United States Patent [19]

Yamakoshi et al.

[11] **3,844,773**

[45] **Oct. 29, 1974**

[54] **FREE CUTTING STEEL CONTAINING MULLITE**

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[73] Assignee: **Kobe Steel, Limited**, Kobe, Japan

[22] Filed: **May 10, 1973**

[21] Appl. No.: **359,024**

[30] **Foreign Application Priority Data**

May 10, 1972 Japan 47-46141

[52] **U.S. Cl.** .... **75/123 G,** 75/123 L, 75/126 G, 75/128 E, 75/128 P

[51] **Int. Cl.** **C22c 37/00**

[58] **Field of Search** .... 75/123 G, 126 G, 126 L, 75/123 L, 128 P, 128 E

[56] **References Cited**

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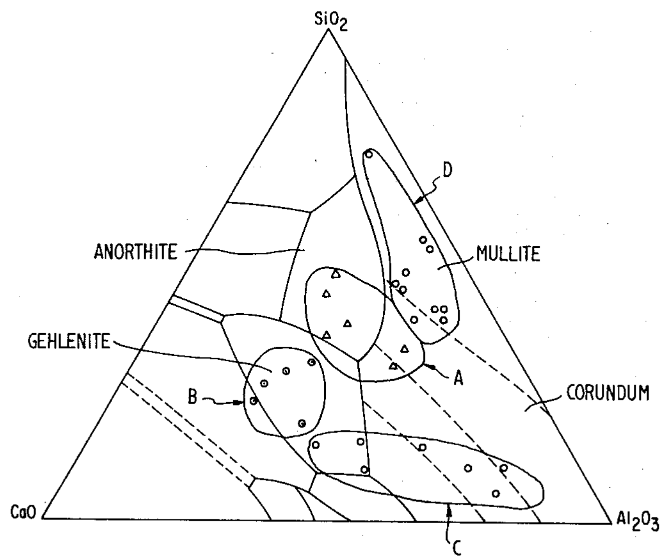
Primary Examiner—L. Dewayne Rutledge
Assistant Examiner—Arthur J. Steiner
Attorney, Agent, or Firm—Oblon, Fisher, Spivak, McClelland & Maier

[57] **ABSTRACT**

A free cutting steel is disclosed having improved cutting properties which leads to improved service life for cutting tools. Th steel is characterized by the presence of a principal component of a nonmetallic inclusion contained within said steel existing essentially in the mullite region of three phase trigonometric diagram of the $CaO—Al_2O_3—SiO_2$ system. The steel also contains 5 to 15 ppm calcium and 0.04 to 0.15 percent sulfur as elements which enhance the cutting properties of said steel. This steel exhibits excellent cutting properties both at high speed cutting using a cemented carbide tool (a super-hard cutting tool) and at low speed cutting using a tool of a high speed steel.

