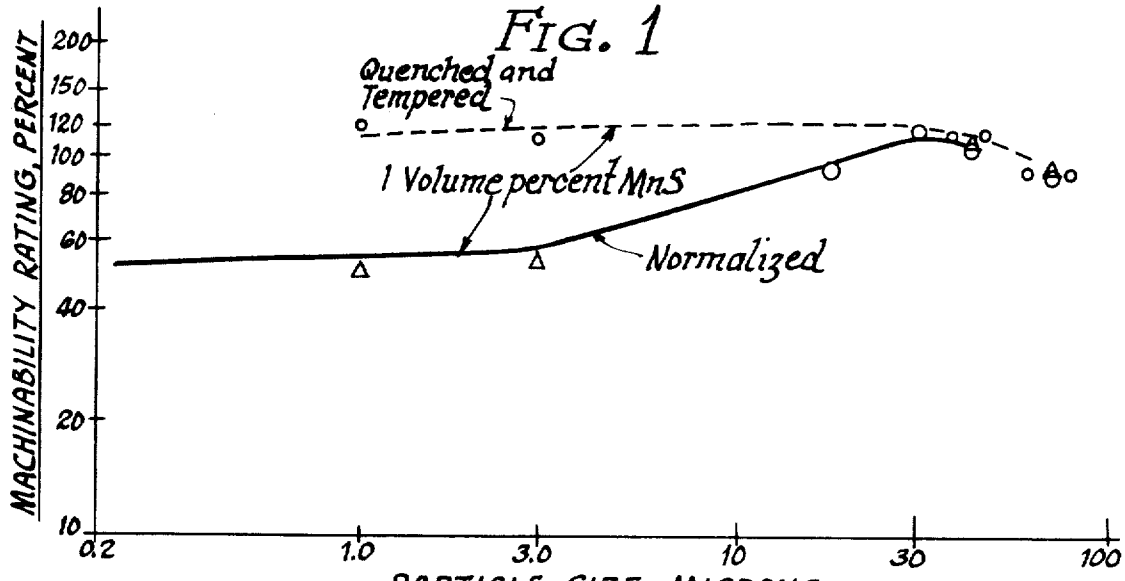
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METALS HAVING IMPROVED MACHINABILITY AND METHOD

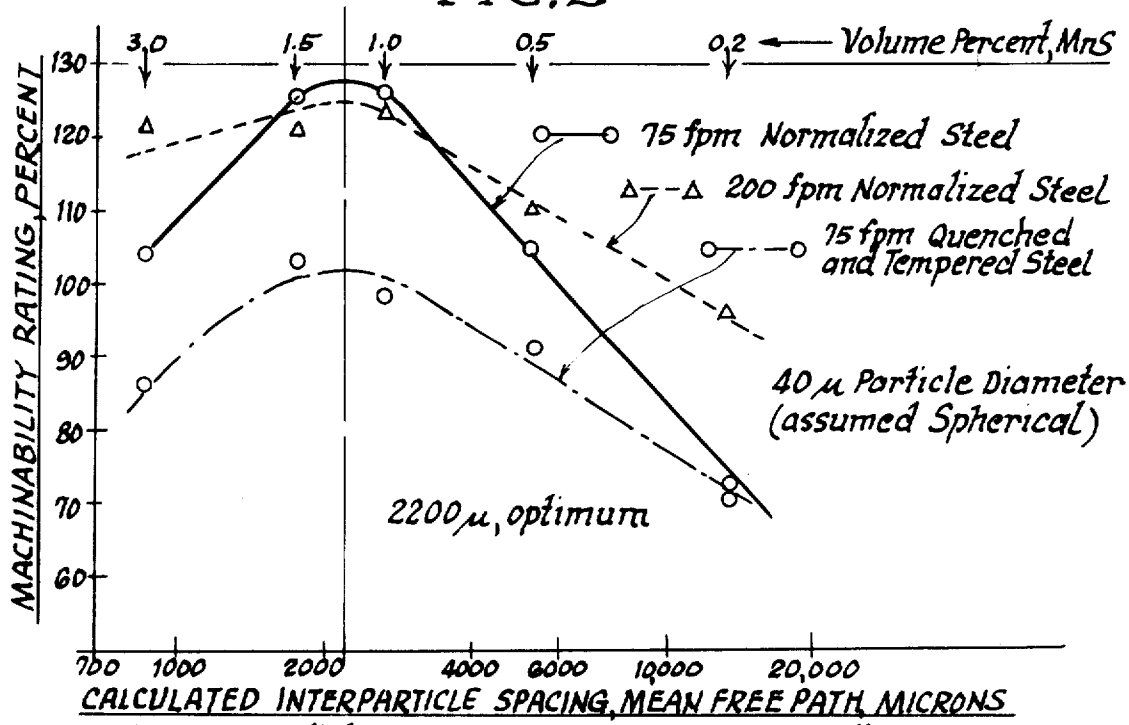
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FIG. 1



Machinability Trend Lines Representing Different Particle Sizes of Additives at One Volume Percent in Steel Machined at Two Different Cutting Speeds

FIG. 2



Effect of Interparticle Spacing of 40-Micron MnS Particles as Free-Machining Additive on Machinability Ratings of 1045 Steel

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METALS HAVING IMPROVED MACHINABILITY AND METHOD

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ABSTRACT OF THE DISCLOSURE

The improvement in machinability of steels and other metals by the inclusion of foreign bodies having a predetermined size and distribution within the metal.

This invention relates to the improvement of the machinability of metals and it relates more particularly to steels having improved machinability characteristics.

To the present, steels having improved machinability have been produced by the addition of lead to steel in the production of leaded steels. Other free machining additives which have been added to steels to improve machinability include tellurium, bismuth, sulphur and selenium. In my issued U.S. Patent No. 2,789,069, description is made of the unexpected improvements which have been experienced in the machinability of steels by the intentional inclusion of copper, and in my issued U.S. Patent No. 3,094,440, description is made of the additions of zinc as a free machining additive to steel. Such additives are believed to function in the manner of an internal lubricant or to provide the cutting tool with a coating to reduce wear and failure whereby an apparent improvement is secured in the machinability characteristics of the metal.

While these free machining additives are effective to improve machinability, they incidentally often undesirably affect others of the physical and mechanical properties of the steel. Thus it is an object of this invention to produce and to provide a method for producing steels and other metals having improved machinability characteristics without detriment to others of the mechanical and physical properties of the steel or other metal.

This invention is addressed to the discovery of an entirely new and novel concept in the means by which the machinability characteristics of steels might be effected. It departs completely from internal lubrication of the steel or the formation of a protective coating on the tool, as evidenced by the fact that the concept of this invention can be demonstrated by modification of the steel to include additives, such as aluminum oxides and the like materials which normally would be expected to increase the hardness of the steel, increase wear on the cutting tool, interfere with internal lubrication, or in other words reduce the machinability characteristics of the steel.

It has been found that size and distribution of foreign bodies (inclusions) in the steel has an unexpected and material effect on the machinability characteristics of the steel. By proper selection of both size and distribution of the inclusions, steels having noticeable improvement in machinability can be produced substantially independently of the chemistry of the inclusions. By proper selection of both the materials and their size and distribution in the steel, improvements can be achieved in the machinability characteristics with minimum effect on others of the mechanical ad physical properties of the steel. In fact, by proper selection of materials having the desired size and distribution in the steel, others of the mechanical properties of the steel can be improved, such as hardness, strength, ductility, surface finish and the like, in addition to marked improvement in the machinability characteristics of the steel.

The unique character of this invention can perhaps best be established by the fact that improvement in machinability characteristics of steels can be achieved by inclusions of such compounds as manganese sulfide, aluminum oxide and the like materials which, based upon current theories, would normally be expected to increase the hardness and brittleness of the steels and materially reduce their machining characteristics. Thus it was entirely unexpected to find that when aluminum oxide particles are incorporated in the desired size and distribution in the steel, marked improvements can be secured in machinability in addition to other improvements otherwise normally expected to be derived from the use of such materials.

The amount of inclusions is not a significant factor since the volume percent of the inclusions will depend somewhat upon the size of the inclusions and the distribution of the inclusions in the steel. It has been found that the desired effect on machinability of steels can be secured when the size of the inclusions of particles is within the range of 10 to 100 microns and preferably 20 to 60 microns and their distribution, as measured by interparticle spacing (Mean Free Path) is within the range of 1000 to 4000 microns and preferably 1600 to 2400 microns. The range and the optimum will vary slightly from the above, depending somewhat upon the chemistry of the inclusions.

By way of modification, it has also been found that the physical shape of the inclusions has a correlation with the machinability rating that is obtained with a particular inclusion. For example, disc shaped inclusions, obtained as by cross rolling of sheets or plates containing the inclusions, gives relatively uniform machinability ratings in both directions. On the other hand, rod-like inclusions, obtained by unidirectional rolling or elongation of the work piece containing the inclusions, gives directional variation in machinability.

As used herein, the term "inclusions" refers, in its broadest sense, to foreign bodies within the metal matrix which, by reason of being foreign to the metal, are capable of separate identification from the standpoint of size and distribution, such as inorganic inclusions of the type silicon carbide, cadmium sulfide, aluminum oxide, zirconium oxide, molybdenum disulfide and the like highly insoluble, high melting point inorganic compounds or metallic compounds. Included also as representative are the free machining additives such as lead, bismuth, selenium, tellurium and sulphur which becomes even more effective in their improvement of machinability, when size and distribution of the metal or compounds formed thereof are controlled as described herein. In its broadest sense, the term would also include voids within the metal of the desired size and distribution since such voids are foreign bodies which yield the desired improvements in machinability when present in the desired size and distribution in the particular metal.

There are various techniques by which such inclusions might be incorporated to achieve the distribution of inclusions of desired size in the metal matrix. The technique which becomes immediately apparent is by the process of powdered metallurgy wherein the inclusions in the desired amounts and size can be uniformly mixed with the powdered metal and pressed into compounds which can then be sintered and forged or otherwise worked to improve the density.

More highly specialized techniques are required to be employed to achieve the desired size and distribution of the inclusions in a metal matrix by addition while the metal is in a molten state. This can be accomplished without difficulty merely by mixing, when the inclusions are insoluble or incompatible with the molten metal or

enjoy a melting point above the temperature of the metal of the matrix. When the inclusion is soluble in the metal or capable of alloying with the metal or being otherwise modified by the molten metal, it is desirable to withhold the addition of the inclusions until the molten metal closely approaches its solidification temperature. As foreign bodies, the inclusions can be generated in situ in the desired size and distribution by separation or by precipitation from the molten metal in response to certain precipitation or insolubilization factors, such as temperature change, elemental additions, gaseous additions, pH change and the like. Such foreign bodies, formed in situ by separation from the metal matrix, will of course remain uniformly distributed throughout the metal upon hardening.

The effect of particle size on the machinability of the steel is illustrated by the following example, using a 1040 steel as the matrix and manganese sulfide of various particle sizes admixed with the steel in the amount of one volume per cent.

EXAMPLE 1

Powdered metal compounds were prepared with 1040 steel to which additions were made in the amount of one volume percent of manganese sulfide particles ranging in particle size from 0.001 to 100 microns. For control, compounds were made of the same metal without the inclusions. The compounds were forged lightly at 2000° F. to round bars which were then heated by normalizing or by quenching and tempering.

The bars were tested for machinability at cutting speeds of 75 and 200 feet per minute by the standard machinability test, hereinafter to be described, which gives machinability ratings for the test bars as represented in the accompanying graph identified as FIG. 1.

It will be seen from the curves that, while machinability ratings for the normalized 1040 steel increase gradually from a rating of 46 with manganese sulfide having a particle size of 0.001 micron, a rapid increase in machinability from about 60 begins with manganese sulfide inclusions having a particle size of 3 microns and that an optimum rating of about 120 is reached in the range of 30–40 microns followed by a rapid falling off as the manganese sulfide particles exceed 60 microns and approach 100 microns in size. Between 3 and 30 microns, the machinability rating increases about 50% from a rating of less than 60 to a rating of 120. It will be significant that the cutting speed has little if any effect on the machinability rating of the tested steels.

Similar tests were conducted on normalized and quenched-and-tempered bars containing one volume percent alumina and other bars containing one volume percent of a mixture of equal parts of alumina and manganese sulfide. While the effects secured with alumina or with a mixture of alumina and manganese sulfide were not as pronounced as with manganese sulfide alone, the tests indicated that the particle size which is effective to increase machinability characteristics of the steel lies generally within the same range as that for manganese sulfide.

The effect of spacing of the inclusions on the machinability characteristics of steel can be demonstrated by the following example using manganese sulfide at the optimum particle size of 40 microns, as determined in Example 1, but in which the amount of manganese sulfide was varied to provide compounds with different spacing between the particles.

EXAMPLE 2

Again powdered metal compounds were prepared with 1040 steel in which manganese sulfide, having an average particle size of 40 microns, was admixed in amounts ranging from 0.2 to 3.0 volume percent. The compounds were forged into round bars and heat treated as in Example 1 and then subjected to the same machinability tests at cutting speeds of 75 and 200 feet per minute, as in Example 1, to determine their machinability ratings.

The results are set forth in the curve identified as FIG. 2.

The interparticle spacing is identified by their mean free path (MFP) as calculated from the formula for spherical particles

$$MFP=\frac{2d(1-f_v)}{3f_v}$$

in which d is the diameter of the particle and f_v is the volume fraction.

From the values represented in the curves, it will be seen that rapid improvement in machinability is experienced with an interparticle spacing of 800 microns. Improvement continues until the interparticle spacing exceeds about 6000 microns with best results being secured with interparticle spacing of 1600–2400 microns, with an optimum in all cases lying between 2000 and 2200 microns.

EXAMPLE 3

The effect of composition, size and distribution of manganese sulfide particles on the mechanical properties and machinability characteristics of medium carbon steels were determined with specimens prepared as in Examples 1 and 2, with variations in volume pecent for interparticle spacing of the manganese sulfide, with the machinability ratings being determined by a constant pressure lathe test, with the following results:

TABLE I

	Composition				MnS additive			Mechanical properties				
		Mn		S								
AISI steel	C, percent	Total, percent	Free, percent	(total), percent	Volume percent	Diameter, microns	Mean free distance, microns	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elongation, percent	Reduction in area, percent	Machinability rating, percent
1151+S	0.48	1.04	0.14	0.52	2.8	33	764	72.7	36.7	20	20	104
1151+S	0.49	0.86	0.34	0.3	1.6	32	1,312	89.1	46.1	25	33.4	125
1151+S	0.51	0.77	0.43	0.22	0.95	26	1,807	92	47.7	26	39	126
1151+S	0.52	0.85	0.67	0.176	0.54	24	2,947	99.7	52.6	22	38.5	105
1151	0.51	0.85	0.77	0.062	0.24	20	5,542	99.2	53.8	28	50	72
1039	0.43	0.83		0.024				105.6	55	24	44	66
1039	0.39	0.82		0.020				102.7	53.8	23	45.3	62
Random iron												

TABLE II

	Composition				MnS additive			Mechanical properties				
		Mn		S								
AISI steel	C, percent	Total, percent	Free, percent	(total), percent	Volume percent	Average diameter, microns	Mean free distance, microns	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elongation, percent	Reduction in area, percent	Machinability rating, percent
1030	0.30	0.98		0.195	0.52	22	2,806	130	114	18	49.9	117
1030	0.33	0.64		0.022				140.5	122.5	14	44.7	40
1030	0.36	0.46		0.182	(1)			92.6	67.9	24	49.1	103
1030	0.34	0.44		0.170	(1)			96.6	72.0	22	48	102
1030	0.34	0.45		0.172	0.6	1.9	210	87	61.2	29	56.9	50
1041	0.40	0.18		0.022				104.2	75.8	20	51	40
Random iron												

In general, it will be seen from the above data that increase in content of manganese sulfide results in lower reduction in area values in tensile tests with progressively higher machinability ratings. For nearly the same content of manganese sufide, the machinability improves with increase in particle size. Table II further indicates that higher strengths and ductility do not significantly impair improvement in machinability, provided the size and distribution of the particles is within the range indicated.

Briefly described, the tests for machinability ratings were conducted in each case by taking a ⅛ inch turn of cut on each bar tested. The cross feed was produced by a horizontal thrust force originating from a constant weight (7 pounds) operating through a pulley system. Cutting speeds of 75 f.p.m. and 200 f.p.m. were used for the bars and for the controls.

The steels were each subjected to four or five tests with a complete test consisting of cutting a group of test samples along with a standard control with cuts on the standard as a control at the beginning and at the end of each test. To compensate for variations which might exist in cutting tool conditions, a new cutting tool was used for each of the separate test groups with the order in which the samples were machined being changed for each successive test so that the reported average would take into consideration differences in cutting edge conditions during the progress of the series of cuts with the same tool.

It appears that these same concepts for improvement in machinability by inclusion of foreign bodies having the desired spacing and distribution can be produced in metals other than steel, such as, for example, in aluminum, titanium, zirconium, molybdenum, nickel, cobalt and the like, or alloys such as high alloy steels, super alloys of nickel and cobalt and the like.

It will be understood that changes may be made in the details of formulation and operation without departing from the spirit of the invention, especially as defined in the following claims.

I claim:

1. Metals having improved machinability characteristics by reason of the inclusion of foreign bodies uniformly distributed throughout the metal of a size within the range of 10 to 100 microns and a spacing between the inclusions averaging within the range of 1000 to 4000 microns.

2. Metals having improved machinability characteristics by reason of the inclusion of foreign bodies uniformly distributed throughout the metal of a size within the range of 20 to 60 microns and a spacing between the inclusions averaging within the range of 1600 to 2400 microns.

3. Steels having improved machinability characteristics by reason of the inclusion of foreign bodies uniformly distributed throughout the steel of a size within the range of 10 to 100 microns and a spacing averaging within the range of 1000 to 4000 microns.

4. Steels having improved machinability characteristics by reason of the inclusion of foreign bodies uniformly distributed throughout the steel of a size within the range of 20 to 60 microns and a spacing averaging within the range of 1000 to 4000 microns.

5. Steels having improved machinability characteristics as claimed in claim 3 in which the inclusions are disc shaped to provide corresponding improvements in machinability in two directions.

6. Steels having improved machinability characteristics as claimed in claim 3 in which the inclusions are rod shaped with corresponding improvement in machinability in the direction in which the rod extends in the steel.

7. Steels having improved machinability characteristics as claimed in claim 3 in which the foreign bodies are selected from the group consisting of silicon carbide, cadmium sulfide, aluminum oxide, zinc oxide and molybdenum disulfide.

8. Steels having improved machinability characteristics as claimed in claim 7 in which the steel has a total sulphur content of not more than 0.25 percent.

9. In the method of improving the machinability of steel comprising the step of admixing foreign particles with the steel to provide inclusions uniformly distributed throughout the steel having an average size within the range of 10 to 100 microns in an amount sufficient to control the volume fraction (f_v) of the foreign bodies in the steel to provide average spacing between the inclusions within the range of 1000 to 4000 microns as determined by the equation

$$\frac{2d(1-f_v)}{3f_v}$$

wherein d is the average diameter of the foreign particles.

10. The method as claimed in claim 9 which includes the step of working the steel in two mutually perpendicular directions to form the inclusions to disc shape to improve machinability in both directions.

11. The method as defined in claim 9 wherein the foreign particles have an average size within the range of 20 to 60 microns and the volume fraction thereof is controlled to provide an average spacing of 1600 to 2400 microns.

12. The method as claimed in claim 9 which includes the step of working the steel in one direction to elongate the inclusions to rod-like shape to provide directional improvement in machinability.

13. The method as claimed in claim 9 in which the inclusions are selected from the group consisting of silicon carbide, cadmium sulfide, aluminum oxide, zinc oxide, and molybdenum disulfide.

14. The method as claimed in claim 9 wherein the foreign particles are in the form of a powder and are admixed with the steel powder, the resulting mixture is formed into compacts and the compacts are densified to form a composite metal.

15. The method as claimed in claim 14 in which the compound is densified by forging.

16. The method as claimed in claim 15 which includes the step of heat treating the compact after densification.

References Cited

UNITED STATES PATENTS

3,094,440	6/1963	Nachtman	148—4
3,278,281	11/1966	Ehringer	75—206
3,440,042	4/1969	Kaufman	75—206

OTHER REFERENCES

Correlation of Machinability With Inclusion Characteristics in Resulphurized Bessemer Steels, Van Vlack, ASM 1952.

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