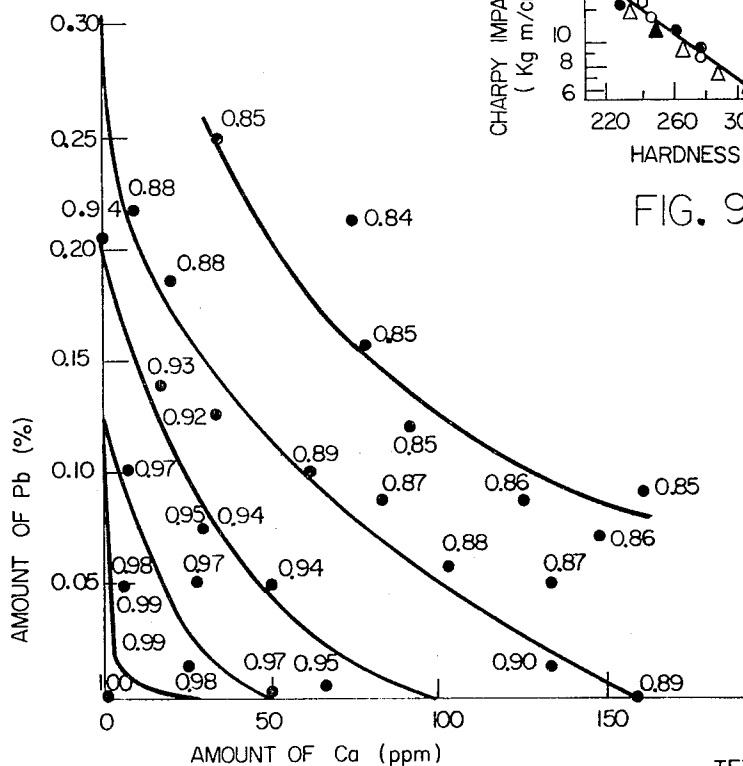


FIG.7
(8)