3 Claims, 14 Drawing Figures



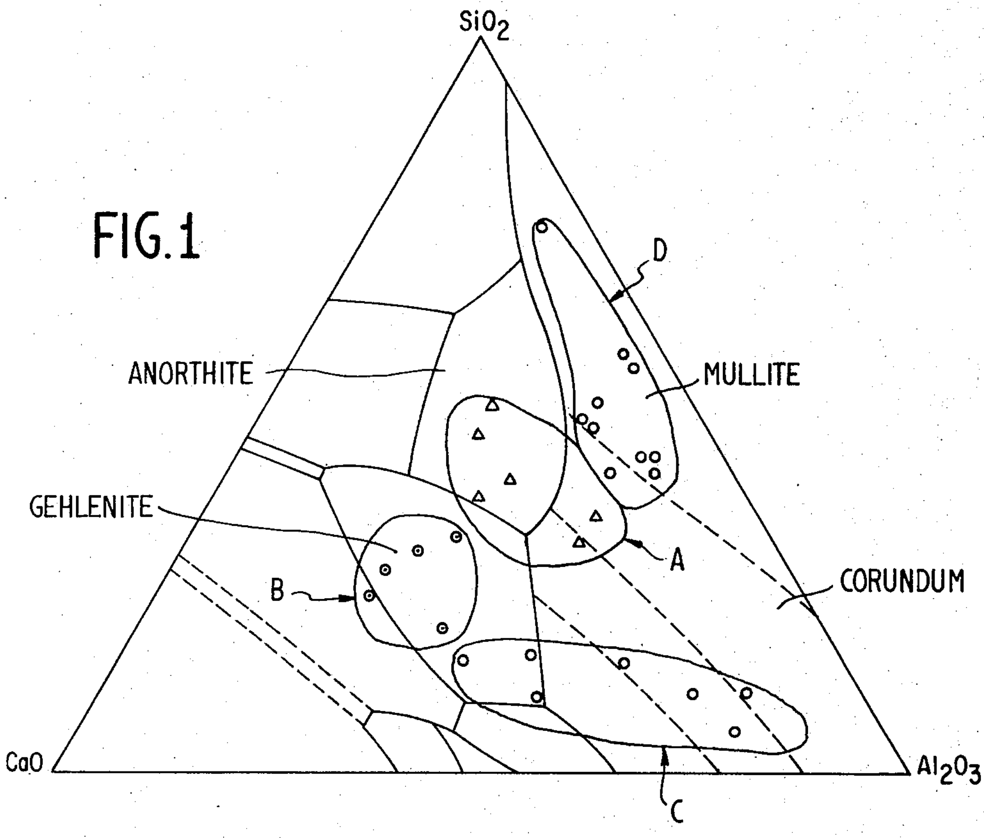

SiO2
D
ANORTHITE
MULLITE
GEHLENITE
A
B
CORUNDUM
CaO
Al2O3
C

FIG.1

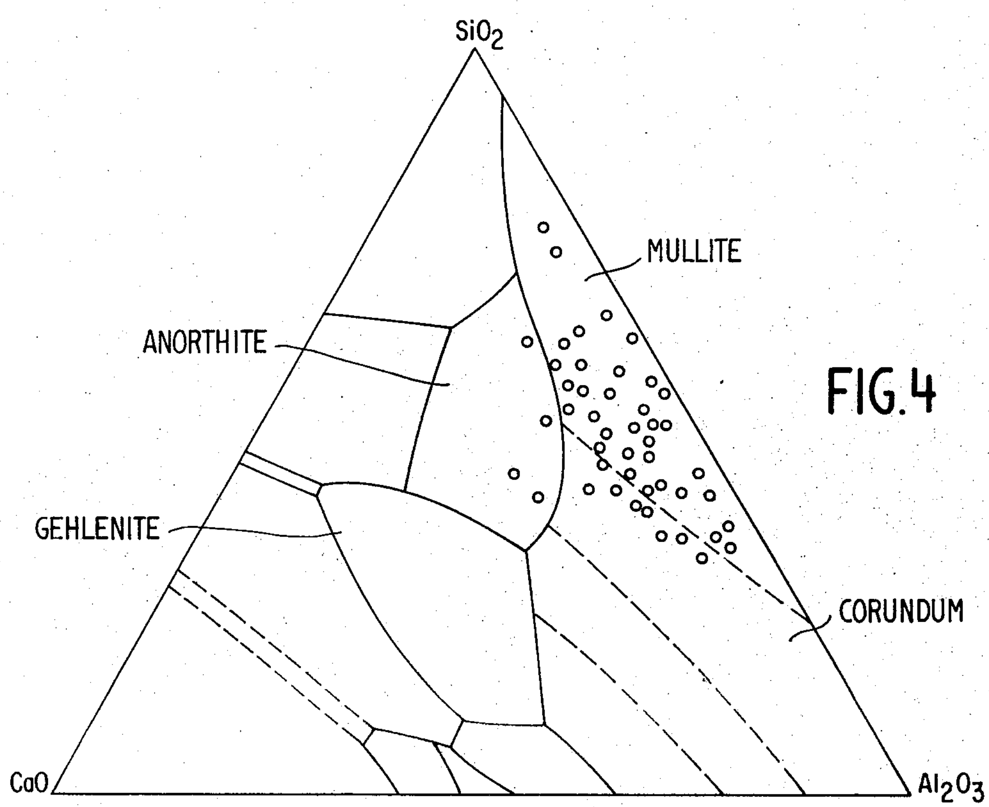

SiO2
MULLITE
ANORTHITE
GEHLENITE
CORUNDUM
CaO
Al2O3

FIG.4

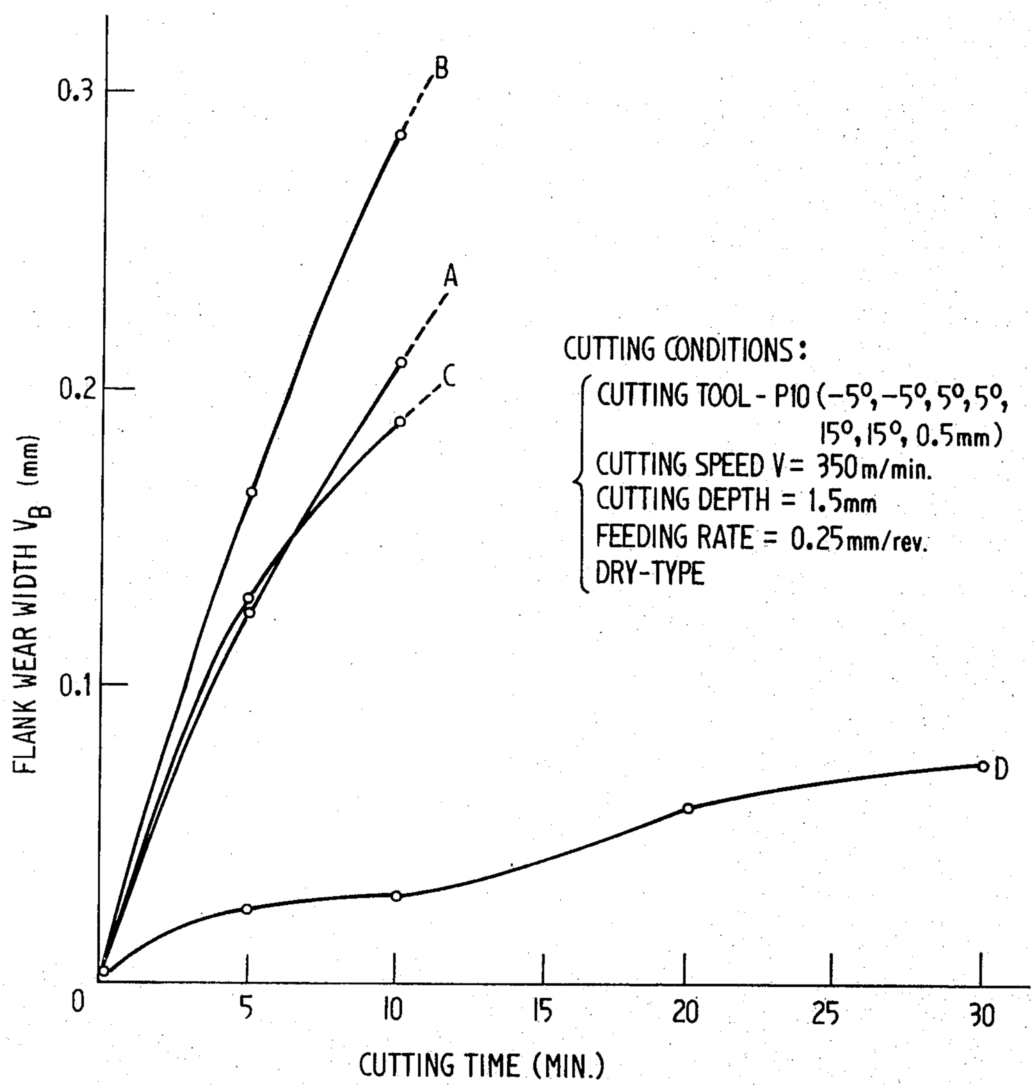
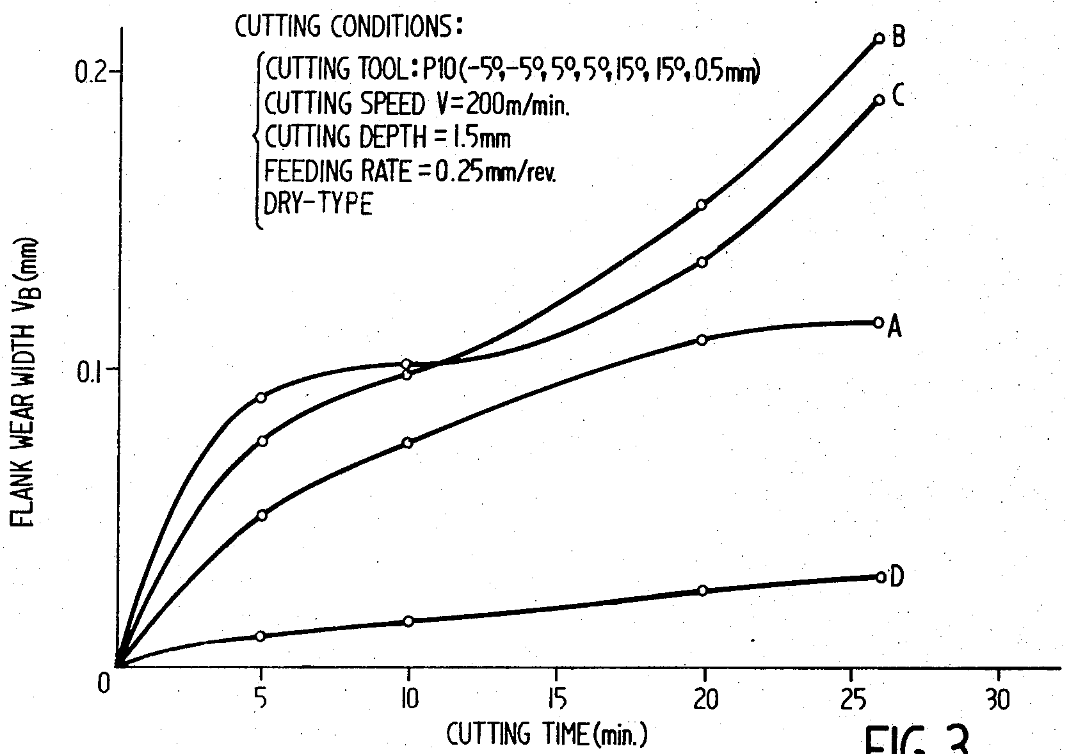

0.3
0.2
0.1
0
FLANK WEAR WIDTH V_B (mm)
B
A
C
D
CUTTING CONDITIONS:
CUTTING TOOL - P10 (−5°, −5°, 5°, 5°, 15°, 15°, 0.5mm)
CUTTING SPEED V = 350m/min.
CUTTING DEPTH = 1.5mm
FEEDING RATE = 0.25mm/rev.
DRY-TYPE
5
10
15
20
25
30
CUTTING TIME (MIN.)

FIG. 2


CUTTING CONDITIONS:
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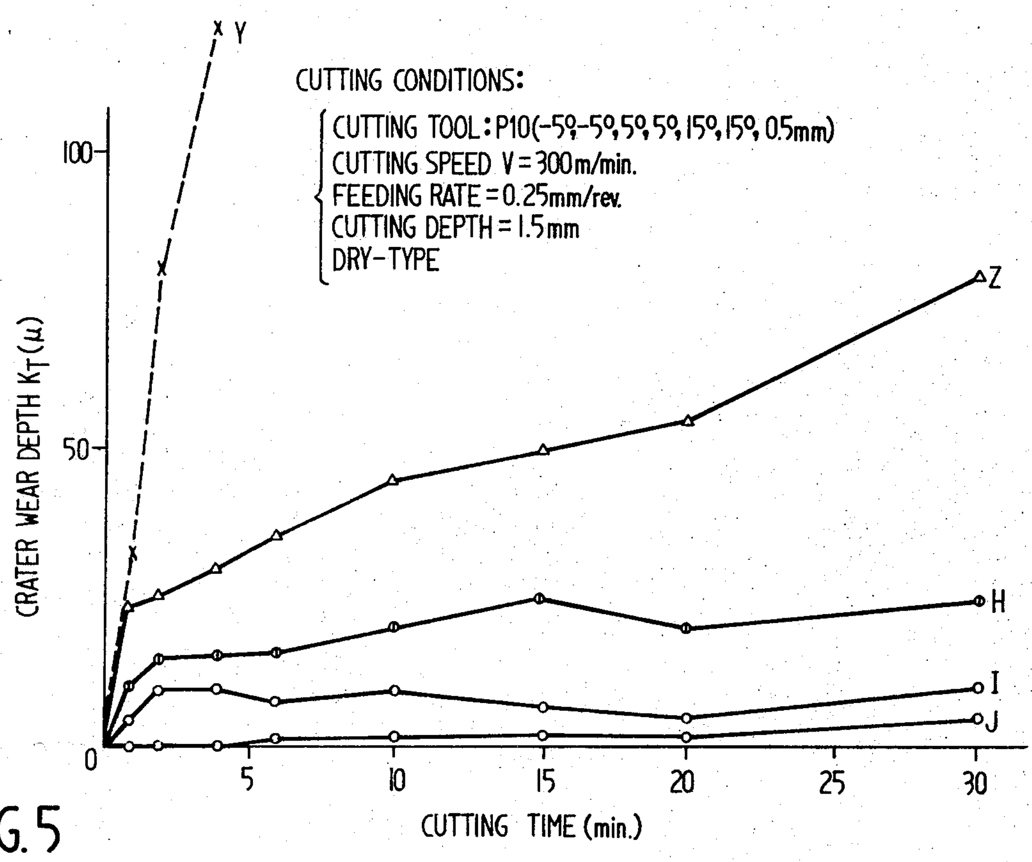
CUTTING SPEED V=200m/min.
CUTTING DEPTH = 1.5mm
FEEDING RATE = 0.25mm/rev.
DRY-TYPE
FLANK WEAR WIDTH VB (mm)
0.2
0.1
0
5
10
15
20
25
30
CUTTING TIME (min.)
A
B
C
D

FIG. 3


CUTTING CONDITIONS:
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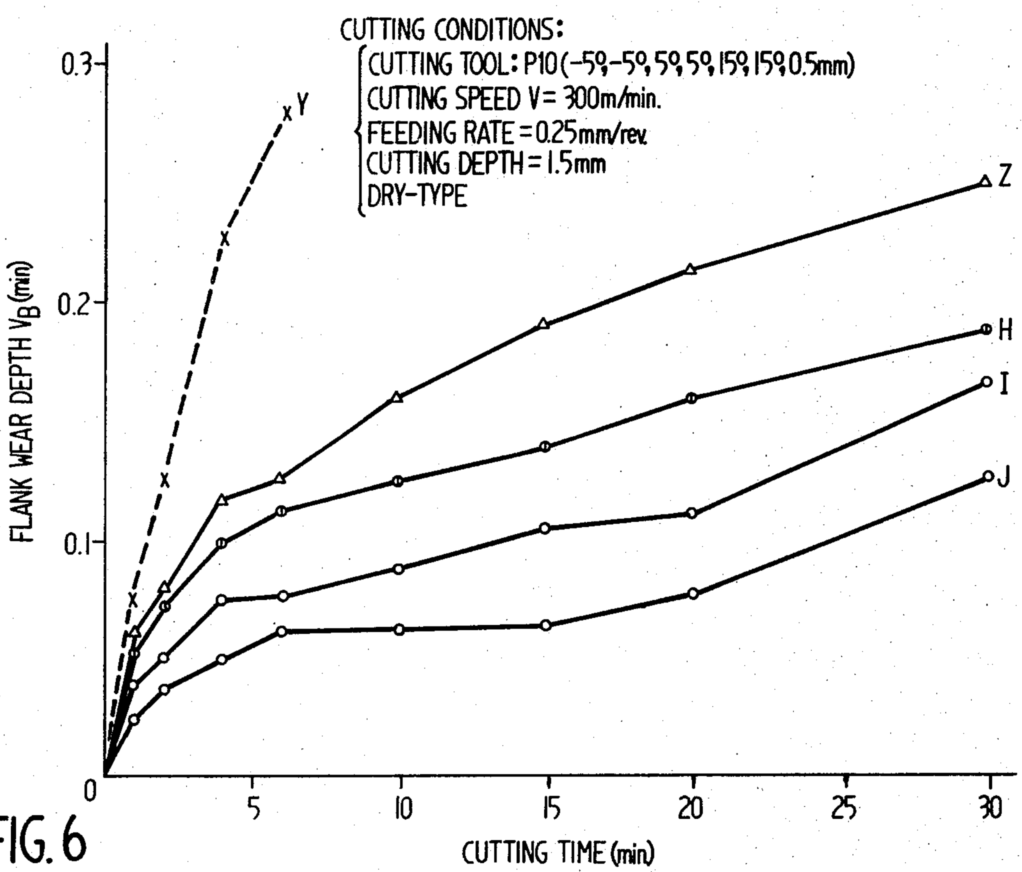
CUTTING SPEED V=300m/min.
FEEDING RATE = 0.25mm/rev.
CUTTING DEPTH = 1.5mm
DRY-TYPE
CRATER WEAR DEPTH KT (μ)
100
50
0
5
10
15
20
25
30
CUTTING TIME (min.)
Y
Z
H
I
J

FIG. 5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CUTTING SPEED V= 300m/min.
FEEDING RATE=0.25mm/rev.
CUTTING DEPTH=1.5mm
DRY-TYPE
FLANK WEAR DEPTH V_B (mm)
0.3
0.2
0.1
0
5
10
15
20
25
30
CUTTING TIME (min)
Y
Z
H
I
J

FIG. 6

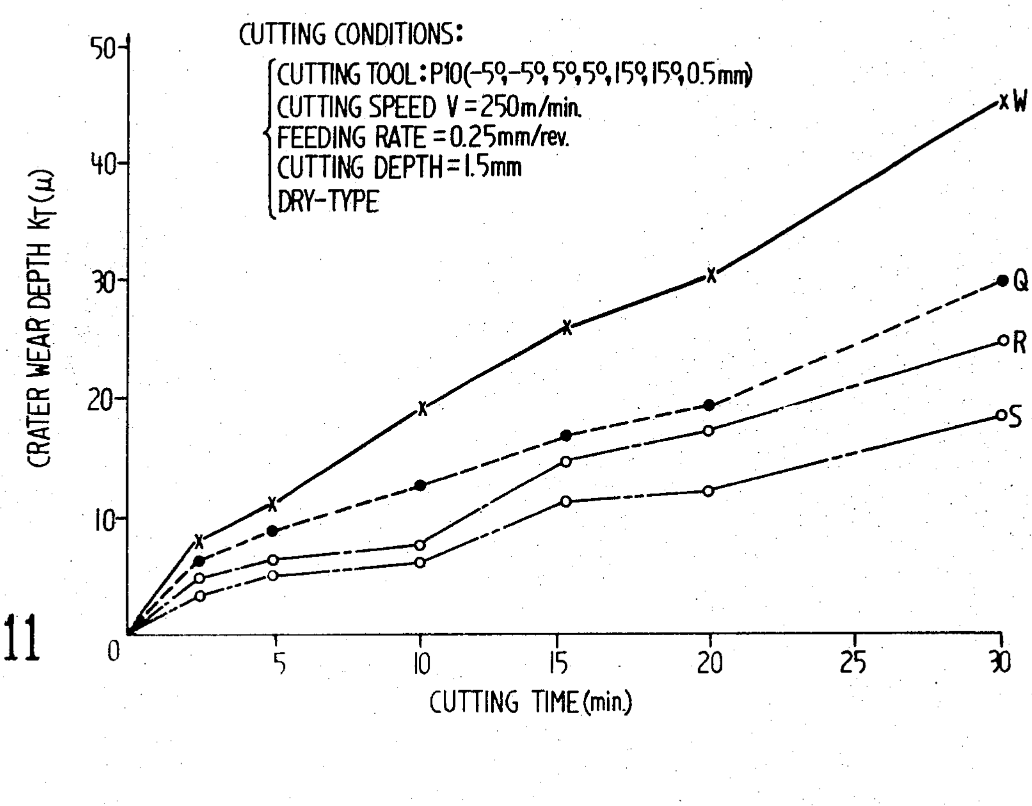
CUTTING CONDITIONS:
CUTTING TOOL: P10(-5°,-5°,5°,5°,15°,15°,0.5mm)
CUTTING SPEED V=250m/min.
FEEDING RATE=0.25mm/rev.
CUTTING DEPTH=1.5mm
DRY-TYPE
CRATER WEAR DEPTH K_T (μ)
50
40
30
20
10
0
5
10
15
20
25
30
CUTTING TIME (min.)
W
Q
R
S

FIG. 11

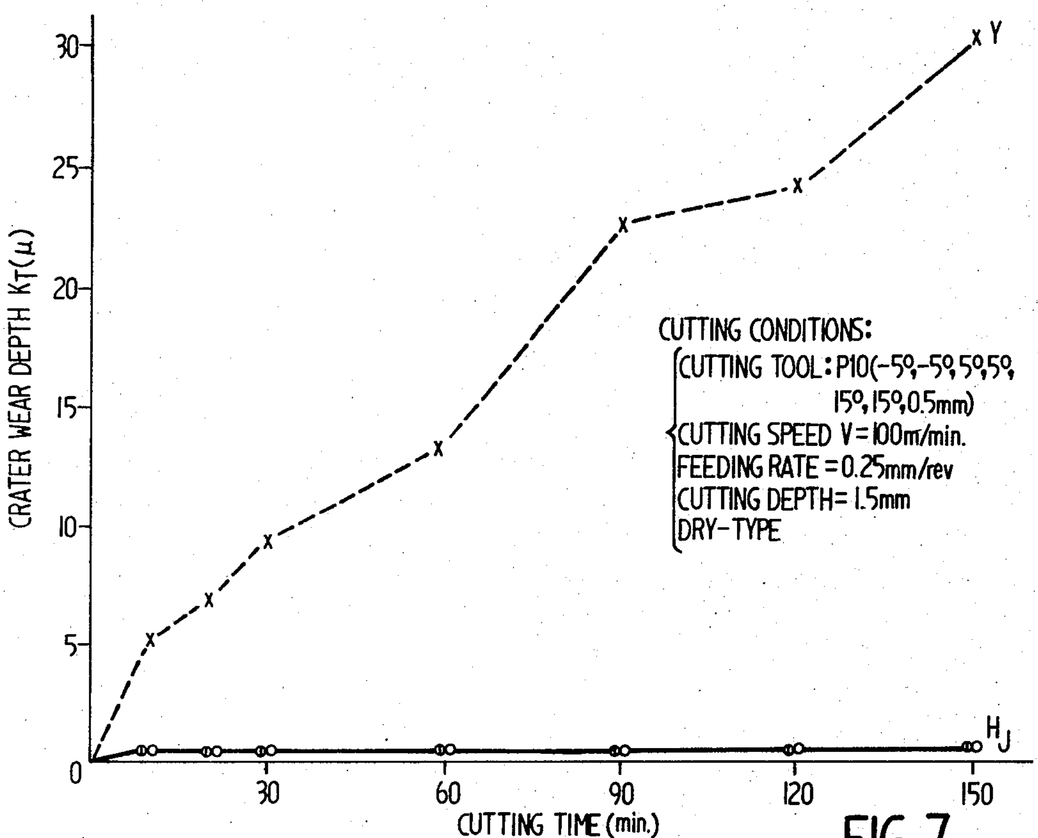
CRATER WEAR DEPTH $K_T(\mu)$
30
25
20
15
10
5
0
30
60
90
120
150
CUTTING TIME (min.)
Y
H
J
CUTTING CONDITIONS:
CUTTING TOOL: P10(-5°,-5°,5°,5°, 15°,15°,0.5mm)
CUTTING SPEED V=100m/min.
FEEDING RATE = 0.25mm/rev
CUTTING DEPTH = 1.5mm
DRY-TYPE

FIG. 7

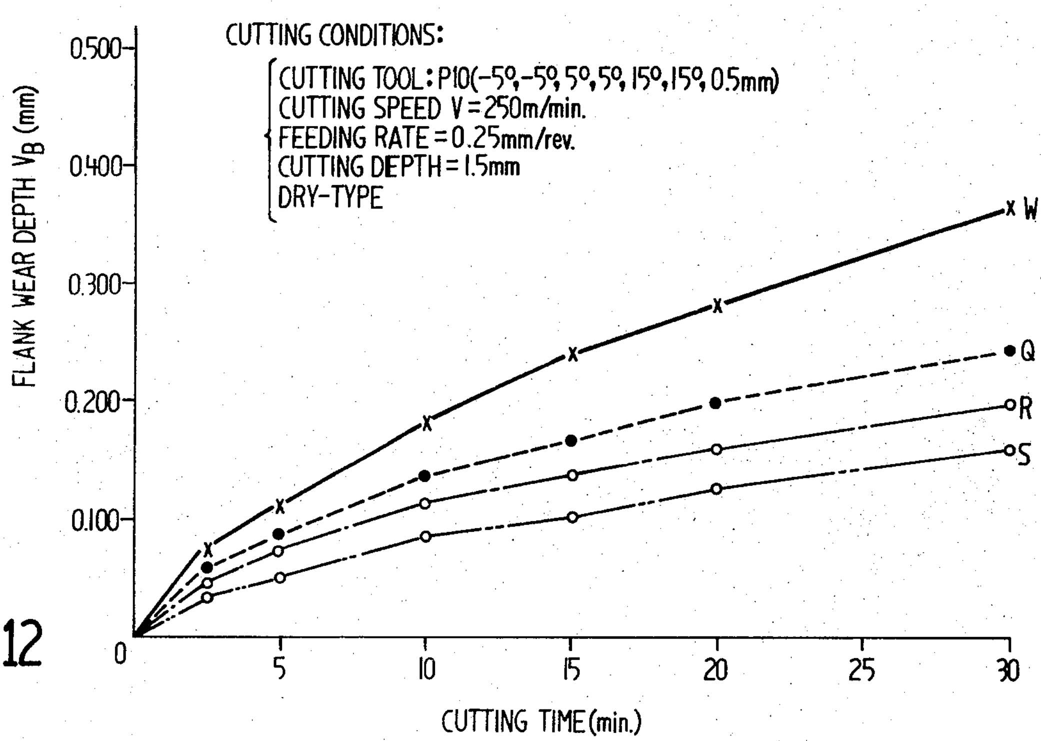
FLANK WEAR DEPTH V_B (mm)
0.500
0.400
0.300
0.200
0.100
0
5
10
15
20
25
30
CUTTING TIME (min.)
W
Q
R
S
CUTTING CONDITIONS:
CUTTING TOOL: P10(-5°,-5°,5°,5°,15°,15°,0.5mm)
CUTTING SPEED V=250m/min.
FEEDING RATE = 0.25mm/rev.
CUTTING DEPTH = 1.5mm
DRY-TYPE

FIG. 12

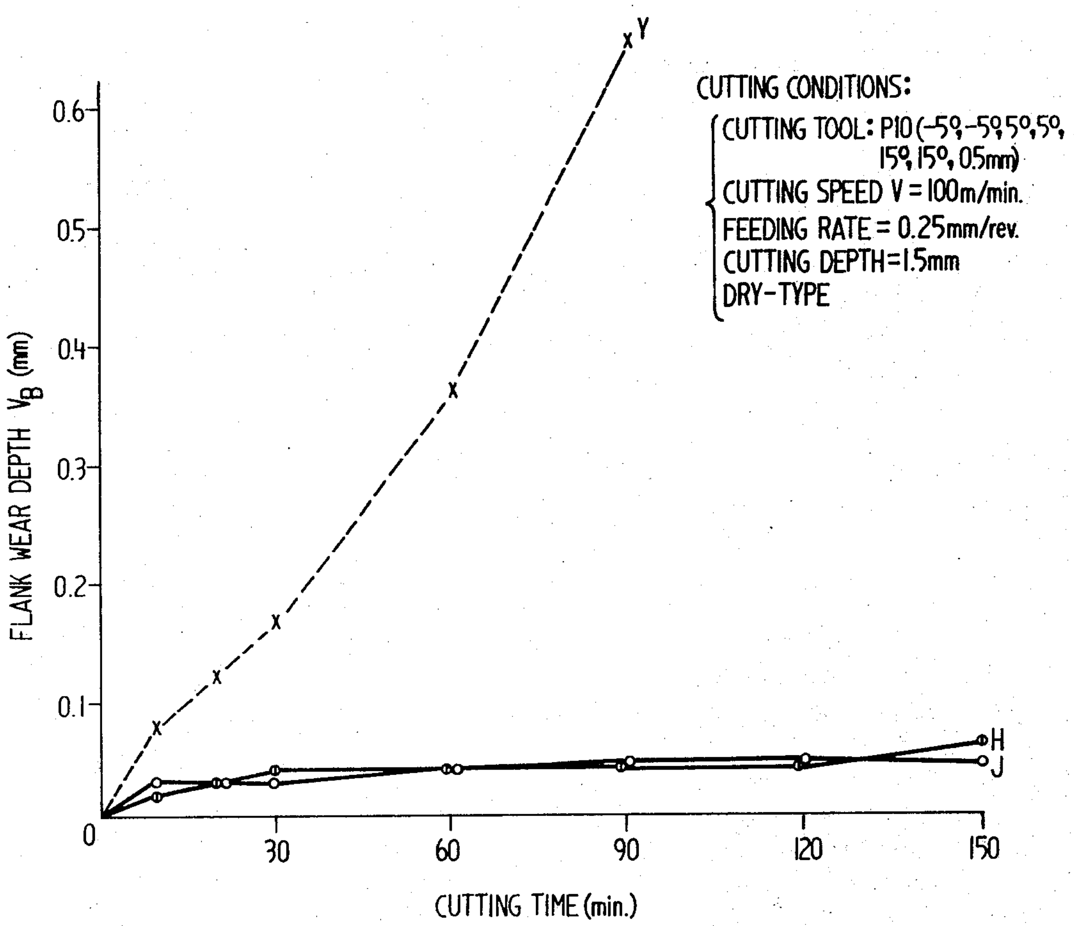
CUTTING CONDITIONS:
CUTTING TOOL: P10 (−5°, −5°, 5°, 5°, 15°, 15°, 0.5mm)
CUTTING SPEED V = 100m/min.
FEEDING RATE = 0.25mm/rev.
CUTTING DEPTH = 1.5mm
DRY-TYPE
FLANK WEAR DEPTH V_B (mm)
CUTTING TIME (min.)
0
0.1
0.2
0.3
0.4
0.5
0.6
30
60
90
120
150
Y
H
J

FIG. 8

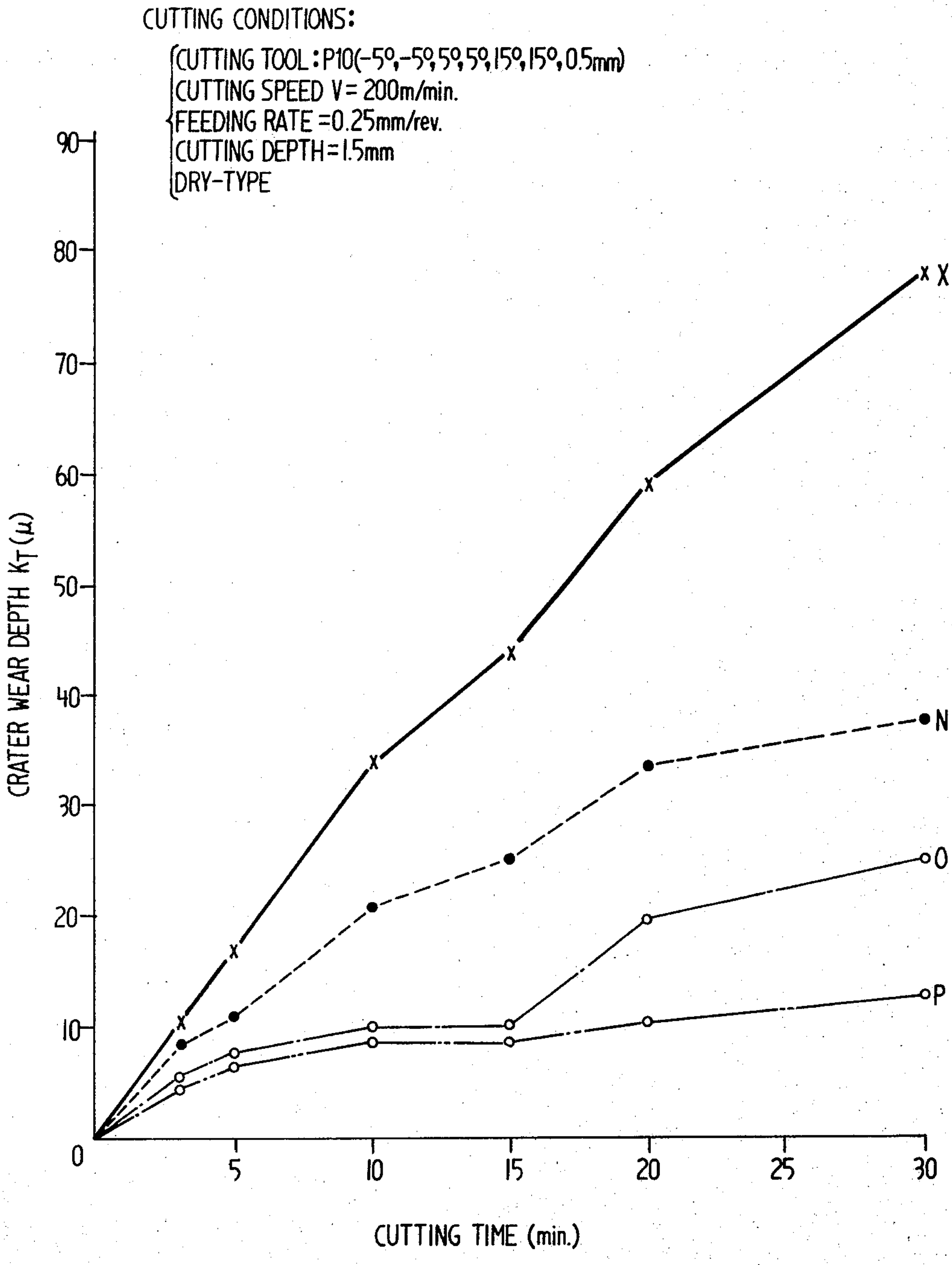
CUTTING CONDITIONS:
CUTTING TOOL: P10(-5°,-5°,5°,5°,15°,15°,0.5mm)
CUTTING SPEED V = 200m/min.
FEEDING RATE = 0.25mm/rev.
CUTTING DEPTH = 1.5mm
DRY-TYPE
CRATER WEAR DEPTH K_T (μ)
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
X
N
O
P
CUTTING TIME (min.)

FIG. 9

CUTTING CONDITIONS:
CUTTING TOOL: P10(−5°,−5°,5°,5°,15°,15°,0.5mm)
CUTTING SPEED V = 200m/min.
FEEDING RATE = 0.25mm/rev.
CUTTING DEPTH = 1.5mm
DRY-TYPE

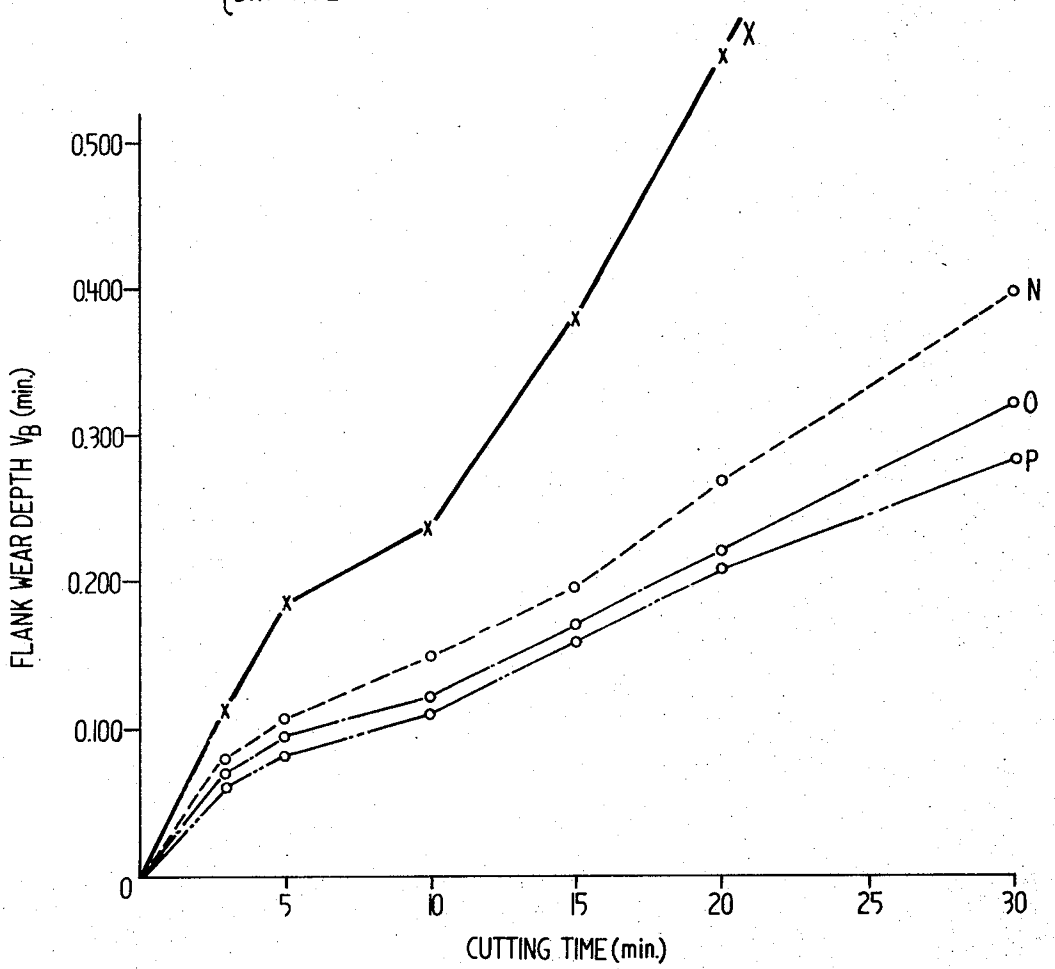

FIG. 10

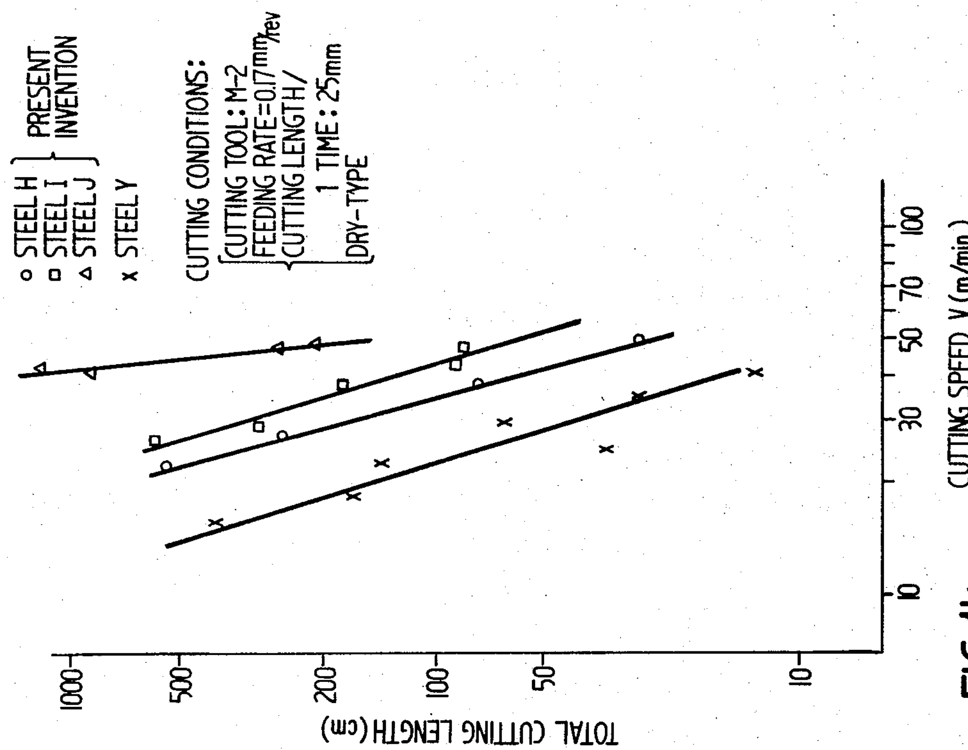
○ STEEL H
□ STEEL I
△ STEEL J
PRESENT INVENTION
x STEEL Y
CUTTING CONDITIONS:
CUTTING TOOL: M-2
FEEDING RATE=0.17mm/rev
CUTTING LENGTH/1 TIME: 25mm
DRY-TYPE
TOTAL CUTTING LENGTH (cm)
1000
500
200
100
50
10
10
30
50
70
80
100
CUTTING SPEED V (m/min.)

FIG. 14

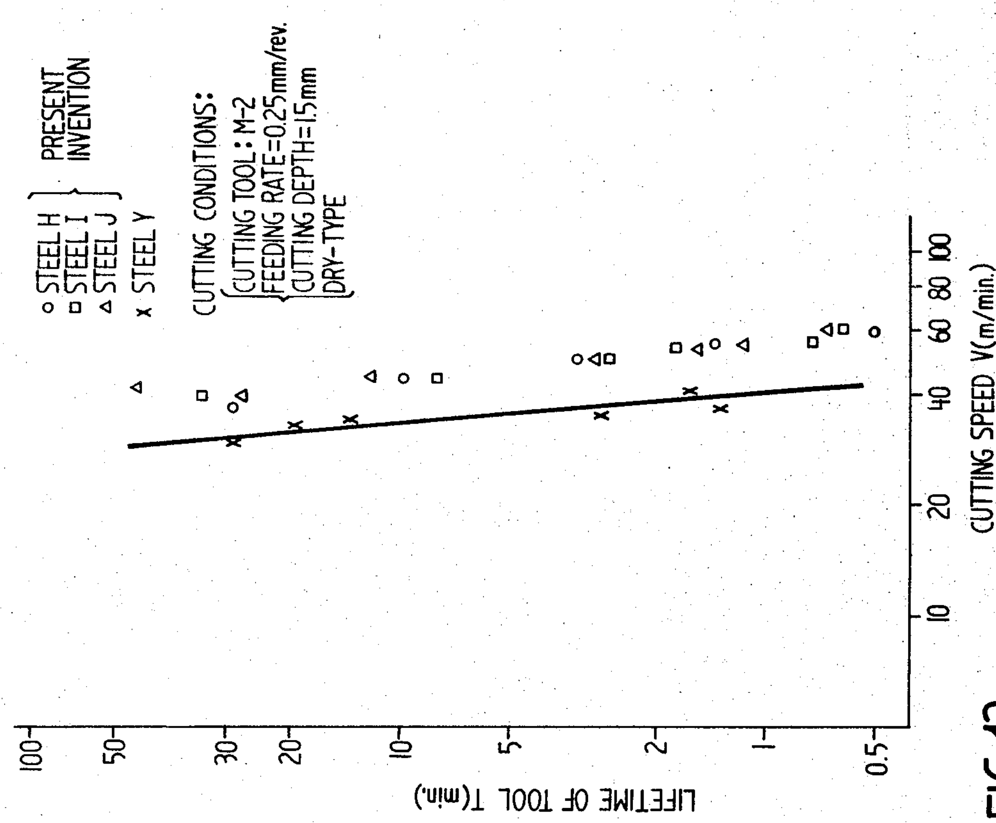
○ STEEL H
□ STEEL I
△ STEEL J
PRESENT INVENTION
x STEEL Y
CUTTING CONDITIONS:
CUTTING TOOL: M-2
FEEDING RATE=0.25mm/rev.
CUTTING DEPTH=1.5mm
DRY-TYPE
LIFETIME OF TOOL T(min.)
100
50
30
20
10
5
2
1
0.5
10
20
40
60
80
100
CUTTING SPEED V(m/min.)

FIG. 13

FREE CUTTING STEEL CONTAINING MULLITE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to free cutting steel having improved cutting properties. More particularly it relates to sulfur-containing and calcium-deoxygenated free cutting steel containing nonmetallic inclusions of a specific composition and content. The sulfur and calcium contents of the steel are present in specific ranges.

2. Description of the Prior Art

Heretofore, many approaches directed to the formation of calcium-deoxygenated, free cutting steel have been attempted and reported, since the discovery in 1960, by Professor H. Opitz of the Aachen Engineering College in West Germany that steel deoxygenated with a deoxidizer containing calcium possesses excellent cutting properties for cemented carbide tools.

Concerning the relationship of nonmetallic inclusions contained in steel as they relate to the cutting properties of the steel, Opitz suggested that nonmetallic inclusions essentially of gehlenite are particularly effective for enhancing the cutting properties of steel, in view of the fact that the melt-adhering matter on the edges of cemented carbide tools during the machining of steels having good cutting properties, is of a composition that falls within the gehlenite region of a trigonometric diagram of the $CaO—Al_2O_3—SiO_2$ system. On the other hand, it has been reported in Japanese Patent Publications 8,340–68 and 29,657–71, that free cutting steels which contain nonmetallic inclusions consisting essentially of anorthite, which also appears in the trigonometric diagram of the $CaO—Al_2O_3—SiO_2$ system, have good cutting properties.

It has been known that calcium-deoxygenated free cutting steels have highly improved cutting properties especially in high speed cutting applications using cemented carbide tools. However, there is little or no improvement in the cutting properties of tools derived from high speed steels under low speed cutting conditions. Thus, there is no difference in the cutting properties of tools derived from high speed steel used at low speeds and tools derived from common steel also used at low speeds.

In view of the differences between the cutting properties of high speed steel and common steels, attempts have been made as disclosed in Japanese Patent Publication 29,661–71 to improve the cutting properties of calcium-deoxygenated, free cutting steel by adding to the steel such elements as S, Pb, and the like, which aid in the improvement of the cutting properties of steel under low speed cutting conditions. However, these attempts have not met with success.

A need, therefore, exists for a free cutting steel which can be used at both low and high cutting speeds with equal facility.

SUMMARY OF THE INVENTION

Accordingly, one object of the invention is to provide a free cutting steel which possesses excellent cutting properties under both high and low speed cutting conditions.

Briefly, this and other objects of the invention as hereinafter will become readily apparent can be provided by a free cutting steel comprising a steel deoxygenated by calcium which contains nonmetallic inclusions consisting essentially of a composition characterized by the mullite region of the trigonometric diagram of the $CaO—Al_2O_3—SiO_2$ system, wherein said steel also contains 5 to 15 ppm Ca and 0.04 to 0.15% S.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. 1 is a trigonometric diagram of the $CaO—Al_2O_3—SiO_2$ system illustrating the various nonmetallic compositions which may be incorporated as inclusions in steel which has been calcium-deoxygenated by combining a Fe-Si alloy and a Ca-Si alloy;

FIGS. 2 and **3** are plots showing the results of cutting tests (flank wear width) of cemented carbide tools which compares the cutting properties of tools of steel D of the present invention with comparative steels A – C;

FIG. 4 is a trigonometric diagram of the $CaO—Al_2O_3—SiO_2$ system showing the compositions of the nonmetallic inclusions contained in the steels of the present invention;

FIGS. 5 to **8** show the results of tests (crater wear depth and flank wear width) with cemented carbide tools which compare the cutting properties of the steels (E – J steels; AISI 1,043 equivalent steels) of the present invention with those of a common steel, AISI 1,045 steel (Y steel) and a calcium-deoxygenated steel (Z steel) (equivalent to AISI 1,045), in which **FIGS. 5** and **6** relate to high speed cutting conditions, while **FIGS. 7** and **8** relate to low speed cutting conditions;

FIGS. 9 to **12** are plots showing the superb cutting properties of alloy steels (AISI 4,135 and 5,130 equivalent steels) of the present invention; and,

FIGS. 13 and **14** are plots comparing the cutting properties of the steels (H – J) of the present invention with those of a common steel Y when tools of high speed steels are used.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Experimental studies have been directed to the development of calcium-deoxygenated steels which possess improved cutting properties to which sulfur has been added in attempts to clarify the relationship between sulfur and the nonmetallic inclusions in the steels and the cutting properties of the steel. As a result, it has been found that calcium-deoxygenated free cutting steels containing nonmetallic inclusions of a specific composition and content, exhibit excellent cutting properties and that the sulfur added to the steel exerts a prominent effect on the cutting properties of the steel when it is used as a cemented carbide tool under high and low speed cutting conditions.

Suitable steels, which may be used in the present invention include low-medium carbon steels such as AISI 1,010 to 1,060 steels and low alloy steels containing at least one alloying element such as Mn, Ni, Cr, Mo, and the like, having the content shown below which includes steels of the AISI 4,000 series, 5,000 series, 6,000 series and 8,000 series:

Mn	0.30 to 1.50%
Cr	up to 2.00%
Mo	up to 0.50%
Ni	up to 2.00%

Other suitable steels include fine grain low carbon or low alloy steels containing from 0.025 to 0.100 percent niobium.

To a melt of a steel which is essentially an SAE standard AISI 1,020 steel containing an oxygen content of 0.01 to 0.04 percent were added an Fe-Si alloy and a Ca-Si alloy to deoxygenate the steel. After the alloys were added to the steel, FeS_2 was added thereto to form nonmetallic inclusions within the steel of a composition which falls within the range of anorthite, gehlenite, corundum or mullite in the $CaO—Al_2O_3—SiO_2$ ternary system. Table I shows when the various alloys are added and the amount of deoxidizer, Ca, and S present in the steel. The compositions of the nonmetallic inclusions are shown in the three phase diagram of the $Cao—Al_2O_3—SiO_2$ system.

TABLE I

Type of steel	Charging in the last stage of convertor refining Fe-Si*	Deoxidizer pre-charged ladle basis Fe-Si*	Deoxidizer pre-charged ladle basis Ca-Si**	Sulfur content (%)
A(AISI 1020)	1.9 Kg/ton	—	1.5 Kg/ton	0.078
B(AISI 1020)	2.5 Kg/ton	—	2.0 Kg/ton	0.076
C(AISI 1020)	3.1 Kg/ton	—	2.5 Kg/ton	0.076
D(AISI 1020)	—	2.5 Kg /ton	2.0 Kg/ton	0.061

*FeSi 25/75
**CaSi 35/65

In Table I, the A – C steels refer to those in which the Fe-Si alloy is charged in the last stage of convertor refining, followed by deoxidation with the Ca-Si alloy precharged in a ladle. Steel D, on the other hand, refers to a steel which is deoxygenated on a deoxidizer precharged ladle basis, i.e., the Ca-Si alloy is placed in the bottom of a ladle followed by the addition of Fe-Si, before pouring molten steel therein. Prior to the deoxygenation treatment, Fe-Mn alloy, or the like are added to the steel, as necessary, for the adjustment of the oxygen content in the molten steel as well as to adjust the composition thereof. Fe-Mn alloy can also be added to the melt at the time of deoxygenation. As can be seen from Table I and FIG. **1**, the compositions of the nonmetallic inclusions are principally found in the anorthite region in the case of steel A, in the gehlenite region with steel B, in the gehlenite and corundum regions with steel C, and in the mullite region with steel D. FIGS. **2** and **3** show the test results of the cutting properties of cemented carbide tools fabricated from the four types of steels. As is clear from FIGS. **2** and **3**, steel D of the present invention shows superior cutting properties in comparison to the other steels, A through C.

To further substantiate the reproducibility of the results obtained for the calcium-deoxygenated steel (steel D) as well as for steels which have experienced the combined effects of calcium deoxygenation and the addition of sulfur, melts (O_2 content from 0.01 to 0.04 percent) of medium carbon steels such as the SAE standard steels AISI 1,035, 1,043, 1,055, and the like, and of low carbon steels such as AISI 4,135, 5,130 and the like are poured into ladles in which there has been placed 2.6 kg/ton of FeSi (25/75) and 1.25 kg/ton of CaSi (35/65) for the deoxygenation of the steels. FeS_2 is added to each of said steels to achieve a sulfur content ranging from 0.04 to 0.10 percent. Table II shows the calcium content found in each portion of the ingots prepared and in the rolled steel products, in addition to the sulfur and niobium contents for each of the basic steels used which include AISI 1,035, 1,043, 1,055, 4,135 and 5,130 steels. FIG. **4** shows the compositions of the nonmetallic inclusions contained in each portion of the ingots and the rolled bar steel products with the aid of the trigonometric diagram of the $Cao—Al_2O_3—SiO_2$ system.

As can be seen from Table II and FIG. **4**, steels E through S of the present invention each have nonmetallic inclusions of compositions which are essentially encompassed by the mullite region of the ternary phase diagram wherein the calcium content ranges from 5 to 15 ppm (0.0005 to 0.0015 percent). More particularly, the test results which show the cutting properties of cemented carbide tools manufactured from steels of this invention under high speed cutting conditions are shown in FIGS. **5** to **8**. In FIGS. **5** to **8**, steel Y is a common AISI 1,045 steel which has been deoxygenated with Fe-Si alloy and aluminum without the addition of sulfur, and steel Z is a AISI 1,045 steel which has been deoxygenated with calcium as in the cases of the H to J steels, with the omission of sulfur (nonmetallic inclusions are of compositions in the mullite region, Ca: 0.0012%, S: 0.02 percent). FIGS. **5** and **6** are plots illustrating the cutting properties of cemented carbide tools made from the steels shown under high speed cutting conditions (V-300 m/min). Steels H to J of the present invention exhibit superior cutting properties in comparison to steel Y, which is a common AISI 1,045 steel and in comparison to steel Z which has nonmetallic inclusions of a composition and a calcium content the same as those of the steels of the present invention, except that sulfur has not been incorporated in the steel. FIGS. **7** and **8** show the cutting properties of cemented carbide tools made from steels H, J and Y under low speed cutting conditions (V=100 m/min). The steels H and J of the present invention exhibit excellent cutting properties, i.e., they are free of flank wear and crater wear, and thus are superior to steel Y which shows flank wear and crater wear. In addition, as shown in FIGS. **9** to **12**, the alloy steels (AISI 4,135 and 5,130

TABLE II

Steels (Basic chemical composition)	S content (%)	Nb content (%)	Ca content (%) Top portion of ingot	Mid portion of ingot	Bottom portion of ingot	As-rolled Rod
E)	0.043	—	0.0008	0.0006	0.0013	0.0010
F) (AISI 1035)	0.065	—	0.0007	0.0010	0.0011	0.0005
G)	0.103	—	0.0006	0.0013	0.0014	0.0010

TABLE II–Continued

Steels (Basic chemical composition)	S content (%)	Nb content (%)	Ca content Top portion of ingot	(%) Mid portion of ingot	Bottom portion of ingot	As-rolled Rod
H)	0.040	—	0.0009	0.0006	0.0011	0.0013
I)	0.066	—	0.0014	0.0007	0.0011	0.0010
J) (AISI 1043)	0.109	—	0.0008	0.0006	0.0012	0.0007
Y)	0.020	—	—	—	—	—
Z)	0.025	—	0.0008	0.0012	0.0014	0.0011
K)	0.042	—	0.0006	0.0007	.0011	0.0014
L) (AISI 1055)	0.061	—	0.0007	0.0006	0.0013	0.0010
M)	0.098	—	0.0007	0.0009	0.0011	0.0006
X)	0.015	—	—	—	—	—
N) (AISI 4135)	0.043	0.074	0.0005	0.0007	0.0008	0.0007
O)	0.067	—	0.0008	0.0008	0.0012	0.0007
P)	0.103	0.077	0.0007	0.0008	0.0011	0.0006
W)	0.025	—	—	—	—	—
Q) SCr22	0.042	0.045	0.0006	0.0009	0.0011	0.0010
R) (AISI 5130)	0.061	—	0.0005	0.0006	0.0012	0.0008
S)	0.110	0.047	0.0007	0.0007	0.0012	0.0010

equivalent steels) of the present invention exhibit superior cutting properties in comparison to steels X and W to which sulfur has not been added in contrast to the carbon steels of the present invention. FIGS. **13** and **14** further show the superior cutting properties obtained for high speed cutting steels made from the steels of the present invention. Specifically, FIG. **13** shows the results of test conducted with a lathe having a bit tool of a high speed steel. The results show the superior lifetimes obtained for bit tools made from the cutting steels (H – J) of the present invention in comparison to the lifetime obtained for the bit tool manufactured from common steel Y. Further, FIG. **14** shows that drills of high speed steels, when used in tests conducted on a drilling machine, are capable of cutting for far longer lengths when steels (H – J) of the present invention are used in comparison to common steel Y.

As is apparent from the foregoing description, when the nonmetallic inclusions are limited to the mullite regions and when the calcium content is limited to the range from 5 to 15 ppm, calcium-deoxygenated and sulfur-containing free cutting steels are obtained which exhibit excellent cutting properties when sulfur is also present in the steel.

The content of calcium should be limited to the range from 5 to 15 ppm, because if the calcium content is less than 5 ppm, the intended deoxygenation effects can not be achieved by the addition of calcium. On the other hand, if the calcium content exceeds 15 ppm, then the oxygen content of the steel will increase (naturally, part of the Ca is considered to exist in steel in the form of CaS). Thus, the steel is likely to exhibit poor mechanical properties. In general, sulfur may be present in the steel as an impurity in a content in the neighbourhood of 0.03 percent. However, for the purposes of this invention, the sulfur content is specifically desired to be within the range from 0.04 to 0.15 percent based on the total amount of material. Sulfur contents less than 0.04 may not yield the desired effects in the product steels, while sulfur contents in excess of 0.15 percent will not yield steels having improved cutting properties and results in steels having poor mechanical properties such as toughness. In the case of steels containing niobium, niobium should be present therein in the range of 0.025 to 0.1 percent to maintain a fine grain size, while niobium contents greater than 0.100 percent will result in steels having poor cutting properties because of the formation of carbides and/or nitrides of niobium. The carbon and silicon contents of the free cutting steel range from 0.1 to 0.6 percent and 0.05 to 0.4 percent respectively.

Having now fully described the invention, it will be apparent to one of ordinary skill in the art that many changes and modifications can be made thereto without departing from the spirit or scope of the invention as set forth herein.

What is claimed as new and intended to be covered by Letters Patent is:

1. A free cutting steel which contains 0.10 to 0.60 percent carbon, 0.50 to 0.40 percent silicon, 0.04 to 0.15 percent sulphur, and is calcium deoxygenated by the addition of 5 to 15 ppm calcium which forms nonmetallic inclusions of a composition consisting essentially of the mullite region of a three phase trigonometric diagram of the $CaO—Al_2O_3—SiO_2$ system, whereby said free cutting steel exhibits superior cutting properties because of the presence of said nonmetallic inclusions, said calcium and said sulfur therein.

2. The free cutting steel of claim **1**, wherein said free cutting steel further contains at least one alloy component selected from the group consisting of 0.03 to 1.50% Mn, up to 2.00% Cr, up to 0.50% Mo, and up to 2.00% Ni.

3. The free cutting steel of claim **1**, wherein said steel further contains 0.025 to 0.100 percent niobium.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,844,773 Dated October 29, 1974

Inventor(s) Noboru Yamakoshi et al.

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

Column 6, line 42, "0.50 to 0.40 percent silicon" should read -- 0.05 to 0.40 percent silicon --

Signed and sealed this 4th day of February 1975.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents