

[72] Inventor **Chiaki Asada**
Nagoya, Japan
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[45] Patented **Dec. 28, 1971**
[73] Assignee **Daido Seiko Kabushiki Kaisha**
Nagoya, Aichi Prefecture, Japan
[32] Priority **Sept. 19, 1967**
[33] **Japan**
[31] **42/59620**

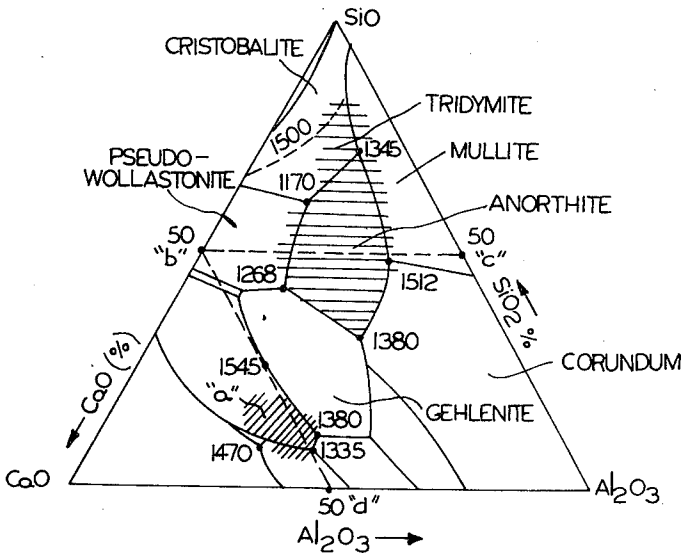
[54] **FREE CUTTING STEELS**
2 Claims, 10 Drawing Figs.

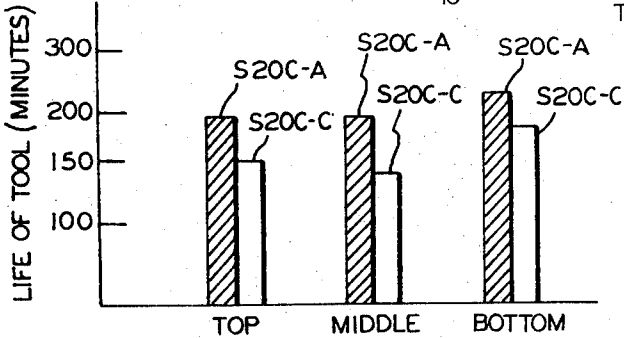
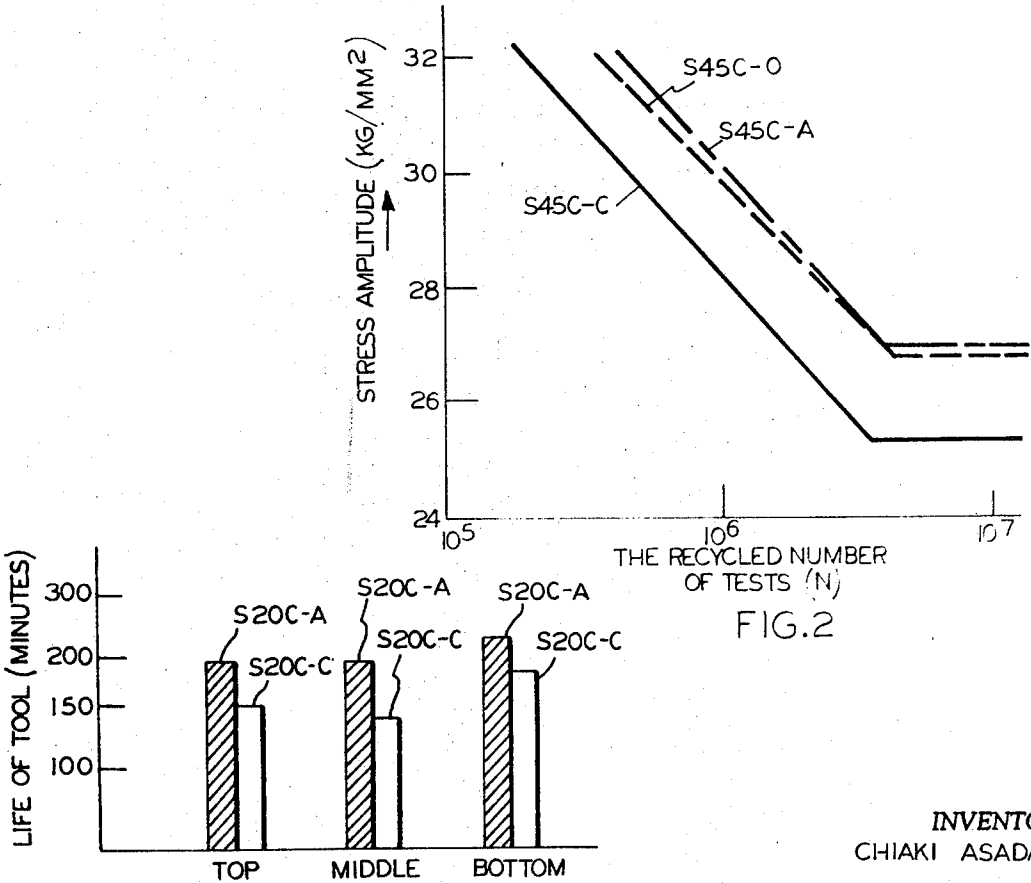
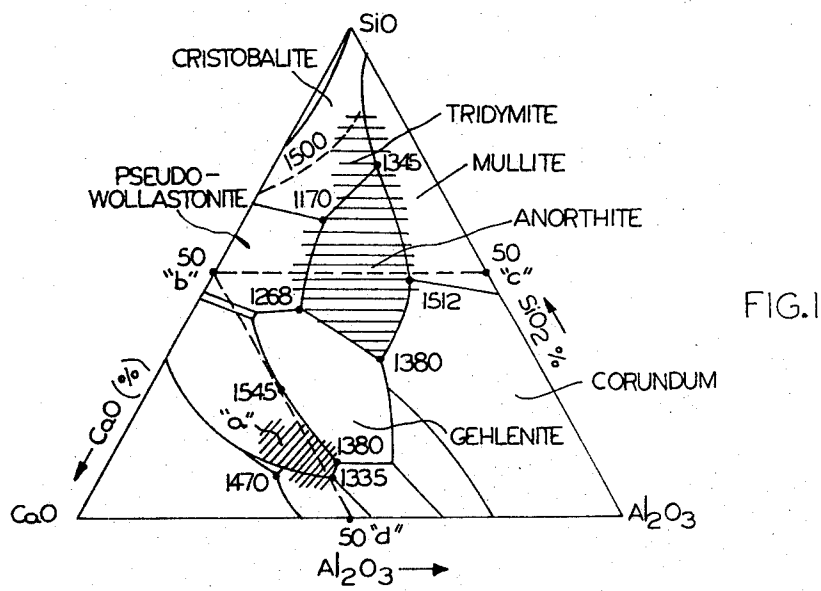
[52] U.S. Cl. **75/123,**
75/128 R, 75/128 W
[51] Int. Cl. **C22c 37/00**
[50] Field of Search..... **75/123,**
126, 128

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Primary Examiner—Hyland Bizot
Attorney—Wenderoth, Lind & Ponack

ABSTRACT: This invention relates to free-cutting carbon steels such as S20C steel, S30C steel, S45C and S55C steel as indicated by the Japanese Industrial Standards (or steel Nos. 1020 to 1055 as indicated by the SAE Standards) containing 0.20 to 0.56 percent carbon, 0.24 to 0.33 percent silicon and 0.35 to 0.78 percent manganese. Also, this invention relates to free-cutting Ni-Cr steels, Cr-Mo steels and Cr steels containing 0.29 to 0.42 percent carbon, 0.24 to 0.33 silicon, 0.51 to 0.75 percent manganese, 0.07 to 2.89 percent nickel, 0.76 to 1.14 percent chromium and 0 to 0.26 percent molybdenum. They are characterized by the oxide inclusion contained in them, and also the calcium content and the improved free-cutting characteristic.





INVENTOR
CHIAKI ASADA

BY *Wendroth, Lund & Tonack*
ATTORNEYS

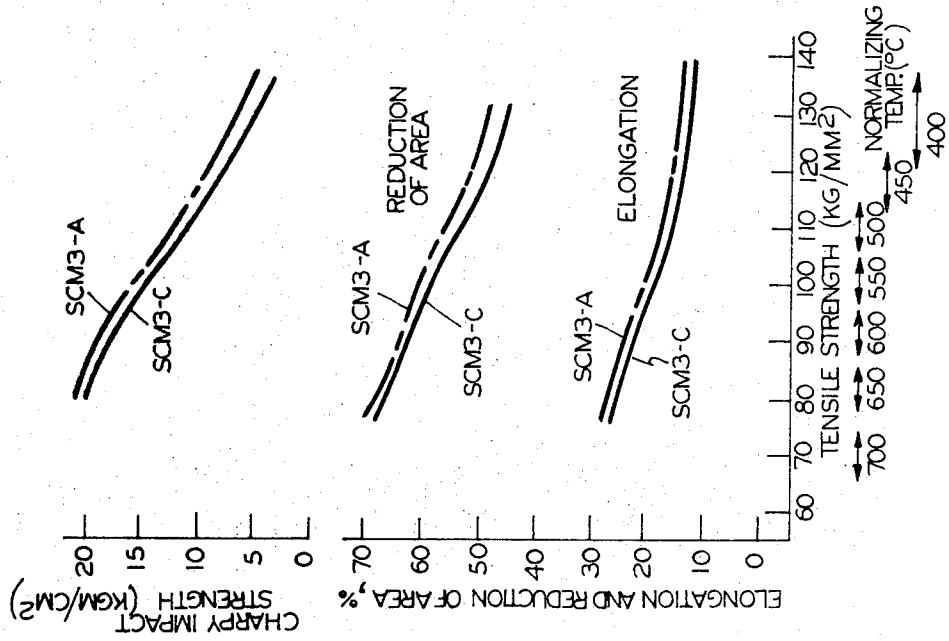


FIG. 4

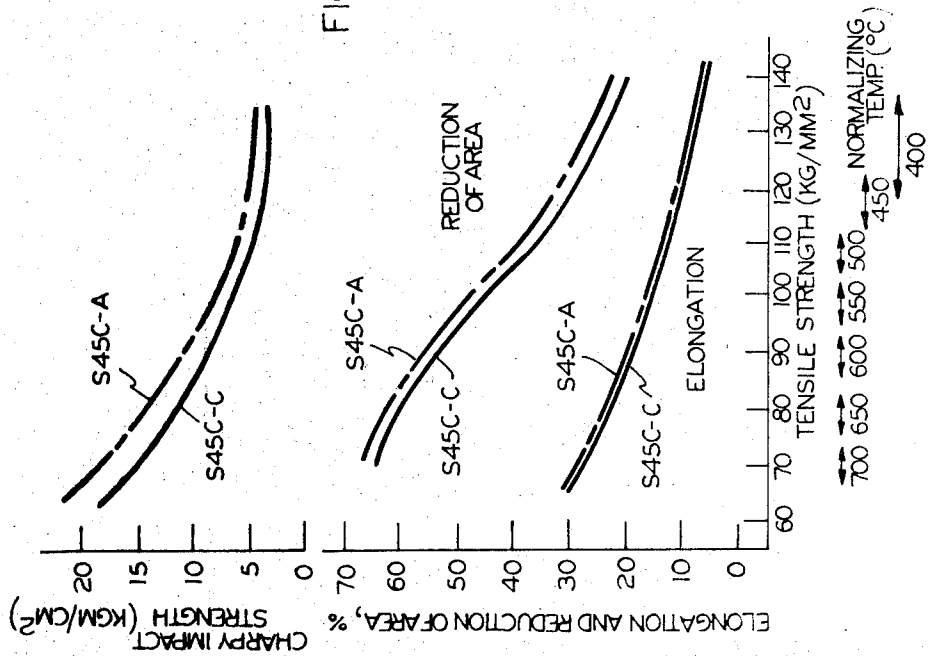


FIG. 3

INVENTOR
CHIAKI ASADA

BY *Wendroth, Lund & Ponack*
ATTORNEYS

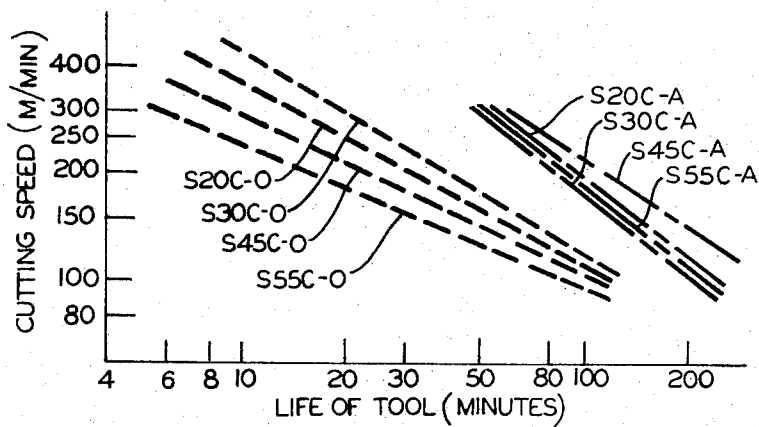


FIG. 5

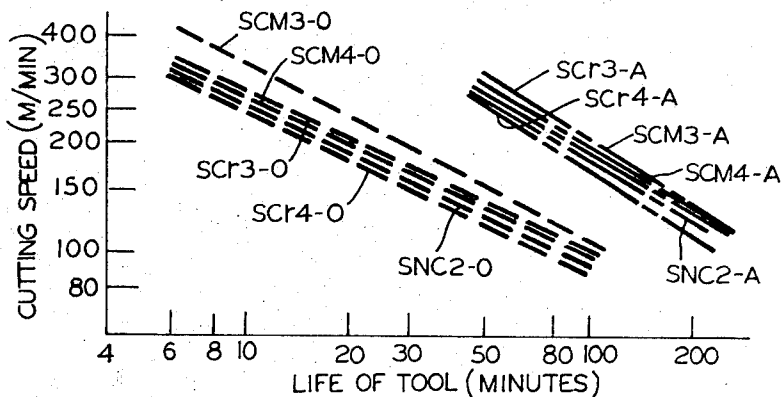


FIG. 6

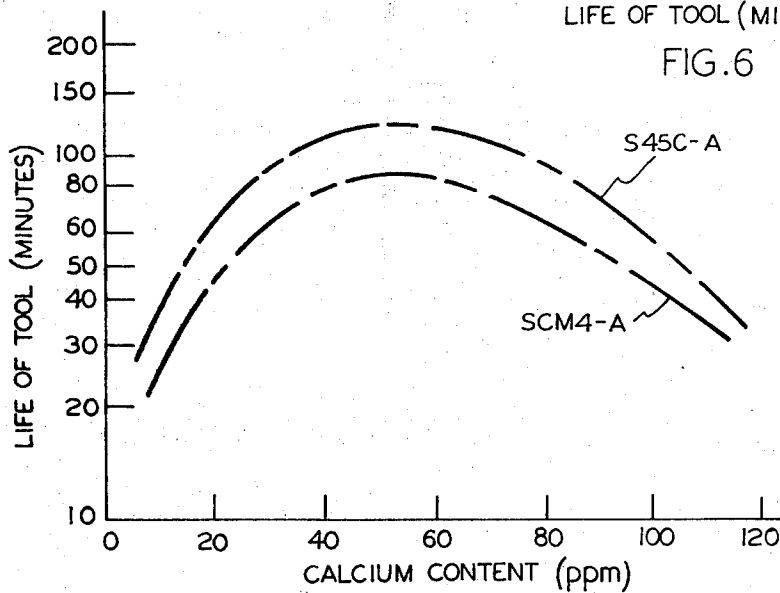


FIG. 8

INVENTOR
CHIYAKI ASADA

BY

Wendroth, Lind & Ponack
ATTORNEYS

PATENTED DEC 28 1971

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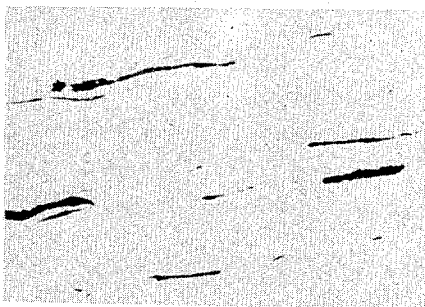


Fig. 9

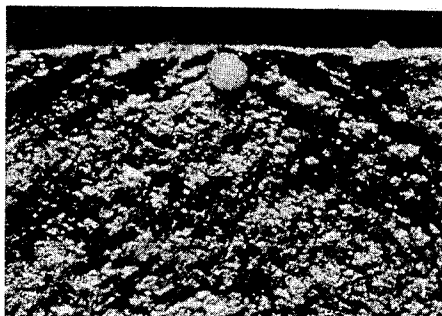


Fig. 10

CHIAKI ASADA

Inventor

By Wendersoth, Lind & Ponack

Attorneys

FREE CUTTING STEELS

This invention relates to free-cutting steels which can easily be cut and which are obtained by controlling the oxide inclusion contained in certain steel. Particularly, this invention relates to free-cutting steels containing an oxide inclusion which consists of anorthite ($\text{CaO}:\text{Al}_2\text{O}_3:2\text{SiO}_2$) as a principal component and having a calcium content of from 20 to 100 parts per million (20 to 100 p.p.m.).

Heretofore, a specific element such as P, N, Pb, Bi, S, Se or Ti is incorporated in the conventional free-cutting steels as a free-cutting component. In such free-cutting steels, the components such as P and N cause brittleness in the body of the steel and also a component such as Pb or Bi is crystallized in a different phase as fine crystals separate from the structure of the steels. Also, a component such as S, Se or Te is combined with other elemental components contained in the steel and forms the different phase in the structure of steel.

This invention, however, relates to free-cutting steels which are developed on the basis of the utilization of an oxide inclusion and therefore such free-cutting steels are different in their intrinsic nature from the conventional free-cutting steels as mentioned above.

This invention is fully explained hereinafter by referring to the accompanying drawings in which:

FIG. 1 is a trigonometric diagram illustrating the distribution of the three components CaO , Al_2O_3 and SiO_2 contained in the known free-cutting steel and the free-cutting steel of this invention.

FIG. 2 is a graph with curves illustrating the relationships between the strength fatigue and the number of cycles in the test when S45C-A steel, S45C-C steel and S45C-O steel were tested for fatigue. In FIG. 2, the horizontal axis indicates the number of cycles and the vertical axis indicates the stress amplitude. It is noted that S45C-A steel, was produced by treating S45C steel so as to have an A-type oxide inclusion and S45C-C steel was produced by treating S45C steel so as to have a C-type oxide inclusion as defined in the Japanese Industrial Standards. Also, it is noted that S45C-O steel was not treated and so it is the same as S45C steel.

FIG. 3, is a graph with curves illustrating the relationship between the elongation, the reduction of area or the Charpy impact strength and the tensile strength when the above mentioned S45C-A steel and S45C-C steel were tested for their mechanical properties. The horizontal axis indicates the tensile strength and the vertical axis indicates the elongation, the reduction of area and the Charpy impact strength.

FIG. 4 is a graph with curves illustrating the relationship between the elongation, the reduction of area or the Charpy impact strength and the tensile strength when SCM3-A steel and SCM3-C were tested for their mechanical properties. It is noted that SCM3-A steel was produced by treating SCM3 steel so as to have an A-type oxide inclusion and SCM3-C steel was produced by treating SCM3 steel so as to have a C-type oxide inclusion as defined in the Japanese Industrial Standards. The horizontal axis indicates the tensile strength and the vertical axis indicates the elongation, the reduction of area and the Charpy impact strength.

FIG. 5 is a graph with curves illustrating the relationship between the cutting speed and the life of the tool when S20C-A steel, S30C-A steel, S45C-A steel, S55C-A steel, S20C-O steel, S30C-O steel, S45C-O steel and S55C-O steel were tested therefor. It is noted that the former four steels were produced by treating S20C steel, S30C steel, S45C steel and S55C steel so as to have an A-type oxide inclusion, and the latter four steels were not treated and therefore they are the same as S20C steel, S30C steel, S45C steel and S55C steel respectively. In FIG. 5 the vertical axis indicates the cutting speed and the horizontal axis indicates the life of the tools tested.

FIG. 6 is a graph with curves illustrating the relationship between the cutting speed and the life of the tools when SCR3-A steel, SCR4-A steel, SCM3-A steel, SCM4-A steel, SNC2-A steel, SCR3-O steel, SCR4-O steel, SCM3-O steel, SCM4-O steel and SNC2-O steel were tested therefor. It is noted that

the former five steels were produced by treating SCR3 steel, SCR4 steel, SCM3 steel, SCM4 steel and SNC2 steel so as to have an A-type oxide inclusion respectively, and the latter five steels were not treated and therefore they are the same as the steels indicated by SCR3, SCR4, SCM3, SCM4 and SNC2 respectively. In FIG. 6, the horizontal axis indicates the life of the tools tested and the vertical axis indicated the cutting speed.

FIG. 7 is bar graph showing the life of the tools comparing S20C-A steel with S20-C steel. It is noted that S20C-C steel was produced by treating S20C steel so as to have a C-type oxide inclusion as defined in the Japanese Industrial Standards.

FIG. 8 is a graph with curves illustrating the relationship between the life of tools and the calcium content of S45C-A steel and SCM4-A steel. The life of tools is indicated by the vertical axis and the calcium content is indicated by the horizontal axis.

FIG. 9 is a photograph showing the status of the A-type inclusion contained in the free-cutting steel according to this invention and FIG. 10 is a photograph showing the status of the C-type oxide inclusion contained in the known free cutting steel.

Some free-cutting steels which were developed on the basis of the utilization of an oxide inclusion have been reported by H. Opity and others of the Aachen engineering college in West Germany. Such free-cutting steels are illustrated in FIG. 1 and it is noted that they are melted so as to contain an oxide inclusion which consists of the components within an area around the line $\bar{b}\bar{d}$ connecting the 50 percent point "b" on the $\text{CaO}-\text{SiO}_2$ line with the 50 percent point "d" on the $\text{CaO}-\text{Al}_2\text{O}_3$ line, and particularly within the hatched area as indicated by the sign "a" and also that the oxide inclusion consists of gehlenite ($2\text{CaO}:\text{Al}_2\text{O}_3:\text{SiO}_2$) as a principal component and the oxide inclusion exists in the form of globular oxide or agglomerate which is referred to as a C-type oxide inclusion as stated hereinabove.

Also the free-cutting steels of this invention are illustrated by referring to FIG. 1 and it should be noted that they are melted so as to contain an oxide inclusion which consists of the components within the hatched area around the line $\bar{b}\bar{c}$ connecting the 50 percent point "b" on the $\text{CaO}-\text{SiO}_2$ line with the 50 percent point "c" on the $\text{SiO}_2-\text{Al}_2\text{O}_3$ line and also that the oxide inclusion consists of anorthite ($\text{CaO}:\text{Al}_2\text{O}_3:2\text{SiO}_2$), as a principal component, and as an additional component tridymite (SiO_2), mullite ($3\text{Al}_2\text{O}_3:2\text{SiO}_2$), Pseudo-wollastonite ($\text{CaO}:\text{SiO}_2$) or corundum (Al_2O_3). This is the first essential feature of this invention. Also, it should be noted that the compositions of the free-cutting steels of this invention are controlled so as to have a calcium content ranging from 20 to 100 p.p.m. This is the second essential feature of this invention.

The reasons why the free-cutting steels of this invention are characterized by the first essential featured are explained as follows.

As can be seen from the photograph of FIG. 9, the free-cutting steel of this invention contains an oxide inclusion having the characteristic that it is elongated in the direction of rolling. The oxide inclusion is referred to as an A-type oxide inclusion as stated hereinbefore. Thus, it will be understood that the A-type oxide inclusion is distinguishable from the C-type oxide inclusion contained in the conventional free-cutting steel as shown in the photograph of FIG. 10. The photograph of FIG. 10 shows that the C-type oxide inclusion having a size of about 40μ in diameter becomes a starting point for destroying the steel due to fatigue and decreasing impact strength of the steel and thus the C-type oxide inclusion is not desirable for the free-cutting steels. On the contrary, the A-type oxide inclusion does not cause such phenomena.

An inclusion of S45C steel was converted into the A-type oxide inclusion thereby to form S45C-A steel and also an inclusion of S45C steel was converted into the C-type oxide inclusion thereby to form S45C-C steel as shown in the follow-

ing table 1. In table 1, it is noted that S45C-O steel contained an unconverted inclusion, and also that each of the steels has the chemical composition as indicated. The test samples of these steels were normalized and then they were tested for the fatigue strength by using a fatigue test machine by which the test samples are fatigued by the action of bending moment derived by rotating a weight. The test results are shown in FIG. 2. As is obvious from the curves as shown in FIG. 2, S45C-A steel has a fatigue strength similar to the fatigue strength of S45C-O steel, but the fatigue strength of S45C-C steel is reduced.

S45C steel and S55C steel having the chemical composition as shown in the following table 4 was converted into the A-type oxide inclusion thereby to form S20C-A steel, S30C-A steel, S45C-A steel and S55C-A steel respectively. In table 4, it is noted that S20C-O steel, S30C-O steel, S45C-O steel and S55C-O steel correspond to S20C steel, S30C steel, S45C steel and S55C steel respectively containing an unconverted inclusion. They were normalized and subjected to a cutting test at a feed of 0.2 mm./rev., 2.0 mm. of depth of cut and a frank wear width of $V_R=0.3$ mm. by using a P 10 tool which is made of a TiC type ultrahard steel containing TiC in an

TABLE 1

Chemical components (percent)							Mechanical properties				
Steels	C	Si	Mn	P	S	Ca	Yield point (kg./mm. ²)	Tensile strength (kg./mm. ²)	Elongation (percent)	Reduction of area (percent)	Hardness (H _B)
S45C-A...	0.45	0.32	0.72	0.014	0.013	0.009	43.6	70.9	28.2	50.0	213
S45C-C...	0.42	0.30	0.73	0.019	0.009	0.0058	43.9	72.1	30.0	49.0	211
S45C-O...	0.45	0.32	0.75	0.019	0.015	Trace	43.3	74.5	24.9	45.9	212

NOTE.—850° C. × 2 hAc.

An inclusion of S45C steel having the chemical composition as shown in the following table 2 was converted into the A-type oxide inclusion thereby to form S45C-A steel and also an inclusion of S45C steel having the chemical composition as shown in the following table 2 was converted into the C-type oxide inclusion thereby to form S45C-C steel. The S45C-A steel and the S45C-C steel were tested for their mechanical properties. The test results are shown in FIG. 3.

TABLE 2

Chemical components, percent						
Steels	C	Si	Mn	P	S	Ca
S45C-A...	0.42	0.30	0.73	0.019	0.009	0.0058
S45C-C...	0.40	0.33	0.67	0.011	0.013	0.0051

An inclusion of SCM3 steel having the chemical composition as shown in the following table 3 was converted into the A-type oxide inclusion thereby to form SCM3-A steel and also an inclusion of SCM3 steel having the chemical composition as shown in the following table 3 was converted into the C-type oxide inclusion thereby to form SCM3-C steel. The SCM3-A steel and the SCM3-C steel were tested for their mechanical properties. The test results are shown in FIG. 4.

TABLE 3

Chemical components, percent								
Steels	C	Si	Mn	P	S	Cr	Mo	Ca
SCM3-A.....	0.36	0.31	0.75	0.014	0.014	1.04	0.24	0.0051
SCM3-C.....	0.37	0.28	0.72	0.010	0.009	1.12	0.27	0.0057

As is obvious from the curves as shown in FIGS. 3 and 4, the elongation, the reduction of area and the Charpy impact strength of both the S45C-C steel and the SCM3-C steel are

amount of about 28 percent. The test results are shown in FIG. 5.

TABLE 4

Chemical components, percent							
Steels	Sign	C	Si	Mn	P	S	Ca
S20C.....	{A	0.22	0.31	0.50	0.021	0.016	0.0060
	{O	0.22	0.29	0.38	0.018	0.012	0.0069
	{A	0.29	0.33	0.63	0.016	0.020	0.0052
S30C.....	{O	0.32	0.24	0.70	0.013	0.030	0.0001
	{A	0.42	0.30	0.73	0.019	0.009	0.0058
S45C.....	{O	0.45	0.32	0.75	0.019	0.015	0.0009
	{A	0.54	0.29	0.78	0.014	0.020	0.0061
S55C.....	{O	0.56	0.25	0.72	0.014	0.030	0.0001

As can be seen from FIG. 5, the life of the tool is improved and particularly at a cutting speed of above 100 meters per minute when the A-type inclusion-containing steels are cut.

An inclusion contained in each of SCR3 steel, SCR4 steel, SCM3 steel, SCM4 steel and SNC2 steel having the chemical composition as shown in the following table 5 was converted into the A-type oxide inclusion thereby to form SCR3-A steel, SCR4-A steel, SCM3-A steel, SCM4-A steel and SNC2-A steel respectively. In table 5 it is noted that SCR3-O steel, SCR4-O steel, SCM3-O steel, SCM4-O steel and SNC2-O steel correspond to SCR3 steel, SCR4 steel, SCM3 steel, SMC4 steel and SNC2 steel respectively contain an unconverted inclu-

sion. They were normalized and subjected to a cutting test conducted in the same manner as mentioned above. The test results are shown in FIG. 6.

TABLE 5

Chemical components, percent										
Steels	Sign	C	Si	Mn	P	S	Ni	Cr	Mo	Ca
SCR3.....	{A	0.36	0.23	0.71	0.014	0.012	0.07	1.08	-----	0.0051
	{O	0.34	0.24	0.73	0.012	0.009	0.08	1.05	-----	0.0007
SCR4.....	{A	0.41	0.27	0.69	0.016	0.009	0.10	1.02	-----	0.0049
	{O	0.39	0.30	0.72	0.013	0.011	0.11	0.99	-----	0.0010
SCM3.....	{A	0.36	0.31	0.75	0.014	0.014	0.12	1.04	0.24	0.0051
	{O	0.35	0.28	0.71	0.011	0.011	0.09	1.01	0.22	0.0006
SCM4.....	{A	0.42	0.26	0.74	0.015	0.012	0.09	0.98	0.25	0.0057
	{O	0.41	0.30	0.69	0.011	0.008	0.10	1.00	0.23	0.0008
SNC2.....	{A	0.30	0.29	0.51	0.016	0.012	2.87	0.76	-----	0.0064
	{O	0.29	0.27	0.59	0.013	0.011	2.89	0.81	-----	0.0009

lowered as compared with those of the S45C-A steel and the SCM3-A steel.

An inclusion contained in each of S20C steel, S30C steel, 75

As can be seen from FIG. 6, the life of the tool is improved and particularly at a cutting speed of above 100 meters per minute.

S20C-A steel and S20C-C steel as given in the following table 6 were subjected to cutting tests under a feed of 0.168 mm./rev., 1.0 mm. of depth of cut, a frank wear width of $V_F=0.3$ mm. and a cutting speed of 150 m./min. by using the P 10 tool. The test samples were made of the top, middle and bottom part of the body of each of the steels. The test results are shown in FIG. 7. As can be seen from FIG. 7 a longer life was obtained for the tool tested for S20C-A steel as compared with the tool tested for S20C-C steel.

TABLE 6

Steels	Chemical components, percent						
	C	Si	Mn	P	P	P	Ca
S20C-A	0.20	0.27	0.35	0.006	0.016	0.0078	The A-type oxide inclusion.
S20C-C	0.22	0.28	0.43	0.015	0.019	0.0067	The C-type inclusion.

Next, the reasons why the free-cutting steels of this invention are characterized by the second essential feature are explained as follows.

The test steels such as S45C-A steel Nos. 1 to 12 and SCM4-A steel Nos. 41 to 47 as listed in the following table 7 were subjected to cutting tests under a feed of 0.20 mm./rev., 2.0 mm. of depth of cut and a cutting speed of 200 mm./min. by using the P 10 tool having a back rake angle of -5° , a side rake angle of -5° , an end relief angle of 5° , a side relief angle of 5° , an end cutting angle of 30° , a side cutting angle of zero and a nose radius of 0.4 mm. for determining the relationship between the life of the tools and the calcium content of the steel. The test results are shown in FIG. 8.

TABLE 7

Steels	Nos.	Chemical components, percent								
		C	Si	Mn	P	S	Cr	Mo	Ca	
S45C-A	1	0.45	0.33	0.73	0.023	0.013	-----	-----	0.0007	
	2	0.45	0.32	0.75	0.019	0.015	-----	-----	0.0009	
	3	0.46	0.33	0.71	0.021	0.013	-----	-----	0.0012	
	4	0.45	0.30	0.73	0.015	0.013	-----	-----	0.0020	
	5	0.44	0.34	0.79	0.019	0.013	-----	-----	0.0022	
	6	0.45	0.33	0.80	0.019	0.012	-----	-----	0.0026	
	7	0.45	0.30	0.71	0.016	0.013	-----	-----	0.0030	
	8	0.42	0.30	0.73	0.019	0.009	-----	-----	0.0058	
	9	0.42	0.31	0.72	0.018	0.011	-----	-----	0.0066	
	10	0.45	0.33	0.72	0.016	0.011	-----	-----	0.0090	
	11	0.45	0.35	0.72	0.016	0.012	-----	-----	0.0098	
	12	0.45	0.31	0.79	0.019	0.012	-----	-----	0.0113	
SCM4-A	41	0.39	0.31	0.70	0.017	0.009	1.11	0.25	0.0004	
	42	0.41	0.30	0.67	0.011	0.012	1.02	0.24	0.0017	
	43	0.41	0.31	0.68	0.016	0.014	1.01	0.26	0.0029	
	44	0.38	0.29	0.74	0.014	0.011	1.07	0.22	0.0048	
	45	0.42	0.26	0.72	0.012	0.011	1.06	0.21	0.0054	
	46	0.39	0.33	0.71	0.011	0.014	0.99	0.24	0.0087	
	47	0.39	0.27	0.69	0.014	0.012	1.14	0.26	0.0102	

As can be seen from FIG. 8, the life of the tool is lowered and is not satisfactory when S45C-A steel and SCM4-A steel contain calcium in an amount of below about 20 p.p.m. or above about 100 p.p.m. Thus, it is understood that the calcium content of the free-cutting steels of this invention is an essential feature and the calcium content is required in the range varying from 20 p.p.m. to 100 p.p.m.

The inventor has found that the A-type oxide inclusion contained in the free-cutting steels of this invention is softened or molten when said steels are cut with the cutting tool and that the tool was covered with the molten oxide inclusion and the tool is protected from wear. The typical S-containing free-

cutting steel, the Pb-containing free-cutting steel and the free-cutting steel of this invention were compared with nonfree-cutting steel by evaluating their shear strain on the cutting shear plane based on the effect of stress concentration in the inclusion and the frictional stress on the rake face of the tool based on the effect of less friction. The following table 8 shows the ratio of the shear strain on the cutting shear plane for the free-cutting steels to the shear strain on the cutting shear plane for the nonfree-cutting steel and also the ratio of the frictional stress on the rake face of the tool for the free-cutting steels to the frictional stress on the rake face of the tool for the nonfree-cutting steel.

TABLE 8

Steels	Ratio of the shear strain on the cutting shear plane	Ratio of the frictional stress on the rake face of the tool
Steels of this invention	1.0	0.5
Pb-containing free cutting steel	0.8	0.8
S-containing free cutting steel	0.6	Above 1.0 when the shear strain is small, but when the shear strain is large, the ratio is below 1.0

It is obvious from the data as shown in table 8 that the free-cutting characteristic of the free-cutting steels of this invention is not due to the effect of stress concentration in the oxide inclusion but due to less frictional stress on the rake face of the tool. Thus, it is necessary that the oxide inclusion be softened or molten depending on the cutting conditions of the free-cutting steels and it was found from measurement of the temperature on the rake face and observation of the layer adhered to the tool that the oxide inclusion contained in the free-cutting steels of this invention must have a melting point of from 1,100° C. to 1,550° C. and also that the melting point was determined by the oxide inclusion contained in the free-cutting steels of this invention.

What I claim is that:

- 1. Free-cutting plain carbon steels consisting essentially of 0.2 to 0.5 percent carbon, 0.24 to 0.33 percent silicon and 0.35 to 0.78 percent manganese, said steels being characterized by an oxide inclusion comprising anorthite ($\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) as a principal component and a calcium content ranging from 20 to 100 p.p.m. and balance iron.
- 2. Free-cutting Ni-Cr, Cr-Mo and Cr-steels consisting essentially of 0.29 to 0.42 percent carbon 0.24 to 0.33 percent silicon, 0.51 to 0.75 percent manganese, 0.07 to 2.89 percent nickel, 0.76 to 1.14 percent chromium and 0 to 0.26 percent molybdenum, said steels being characterized by an oxide inclusion comprising anorthite ($\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) as a principal component and a calcium component ranging from 20 to 100 p.p.m. and balance iron.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,630,723

DATED : December 28, 1971

INVENTOR(S) : ASADA

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 47, change "0.5" to -- 0.56 --.

Signed and Sealed this

Fifteenth **Day of** *May* 1979

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

DONALD W. BANNER
Commissioner of Patents and Trademarks