RELIEF FACE OF TOOL AFTER
THE S50CYF STEEL WAS CUT

INVENTORS
TETSURO ITO
GOSHI KATO
ATSUYOSH KIMURA

BY
Wenderoth, Lind & Ponack
ATTORNEYS



INVENTORS

TETSURO ITO
GOSHI KATO
ATSUYOSHI KIMURA

BY

Wendroth, Lund & Ponack

ATTORNEYS

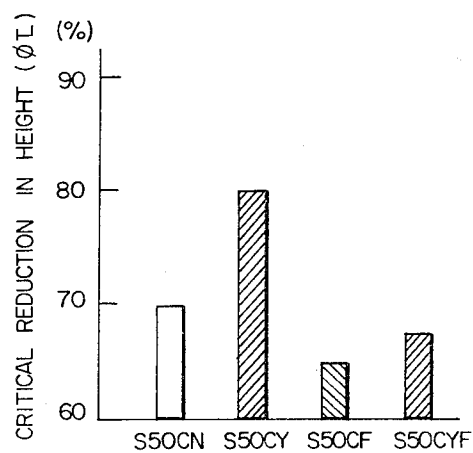


FIG. 11

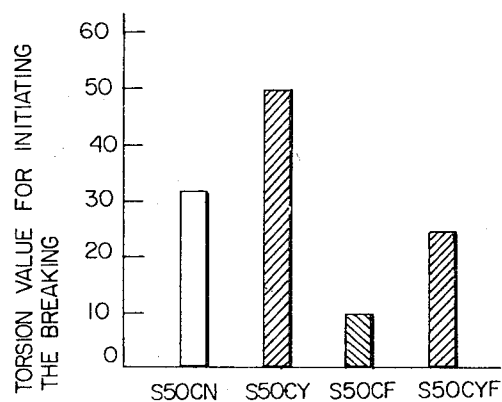


FIG. 12

INVENTORS

TETSURO ITO
GOSHI KATO
ATSUYOSHI KIMURA

BY

Wendroth, Lind & Penack

ATTORNEYS

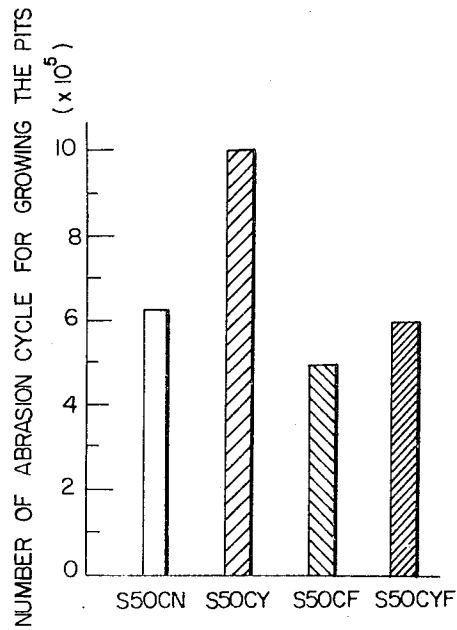


FIG. 13

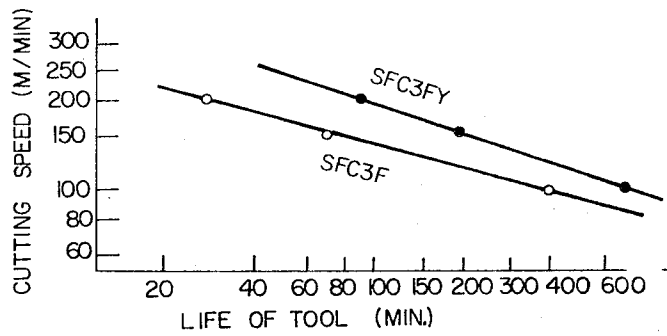


FIG. 14

INVENTORS

TETSURO ITO
GOSHI KATO
ATSUYOSHI KIMURA

BY

Wendelb, Lund & Tonack

ATTORNEYS

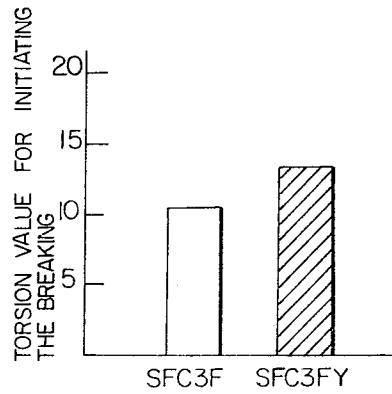


FIG. 15

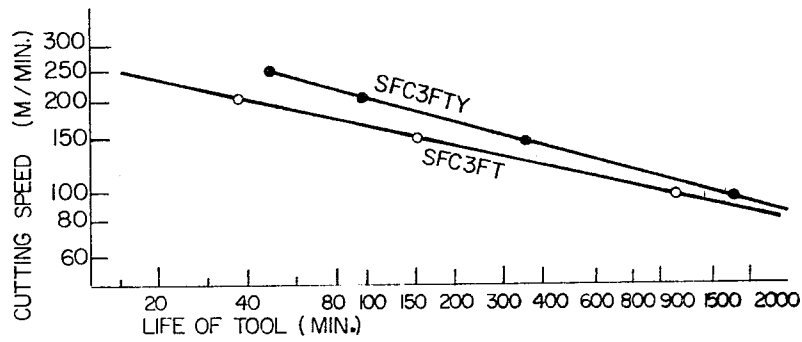


FIG. 16

INVENTORS

TETSURO ITO
GOSHI KATO
ATSUYOSHI KIMURA

BY

Wunderlich, Lund & Tonack

ATTORNEYS

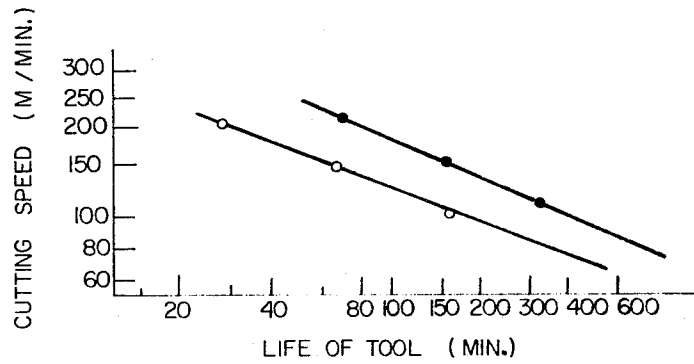


FIG. 17

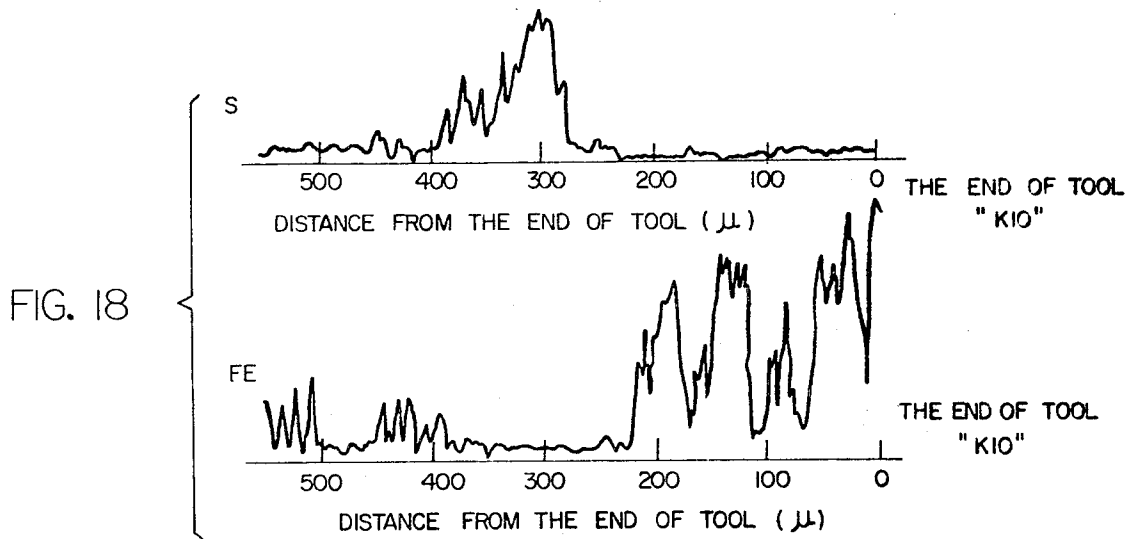


FIG. 18

INVENTORS

TETSURO ITO
GOSHI KATO
ATSUYOSHI KIMURA

BY *Wendroth, Lund & Knack*
ATTORNEYS

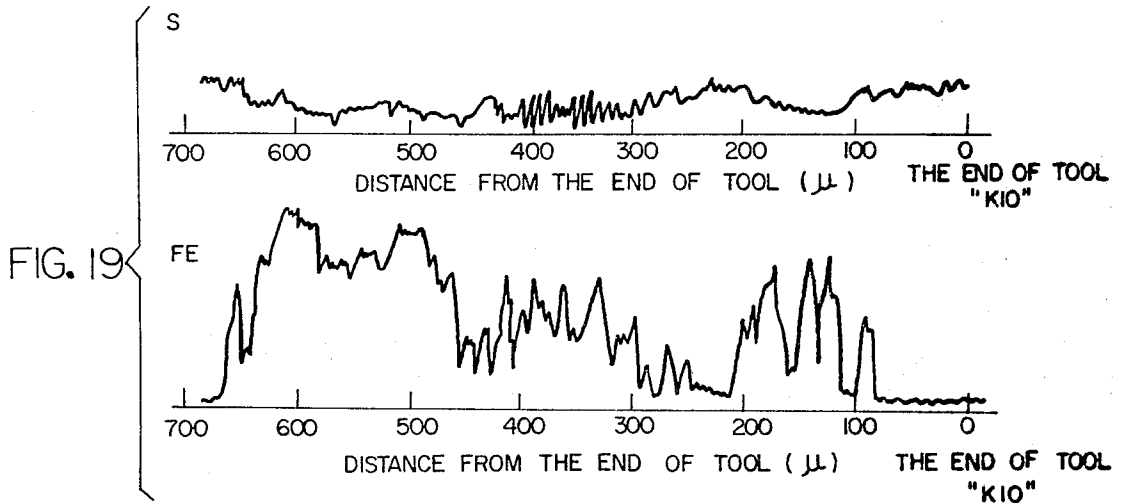
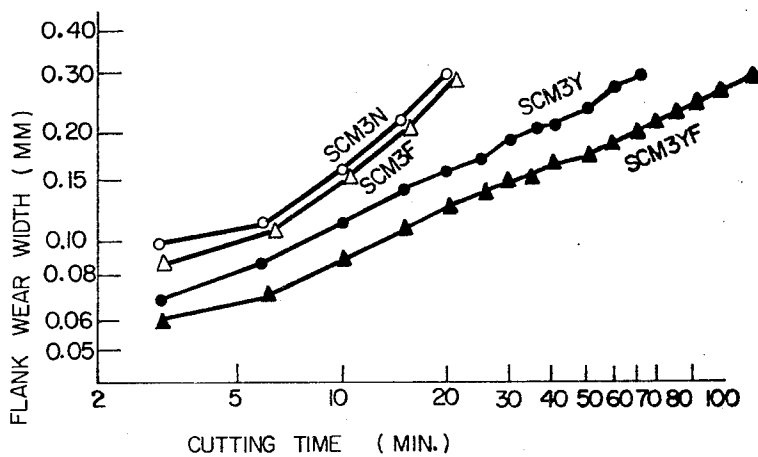


FIG. 20

INVENTORS

TETSURO ITO
GOSHI KATO
ATSUYOSHI KIMURA

BY

Wendroth, Fung & Penack
ATTORNEYS

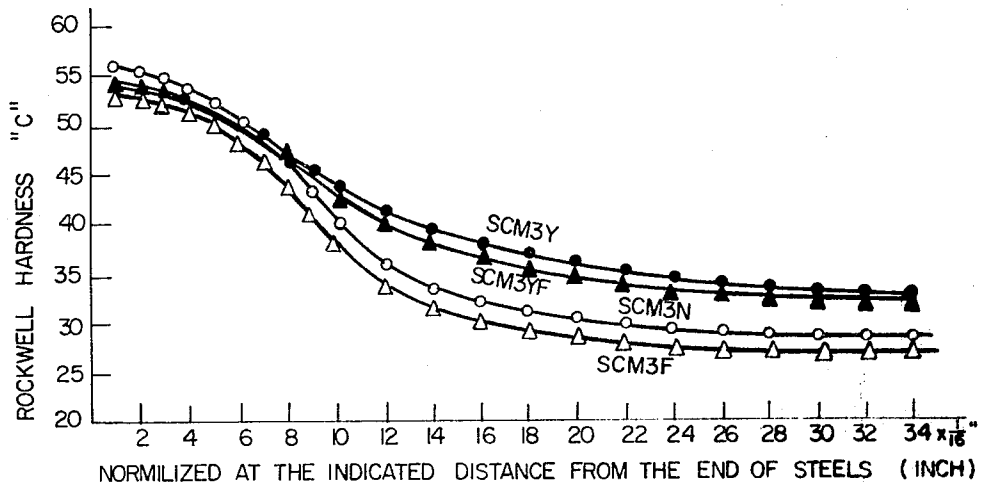


FIG. 21

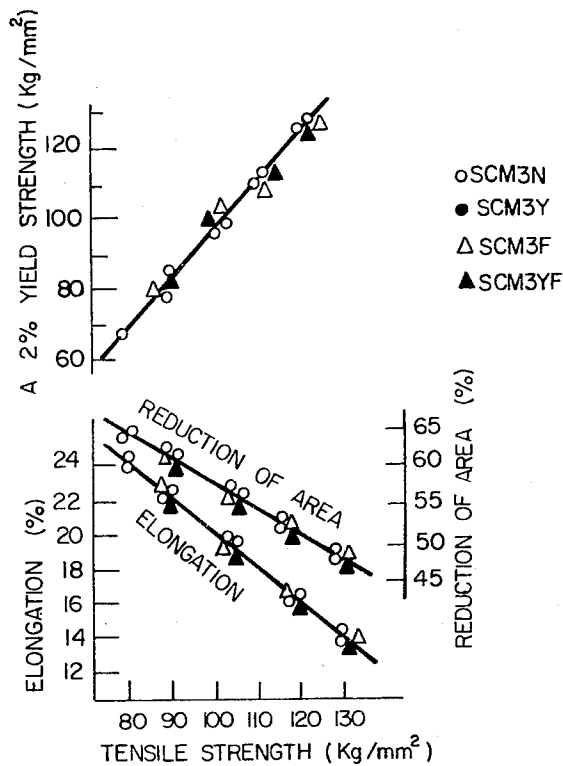


FIG. 22

INVENTORS

TETSURO ITO
GOSHI KATO
ATSUYOSHI KIMURA

BY

Wendroth, Lund & Tonack

ATTORNEYS

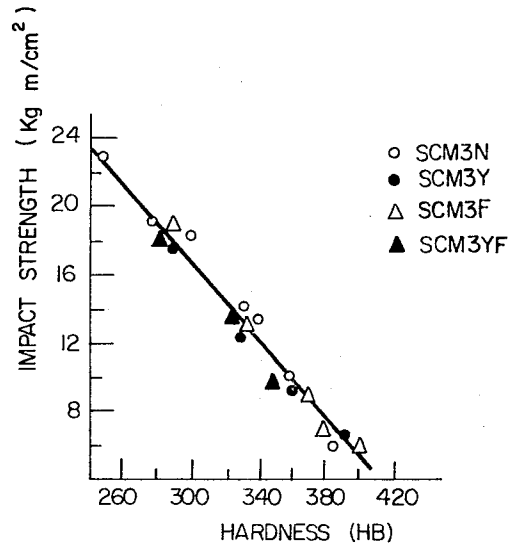


FIG. 23

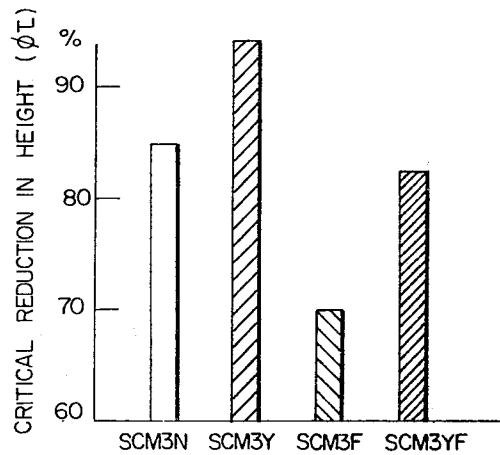


FIG. 24

INVENTORS

TETSURO ITO
GOSHI KATO
ATSUYOSHI KIMURA

BY

Wanderath, Lund & Ponack
ATTORNEYS

FREE CUTTING STEELS

This invention relates to free cutting steels containing in combination calcium and at least one member selected from the group consisting of lead, sulfur and tellurium.

The cutting technique and workability of the steels are recognized to be of great importance in order to meet the increased production of the steel articles and various kinds of free cutting steels have been developed by incorporating one or more members, in combination, selected from the group consisting of sulfur, lead, selenium, tellurium, bismuth, phosphorus and nitrogen with steels. Recently, free cutting steels containing calcium have come to draw the attention of those in the art due to the facts that they produce a deposition layer on a cutting tool for preventing the abrasion of tool and improve the life of tool.

The copending Japanese Pat. application No. 59,620 filed on Sept. 19, 1967 discloses the free cutting steels containing anorthite as the principal oxide inclusion. Such free cutting steels contain calcium in an amount varying from 20 p.p.m. to 100 p.p.m. (0.002 to 0.01 percent by weight).

Also the copending Japanese Pat. application No. 14,630 filed on Mar. 3, 1968 discloses the free cutting stainless steels containing calcium in an amount varying from 100 p.p.m. to 600 p.p.m. (0.01 to 0.06 percent by weight). The base steels contain Cr or Cr and Ni or Cr and Mn or Cr, Ni and Mn as the principal alloying elements.

The inventors have found that such a Ca-containing free cutting steel improves the life of tool when it is cut under high speed but it does not improve the life of tool when it is cut under low speed as compared with the life of tool when the base steel not containing the free cutting additive or additives is cut under low speed. In this connection, it was reported and recognized in the art that the free cutting steels containing the single member or in combination, more members selected from the group consisting of Pb, S and Te remarkably improve the life of tool when they are cut under low or medium speed but that they slightly improve the life of tool when they are cut under high speed.

The object of this invention is to provide free cutting steels without the above-mentioned defects as inherent to the conventional free cutting steels. The object of this invention can be achieved by providing the free cutting steels containing in combination calcium and at least one member selected from the group consisting of Pb, S and Te.

The inventors have found that the free cutting steels in accordance with this invention are remarkably improved in their mechanical properties, workability and etc., as compared with the free cutting steels containing Ca or Pb or Pb, S and Te when they are cut under low or medium or high speed, and also that the free cutting steels in accordance with this invention have the abrasion resistance, hardenability, cold and hot workability similar to those of the base steels. It should be noted that the base steels used in this invention have the following chemical compositions.

Components	% by weight
C	0.05-0.80
Si	below 2.00
Mn	below 4.00
P	below 0.10
Cu	below 0.60
Ni	below 5.00
Cr	below 6.00
Mo	below 1.00
W	below 1.00
Ti	below 0.50
V	below 0.50
Nb	below 0.50
B	below 0.01

In accordance with this invention, the base steels must contain as the free cutting elements calcium in an amount of from 0.0010 to 0.030 percent by weight and at least one member selected from lead in an amount of from 0.03 to 0.35 percent by weight, sulfur in an amount of below 0.5 percent by weight and tellurium in an amount of from 0.01 to 0.10 percent by weight for producing the subject free cutting steels having the improved cutting property and workability. The inventors have found that the free cutting steels are not improved in their workability when they contain calcium in an amount outside the range as defined above. Also, the inventors have found that the free cutting steels are decreased or not improved in their workability when they contain Pb, S and Te in an amount outside the range as defined above.

Further there are explained hereinafter the reasons why the amount of the components contained in the base steels is defined within the range as mentioned above.

The lower limit of carbon is defined to 0.05 percent by weight for obtaining the necessary strength for the steels. The upper limit of carbon, silicon or manganese is defined to 0.30, 2.0 or 4.0 percent by weight for obtaining the necessary tenacity and workability for the steels. Phosphorus is an additive for increasing the workability of the steels but the amount of phosphorus is defined to the upper limit of a 1.0 percent by weight because the tenacity and ductility of the steels are affected as the phosphorus content increases. The upper limit of nickel, chromium or molybdenum is defined to 5.0, 6.0 or 1.0 percent by weight because the workability of the steels are decreased when the steels contain Ni, Cr or Mo in a larger amount over the upper limit thereof. Tungsten is harmful to workability; copper causes brittleness; titanium, vanadium and niobium are harmful to hardenability; and boron is harmful to workability of the steels as the content thereof increases and thus their upper limit is defined to 1.0, 0.5, 0.5, 0.5 and 0.01 percent by weight respectively.

Examples of the free cutting steels in accordance with this invention as well as the base steels and control steels are listed in the following table 1.

TABLE 1

Steels	Chemical components										Hardness after normalized
	C	Si	Mn	P	S	Cu	Cr	Mo	Pb	Te	
S20CN (base).....	0.21	0.24	0.38	0.018	0.012	0.13	0.08	-----	-----	-----	151
S20CF.....	0.20	0.31	0.40	0.018	0.015	0.12	0.11	-----	0.09	-----	150
S20CY.....	0.21	0.31	0.50	0.021	0.016	0.12	0.10	-----	-----	0.0053	153
S20CYF.....	0.20	0.28	0.38	0.019	0.015	0.12	0.10	-----	0.18	-----	151
S50CN (base).....	0.51	0.28	0.75	0.014	0.018	0.11	0.10	-----	-----	-----	215
S50CF.....	0.50	0.29	0.78	0.015	0.019	0.10	0.14	-----	0.22	-----	213
S50CY.....	0.51	0.30	0.74	0.014	0.020	0.10	0.12	-----	-----	0.0050	214
S50CYF.....	0.50	0.27	0.68	0.016	0.020	0.10	0.12	-----	0.20	-----	215
SFC3F.....	0.08	0.10	0.99	0.068	0.318	0.12	0.15	-----	0.20	-----	124
SFC3YF.....	0.09	0.09	1.01	0.071	0.321	0.11	0.15	-----	0.21	-----	123
SFC3FT.....	0.07	0.05	0.99	0.075	0.321	0.13	0.16	-----	-----	0.0030	126
SFC3FTY.....	0.08	0.08	0.98	0.075	0.315	0.13	0.15	-----	0.21	0.041	124
SUM1B (base).....	0.11	0.18	0.78	0.014	0.183	0.23	0.10	-----	0.20	0.043	120
SUM1BY.....	0.10	0.20	0.76	0.015	0.181	0.20	0.11	-----	-----	0.0025	122
SCM3N (base).....	0.35	0.29	0.69	0.018	0.012	0.14	1.00	0.24	-----	-----	269
SCM3Y.....	0.36	0.28	0.69	0.016	0.013	0.12	0.98	0.21	-----	-----	269
SCM3F.....	0.35	0.31	0.71	0.017	0.013	0.12	0.98	0.22	-----	0.0031	270
SCM3YF.....	0.35	0.30	0.70	0.018	0.011	0.12	1.00	0.23	-----	0.0028	270

In table 1, it is noted that the base steels are S20CN, S50CN, SUM1B and SCM3N as designated in the Japanese Industrial Standards, and F-type, Y-type and YF-type steels contain lead, calcium and lead plus calcium respectively.

Now, this invention is fully explained by referring to the accompanying drawings in which:

FIG. 1 shows curves illustrating the relationship between the flank wear width and the cutting period of time when S20CN, S20CF, S20CY and S20CYF steels were normalized and then cut at the feed of 0.2 mm./rev., the depth of cut of 2.0 mm. and the cutting speed of 200 m./min. by using the cutting tool "P 10" having the back rake angle of -5, the side rake angle of -5, the end relief angle of 5, the side relief angle of 5, the cutting angle of 30, the side cutting angle of 0 and the nose radius of 0.4 mm. It can be seen from the curves as indicated in FIG. 1 that the S20CYF steel of this invention which contains 0.18 percent of Pb and 0.0051 percent of Ca is remarkably improved as compared with the S20CF steel and the S20CY steel. When the steels were cut for 60 minutes, the flank wear width of the tool is given in the following table 2.

TABLE 2

Steels	Flank wear width (mm.)
S20CN	0.175
S20CF	0.182
S20CY	0.062
S20CYF	0.035

The above-mentioned steels were normalized to have the hardness (HB) of 135 and test pieces were made of the normalized steels. The test pieces have the size of 6 mm.φ×12 mm. and they were tested for the critical reduction in height. The test was conducted for 20 times in each of the steels. The results of the test are shown in FIG. 2. As it is obvious from FIG. 2, the S20CYF steel of this invention has the cold workability similar to that of the S20CN steel but higher cold workability than that of the S20CF steel containing Pb alone. It should be understood that the critical reduction in height (φL) is indicated by the following equation.

$$\phi L = \frac{H-h}{H} \times 100(\%)$$

wherein, H indicates the initial height of the test piece and h indicates the final height of the test piece after it was compressed.

Also the above-mentioned steels were tested for hot workability. The test pieces having the size of 8 mm.φ×30 mm. were made of the steels and the test pieces were tested for the torsion value for initiating the breaking of them at the strain speed of 2 sec.⁻¹ at 1,100° C. by using the high temperature-torsion test machine. The results of the tests are shown in FIG. 3. As it is obvious from FIG. 3, the S20CYF steel of this invention has the hot workability similar to that of the S20CN steel but higher hot workability than that of the S20CF steel containing Pb alone.

Free cutting steels were produced by incorporating various amounts of calcium and lead with S50CN steel and then they were normalized. The normalized free cutting steels were cut at the feed of 0.20 mm./rev. and the depth of cut of 2.0 mm. under high cutting speed by using a cutting oil and the cutting tool "P 10" having the back rake angle of -5, the side rake angle of -5, the end relief angle of 5, the side relief angle of 5, the end cutting angle of 30, the side cutting angle of 0 and the nose radius of 0.4 mm. The life of tool was evaluated at the flank wear width of 0.3 mm. The results of the tests are shown in FIG. 4. In FIG. 4, the life of tool is indicated by using the abbreviation (T) of the multiple number calculated by assuming that the life of tool is 1.0 when the S50CN steel was cut. As it

is obvious from FIG. 4, the life of tool is remarkably improved as the amount of Ca and Pb contained in the free cutting steels increase and also the life of tool is improved by increasing the amount of Ca even if the amount of Pb is decreased.

FIG. 5 shows the life of tool when the S20CN, S50CY, S50CF and S50CYF steels were normalized and cut under low speed. The normalized base steel and the free cutting steels were cut at the feed of 0.12 mm./rev. and the depth of cut of 1.0 mm. under high cutting speed of 50 m./min. by using a cutting oil and the cutting tool "SKH4" having the back rake angle of 0, the side rake angle of 15, the end relief angle of 7, the side relief angle of 7, the end cutting angle of 10, the side cutting angle of 0 and the nose radius of 0.5 mm. The life of tool was evaluated until the tool becomes to have no ability for cutting the test samples. As it is obvious from FIG. 5, the free cutting steel designated as S50CY steel, which contains calcium alone, is not improved in its workability as compared with the base steel designated as S50CN steel but the free cutting steel designated as S50CYF, which contains calcium and lead in combination, is remarkably improved in its workability as compared with the base steel.

FIG. 6 shows curves illustrating the relationship between the cutting speed and the roughness of the finished surface of each of S50CN, S50CY, S50CF and S50CYF steels when they were normalized and cut. The tests were conducted by cutting the normalized steels at the feed of 0.25 mm./rev. or 0.35 mm./rev. and the depth of cut of 2.0 mm. under the indicated cutting speed by using the cutting tool "P 10" having the back rake angle of -5, the side rake angle of -5, the end relief angle of 5, the side relief angle of 5, the end cutting angle of 30, the side cutting angle of 0 and the nose radius of 4 mm. As it is obvious from FIG. 6, the free cutting steel (S50CYF steel) of this invention indicates to have the good finished surface.

Also, the normalized steels as mentioned above were cut at the feed of 0.18 to 0.48 mm./rev. and the depth of cut of 1.0 mm. by using the cutting tool "P 10" having the back rake angle of 0, the side rake angle of 6, the end relief angle of 7, the side relief angle of 7, the end cutting angle of 10, the side cutting angle of 0 and the nose radius of 0.5 mm. The cut scrap was crushed for testing its brittleness by using a chip breaker and it is found that the cut scrap obtained by cutting the S50CYF steel of this invention can easily be crushed without the use of the chip breaker. The results of tests are given in the following table 3.

TABLE 3

Cutting speed (m./min.)	Feed (mm./rev.)	S50CN	S50CY	S50CF	S50CYF
50	0.48	X	X	O	X
	0.38	X	X	X	X
	0.28	X	X	X	X
	0.18	O	O	X	X
55	0.48	X	X	O	X
	0.38	X	X	O	O
	0.28	O	X	O	O
	0.18	O	O	O	O
100	0.48	O	X	O	O
	0.38	O	X	O	O
	0.28	O	O	O	O
	0.18	O	O	O	O
160	0.48	O	O	O	O
	0.38	X	X	O	O
	0.28	O	O	O	O
	0.18	O	O	O	O
200	0.48	O	O	O	O
	0.38	O	O	O	O
	0.28	X	X	O	O
	0.18	X	X	O	O
250	0.48	O	O	O	O
	0.38	O	O	O	O
	0.28	X	X	O	O
	0.18	X	X	O	O

Note: The mark "X" indicates the use of the chip breaker for crushing the cut scrap and the mark "O" indicates that the chip breaker is not required for crushing the cut scrap.

FIG. 7 shows the microphotographs illustrating the fatigue state of the rake face and the relief face of the tool when S50CN, S50CY, S50CF and S50CYF steels were cut with the cutting tool. As you see from the microphotographs, it is ob-

served that the rake face and the relief face of the tool were abraded when the S50CN steel was cut. Also, it is observed that the abrasion of the rake face and the relief face of the tool was considerably prevented due to the presence of the layer deposited on the rake and relief faces when the S50CY and S50CF steels were cut. Further, it is observed that the tool was not abraded when the S50CYF steel was cut.

FIG. 8 shows curves illustrating the relationship between tensile strength and proof stress or elongation or a 0.2 percent reduction of area when S50CN, S50CYN, S50CNF and S50CYF steels were tested. As you see from the curves, the steels have the similar mechanical properties in the proof stress, elongation and the reduction of area and therefore it is understood that the mechanical properties of the S50CYF steel are not affected by the presence of calcium and lead.

FIG. 9 shows a curve illustrating the relationship between Charpy impact strength and hardness of S50CN, S50CY, S50CF and S50CYF steels when they were heated at 800° C. and annealed at 550° 600° or 650° C. As you see from the curve, the mechanical properties of the S50CYF steel are not affected by the presence of calcium and lead.

FIG. 10 shows curves illustrating the change of fatigue strength affected by the presence of calcium and lead contained in S50CN steel. The test was conducted for three times in each of the test steels and their fatigue strength are given as the average value. In FIG. 10, it is noted that the fatigue strength is indicated by the multiple number calculated by assuming that the S50CN steel has the fatigue strength of 1.0.

The following table 4 shows the relationship between the life of the cutting tool and the fatigue strength of the three types free cutting steels designated as S50CY, S50CF and S50CYF steels. In table 4, it is noted that the life of tool and the fatigue strength of steels are indicated by the multiple number using the abbreviation (T). Also it is noted that S50CY-1 steel, S50C-2 steel or S50CY-3 steel contains 0.002% Ca, 0.005% Ca or from 0.007 to 0.016% Ca, S50CF-1 steel or S50CF-2 steel contains 0.15% Pb or 0.20% Pb, and S50CF-1 steel, S50CYF-2 steel, S50CYF-3 steel or S50CYF-4 steel contains 0.001% Ca plus 0.05% Pb, 0.001% Ca plus 0.10% Pb, 0.002% Ca plus 0.05% Pb or 0.004% Ca plus 0.05% Pb.

TABLE 4

Life of tool	Steels	Fatigue strength
2 T	S50CY-1	0.99 T
	S50CF-1	0.96 T
	S50CYF-1	0.98 T
4 T	S50CY-2	0.97 T
	S50CF-2	0.94 T
	S50CYF-2	0.97 T
	S50CYF-3	0.97 T
5 T	S50CY-3	0.90 T-0.96 T
	S50CYF-4	0.94 T

It is understood from the data as shown in table 4 that the S50CYF-type steels have the fatigue strength similar to or above the fatigue strength of the S50CY-type steels and also that the S50CYF-type steels have the larger fatigue strength than that of the S50CF-type steels.

Also, the following table 5 shows the relationship between the life of the cutting tool and the fatigue strength of the three types free cutting steels designated as S50CY, S50CF and S50CYF steels. As in table 4, the life of tool and the fatigue strength are indicated by using the multiple number. Further, it is noted that S50CY-4 or S50CY-5 steel contains 0.010% Ca or 0.016% Ca; S50CF-2 or S50CF-3 steel contains 0.20% Pb or 0.25% Pb; and S50CYF-5 or S50CYF-6 steel contains 0.005% Ca plus 0.05% Pb or 0.006% Ca plus 0.10% Pb.

TABLE 5

Fatigue strength	Steels	Life of tool
0.94 T	S50CY-4	5 T
	S50CF-2	4 T
	S50CYF-5	5 T
0.89 T	S50CY-5	5 T
	S50CF-3	4 T
	S50CYF-6	16 T

As you see from the data as shown in table 5, the fatigue strength of the S50CYF-type steels is not so much decreased in spite of the high increase of the life of the cutting tool.

FIG. 11 shows the cold workability of each of the steels designated as S50CN, S50CY, S50CF and S50CYF. The steels were normalized to have the hardness (HB) of 135 and 20 test pieces were made of the normalized steels. The test pieces have the size of 6 mm.φ×12 mm. and they were tested for the critical reduction in height (φL). As it is obvious from FIG. 11, the S50CYF steel of this invention indicates substantially the same critical reduction in height as that of the base S50CN steel and eliminates the defect of the S50CF steel containing Pb alone as the free cutting element.

FIG. 12 shows the hot workability of each of the steels as mentioned in FIG. 11. The test pieces have the size of 8 mm.φ×30 mm. and they were tested for the torsion value for initiating the breaking of them at the strain speed of 5 sec.⁻¹ at 1,100° C. by using the high temperature-torsion test machine. As it is obvious from FIG. 12, the S50CYF steel of this invention indicates the torsion value for initiating the breaking of its similar to that of the base S50CN steel and eliminates the defect of the S50CF steel containing Pb alone as the free cutting element.

FIG. 13 shows the abrasion resistance of each of the steels as mentioned in FIGS. 11 and 12. The steels were normalized to have the hardness (HRC) of 63 at the depth of 1.5 mm. and test pieces were made of the normalized steels. The test pieces have the size of 30 mm. in the outside diameter and the contact surface of 5 mm. in width. They were tested for their abrasion resistance. The test was conducted at 1,000 r.p.m. under the surface pressure of 200 kg./mm.² by using the abrasion test machine and the number of abrasion cycle for growing the pit was recorded. The results of tests are shown in FIG. 13. As it is obvious from FIG. 13, the S50CYF steel of this invention indicates substantially the same abrasion resistance as that of the base S50CN steel.

Further, the steels as mentioned in FIGS. 11, 12 and 13 were tested for their crack at surface or root or in depth and it was found that the S50CYF steel of this invention indicates good resistance against such a surface or root or depth crack as compared with that of the base S50CN steel and the such crack resistance of the S50CYF is measured as in the middle value of the S50CY steel containing Ca alone and the S50CF steel containing Pb alone as the free cutting elements.

FIG. 14 shows curves illustrating the relationship between the life of tool and the cutting speed when the free cutting steels designated as SFC3F steel containing S and Pb, and SFC3FY steel containing S, Pb and Ca were cut. The steels were normalized and the normalized steels were cut at the feed of 0.1 mm./rev. and the depth of cut of 0.5 mm. under the indicated cutting speed by using the cutting tool "K 10" having the back rake angle of 0, the side rake angle of 6, the end relief angle of 7, the side relief angle of 7, the end cutting angle of 10, the side cutting angle of 0 and the nose radius of 0.5 mm. The life of tool was evaluated at the flank wear width of 0.2 mm. As it is obvious from the curves shown in FIG. 14, the SFC3FY steel of this invention gives a longer life of tool as compared with the SFC3F steel.

FIG. 15 shows the hot workability of the steels as shown in FIG. 14. The test pieces have the size of 8 mm.φ×30 mm. and

they were tested for the torsion value for initiating the breaking of them at the strain speed of 3 sec.⁻¹ at 1,150° C. by using the high temperature-torsion test machine. As it is obvious from FIG. 15, the SFC3FY steel is improved in the torsion value as compared with the base SFC3F steel.

FIG. 16 shows curves illustrating the relationship between the life of tool and the cutting speed when the free cutting steels designated as SFC3FT steel and SFC3FTY steel were cut. It is noted that the SFC3FT steel contains sulfur, lead and tellurium, and the SFC3FTY steel contains sulfur, lead, tellurium and calcium as the free cutting elements. The steels were normalized and the normalized steels were cut at the feed of 0.1 mm./rev. and the depth of cut of 0.5 mm. under the indicated cutting speed by using the cutting tool "K 10" having the back rake angle of 0, the side rake angle of 6, the end relief angle of 7, the side relief angle of 7, the end cutting angle of 10, the side cutting angle of 0 and the nose radius of 0.5 mm. The life of tool was evaluated at the flank wear width of 0.2 mm. As it is obvious from the curves shown in FIG. 16, the SFC3FTY of this invention gives a longer life of tool as compared with the base SFC3FT steel.

FIG. 17 shows curves illustrating the relationship between the life of tool and the cutting speed when the free cutting steels designated as SUMIB steel and SUMIBY steel were cut. It is noted that the SUMIB steel contains sulfur and the SUMIBY steel contains sulfur and calcium as the free cutting elements. The steels were normalized and the normalized steels were cut in the same manner as in the tests conducted and explained in FIG. 16. The life of tool was evaluated at the flank wear width of 0.2 mm. As it is obvious from the curves shown in FIG. 17, the SUMIBY steel of this invention gives a longer life of tool as compared with the base SUMIB steel.

FIGS. 18 and 19 show distribution of the characteristic X-ray emission density emitted from sulfur and iron contained in the deposited layer on the rake face of tool after the tool was used for cutting the steels designated as SUMIB steel and SUMIBY steel. Both the steels were cut at the feed of 0.1 mm./rev., at the depth of cut of 0.5 mm. and at the cutting speed of 180 meters per minute for 20 minutes by using a cutting oil and the cutting tool "K 10" as explained in the above mentioned tests. FIG. 18 shows the results of test when the tool is used for cutting the SUMIB steel and a considerable amount of Fe is observed over the range varying from the end of the tool to about 250μ. This proves that the rake face of the tool was directly contacted with the scraps of the steel. FIG. 19 shows the results of test when the tool is used for cutting the SUMIBY steel and a considerable amount of S (or CaS) is observed all over the tool but Fe is not observed over the range varying from the end of the tool to about 50μ. This proves that the rake face of the tool was coated with the thin layer containing sulfur and the tool was prevented from abrasion.

FIG. 20 shows curves illustrating the relationship between the flank wear width and the cutting speed when Cr-Mo alloy steel designated as SCM3N and free cutting steels designated as SCM3Y, SCM3F and SCM3YF steels were cut with tool. It is noted that the SCM3Y steel contains calcium, the SCM3F steel contains lead and the SCM3YF steel contains calcium and lead as the free cutting elements. As it is obvious from the curves shown in FIG. 20, the SCM3YF steel of this invention is less abrasion than the other steels. Also, it is noted that all the steels were normalized and the normalized steels were cut at the feed of 0.2 mm./rev. and the depth of cut of 2.0 mm. under the cutting speed of 200 meters per minute by using the cutting tool "P 10" as mentioned in FIG. 6.

Also the steels were tested for time in minutes until the flank wear width of the tool reached 0.30 mm. when the steels

were cut with the cutting tool "P 10" the results of tests are given in the following table 6.

TABLE 6

Steels	Time in minutes
SCM3N	19
SCM3Y	70
SCM3F	21
SCM3YF	150

FIG. 21 shows curves illustrating the hardenability of the steels as shown in FIG. 20. As it is obvious from the curves as shown in FIG. 21, the SCM3YF steel of this invention has better hardenability than that of the SCM3N steel.

FIG. 22 shows curves illustrating the relationship between tensile strength and elongation (percent) or 0.2 percent yield strength or reduction of area when the steels designated as SCM3N, SCM3Y, SCM3F and SCM3YF were tested. In FIG. 22, it should be noted that the SCM3N steel is indicated by the marks "O" and the SCM3Y steel is indicated by the marks "●". Also, the SCM3F steel is indicated by the marks "Δ" and the SCM3YF steel is indicated by the marks "▲". As it is obvious from the curves as shown in FIG. 22, the SCM3YF steel of this invention has the mechanical properties similar to those of the other steels.

FIG. 23 shows a curve illustrating the relationship between hardness (HB) and Charpy impact strength when the steels designated as SCM3N, SCM3Y, SCM3F and SCM3YF were tested. It is noted that all the steels are indicated in the same marks as in FIG. 22 respectively. The steels were normalized at 860° C. and then annealed at 500°, 550°, 600° and 650° C. As it is obvious from the curves as shown in FIG. 23, the SCM3YF steel of this invention has the Charpy impact strength similar to those of the other steels.

FIG. 24 shows the cold workability of the steels designated as SCM3N, SCM3Y, SCM3F and SCM3YF when they were tested for critical reduction in height (φL). All the steels were normalized to have the hardness (HB) of 190 and test pieces were made of the normalized steels. The test pieces have the size of 6mm.φ×12mm. As it is obvious from FIG. 24, the SCM3YF steel of this invention indicates substantially the same critical reduction in height as that of the SCM3N steel and also indicates better critical reduction in height than that of the SCM3F steel containing Pb alone.

As stated in the foregoing, this invention provides the calcium composite free cutting steels which are manufactured by incorporating calcium and at least one member selected from the group consisting of Pb, S and Te with the carbon steels or the alloy steels. Such composite free cutting steels are improved in their cutting property as compared with the free cutting steels which are manufactured by incorporating calcium alone or at least one member selected from the group consisting of Pb, S and Te with the carbon steels or alloy steels. In addition such composite free cutting steels have the mechanical properties, cold and hot workability, hardenability, abrasion resistance and weldability similar to those of the original carbon steels or the original alloy steels.

What we claim is:

1. Free cutting carbon steel and alloy steel having improved cutting properties such that it may be cut at low or high speeds with an improved life to the cutting tool, said steel being characterized by containing as the free cutting elements calcium in an amount of from 0.0010 to 0.020 percent by weight and lead in an amount of from 0.03 to 0.35 percent by weight.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,634,074

Dated January 11, 1972

Inventor(s) Tetsuro ITO, Goshi KATO and Atsuyoshi KIMURA

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

column 2, line 37:

change "0.30" to

--0.80--.

Signed and sealed this 9th day of January 1973.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents