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## STEEL

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6 Claims. (Cl. 75—123)

The invention relates to steel. It is directed more particularly to the improvement of those steels which, in commerce, are commonly referred to as alloy steels, although my invention is not necessarily limited thereto.

The principal object of my invention is to improve the machinability of the said alloy steels. Another object of my invention is to impart to the said alloy steels lower frictional resistance or coefficients of friction than other steels of otherwise similar composition but not containing lead.

In the prior art, the practice most generally resorted to for the purpose of improving the machinability of steel is the addition of sulfur to the steel. For example, certain "free cutting" steels have attained a well established and recognized classification in the steel industry. The Society of Automotive Engineers recognizes this special class of steel and has provided standard specifications for their chemical composition. Sometimes, selenium is used, though the cost thereof is somewhat prohibitive. Normally, where sulfur or selenium is used for improving the machinability of the steel, they are introduced in such quantities as to insure a content in the finished steel of more than .05 per cent sulfur or selenium, or if both are used a total in excess of .05 per cent is usually required.

In the prior art, it has been suggested that from .50 to 2 per cent lead might be incorporated in a ferrous alloy containing from 15 to 30 per cent of chromium for the purpose of reducing the size of the grains and grain boundaries and for preventing grain growth where the alloys are to be subjected to relatively high temperatures and subsequent cooling and for the purpose of rendering the alloy more workable and more resistant to corrosion. However, it has apparently not been conceived that the machinability of alloy steels could be improved by the addition of lead thereto.

This application is a continuation in part of my application Serial No. 208,069, filed May 14, 1938, which is a continuation in part of my application, Serial No. 177,292, filed November 30, 1937.

My invention contemplates the use of small percentages of lead in alloy steels. It contemplates the use of lead in such steels in amounts of .03 to 1.00 per cent, although it is believed that steels containing from .03 to .50 per cent of lead are preferable. It further involves the introduction of the lead into the steels in such a manner that it will be retained therein mainly in submicroscopic form comparatively uniformly dispersed throughout the steel.

My invention is applicable to the so-called nickel steels wherein the carbon may range from .10 to .60 per cent, the manganese from .10 to 1.00 per cent, the silicon from traces to 0.50 per cent, the phosphorus from traces to .05 per cent, the sulfur from traces to .06 per cent and the nickel from .40 to 6.00 per cent. It is also applicable to the "nickel-chromium" steels wherein the carbon ranges from .10 to .60 per cent, the manganese from .10 to 1.00 per cent, the silicon from traces to 0.50 per cent, the phosphorus from traces to .05 per cent, the sulfur from traces to .06 per cent, the nickel from 1.00 to 4.00 per cent and the chromium from .40 to 2.00 per cent. Likewise, it is applicable to the "molybdenum" steels wherein the carbon ranges from .10 to .60 per cent, the manganese from .10 to 1.00 per cent, the silicon from traces to .50 per cent, the phosphorus from traces to .05 per cent, the sulfur from traces to .06 per cent, the chromium from traces to 1.25 per cent, the nickel from traces to 4.00 per cent and the molybdenum from .10 to .50 per cent.

My invention is also applicable to the "chromium" steels wherein the carbon ranges from .10 to 1.10 per cent, the manganese from .10 to 1.0 per cent, the silicon from traces to .50 per cent, the phosphorus from traces to .05 per cent, the sulfur from traces to .06 per cent, and the chromium from .25 to 2.00 per cent. It is also applicable to the "chromium-vanadium" steels wherein the carbon ranges from .10 to 1.00 per cent, the manganese from .10 to 1.00 per cent, the silicon from traces to .50 per cent, the phosphorus from traces to .05 per cent, the sulfur from traces to .06 per cent, the chromium from .50 to 1.50 per cent and the vanadium from .10 to .30 per cent. Likewise, it applies to the "manganese" steels wherein the carbon ranges from .10 to .60 per cent, the manganese from 1.25 to 2.00 per cent, the silicon from traces to .50 per cent, the phosphorus from traces to .05 per cent and the sulfur from traces to .06 per cent.

In the pursuance of my development, lead has been added to the steel by a number of methods which will be discussed more in detail hereinafter. At this point, it will suffice to say that it seems to be important that the lead be added to the steel in subdivided form and under conditions wherein considerable agitation of the steel is occurring. For example, lead has been successfully dispersed throughout the steel by introducing it into molten steel in a crucible in a high frequency induction furnace which naturally causes an agitation of the steel. It has also been successfully dispersed throughout the steel by introducing it into ingot molds during the pouring operation and preferably starting the introduction of lead early in the filling of the mold. It is also important that the lead be introduced in quantities sufficient to insure that the amount desired is retained in the steel. For example, my tests show that the introduction of

cut off bars of S. A. E. 1020, the steels without lead, and the steels of my invention. By dividing the average time required to cut off bars of the steels of my invention by the time required to cut off bars of S. A. E. 1020, I arrived at a ratio which I designate as the "sawability index." Some results of these tests are shown in Table I.

TABLE I.—*Composition and sawability indices of experimental low sulfur steels showing effect of lead*

| Heat No. | Composition | | | | | | | | | Heat treatment | Brinell hardness | Sawability index |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | P | S | Si | Cr | Ni | Mo | Pb | | | |
| 3494 | .15 | .54 | .024 | .025 | .090 | | | | | Norm. 1600° F | 114 | .93 |
| 3495 | .17 | .85 | .025 | .025 | .114 | | | | .070 | do | 121 | .73 |
| 3496 | .47 | .74 | .027 | .025 | .068 | | | | | Norm. 1500° F | 179 | .68 |
| 3497 | .46 | .80 | .024 | .025 | .170 | | | | .197 | do | 179 | .51 |
| 3498 | .88 | .74 | .022 | .024 | .164 | | | | | Norm. 1450° F | 269 | .72 |
| 3499 | .88 | .82 | .023 | .025 | .152 | | | | .183 | do | 277 | .56 |

lead in percentages approximating 1 per cent by weight of the steel may result in a recovery of about .50 to .70 per cent lead under favorable conditions.

I have found that alloy steels containing lead within the range of .03 to 1.00 per cent have improved machinability in various heat treated conditions and as produced by hot rolling. By this is meant that the said alloy steels of otherwise the same chemical composition when heat treated to the same strength and hardness are more easily machinable and can be machined at a greater rate of speed when they contain lead in the range of .03 to 1.00 per cent than when they do not contain this element. I have also found that in steels of essentially the same chemical composition, except for the lead content, those containing lead can be machined under commercial and economical conditions when they have higher hardness and higher strength if the lead is present than when the lead is absent.

Experience has shown that the addition of lead to the said alloy steels within the ranges indicated above does not harmfully affect the forging and rolling characteristics; that said steels may be heat treated by the usual commercial methods; that the resulting heat treated steels have essentially the same mechanical properties, such as yield strength, tensile strength, elongation, reduction of area, impact resistance and hardness as the same steels without lead.

As indicated above, the use of lead to improve the machinability of steels is applicable to steels of different carbon contents. This relation is illustrated by steels of the type known as plain carbon steels in which the carbon content ranges from about .15 to .88 per cent; all of the steels being tested in the normalized condition. These steels were tested for their machinability by sawing tests in which the steels of my invention and steels of the same composition without lead were compared with a steel of the type designated as S. A. E. 1020. In making the sawing tests, comparison was made between the time required to

It will be noted that the sawabality indices of the lead-containing steels, Heats Nos. 3495, 3497 and 3499, are decidedly lower than the comparison steel of essentially the same chemical composition but containing no lead. These outstanding improvements in machinability were effected by lead contents of less than .20 per cent and in steels of hardnesses of the range of about 120 to about 270 on the Brinell scale.

The beneficial effect on the machinability, resulting from the practice of my invention with alloy steels, is illustrated by the data shown in Table II, in which I have used an alloy steel containing the special alloying elements chromium, nickel and molybdenum and have used this steel with and without additions of lead. This steel is rather close to the specified composition for the S. A. E. steels designated as S. A. E. 4340 and X-4340.

The results of sawability tests are shown for these alloy steels after the specimens had been given two heat treatments such as would be used in commercial practice. In the first heat treatment, specimens were heated to 1500° F. quenched in oil and then drawn or tempered at 1000° F. to produce a Brinell hardness of 341. In the second heat treatment, specimens were annealed at 1500° F. and then tempered or drawn at 1250° F., to produce a Brinell hardness of 210. Sawability tests showed conclusively that the lead-containing specimens had better machinability. For example, when these steels were tested at a Brinell hardness of 341, it required about 26 per cent longer time to cut off the bars which did not contain the lead. When the bars were tested at a hardness of 210 Brinell it required 16 per cent longer time to cut off the bars which did not contain the lead.

In addition to the steels of my invention showing greater machinability in saw tests they will, in general, make it possible to increase both speeds and feeds in the ordinary machining operation. This effects an additional saving in the amount of time required to do a given amount of work, or, stated another way, increases the amount of production per machine man hour.

TABLE II.—*Effect of lead on the machinability of Cr—Ni—Mo steels*

| Heat No. | Composition | | | | | | | | | Heat treatment | Brinell hardness | Sawability index |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | P | S | Si | Cr | Ni | Mo | Pb | | | |
| 3502 | .48 | .74 | .022 | .017 | .144 | .72 | 1.42 | .16 | | Oil quench from 1500° F. draw 1000° F | 341 | .73 |
| 3503 | .49 | .77 | .024 | .015 | .150 | .75 | 1.84 | .17 | .158 | do | 341 | .58 |
| 3502 | .48 | .74 | .022 | .017 | .144 | .72 | 1.42 | .16 | | Annealed from 1500° F. draw 1250° F | 210 | .64 |
| 3503 | .49 | .77 | .024 | .015 | .150 | .75 | 1.84 | .17 | .158 | do | 210 | .55 |

In the production of my alloy steels I do not rely upon high percentages of chromium or on the presence of molybdenum to put the lead in solid solution and my invention can be applied to alloy steels in which chromium and molybdenum are not present. In fact, my present application as well as my applications, Serial No. 208,069 and Serial No. 177,292, reveal the introduction of lead into plain carbon steels for the purpose of improving the machinability.

In the practice of my invention two classes of alloying elements are employed, namely, ferrite strengtheners such as nickel, copper, silicon and cobalt and carbide formers such as chromium, molybdenum, tungsten and vanadium. Manganese is also a desirable alloying element and may be said to belong to both of the above classes because it functions to strengthen the ferrite and it also forms carbides but is not as strong a carbide former as the other elements mentioned in that class. Phosphorus within limited percentages is a ferrite strengthener and may be used as such in alloy steels, but because of certain objectionable effects of phosphorus its use as an alloying element is somewhat limited. The elements zirconium, tantalum and columbium also function as carbide formers and likewise serve as grain refining elements. For the purpose of this application, they may be classed as carbide formers. Thus the alloy steels which are responsive to my method of improving their machinability will have as their alloying elements metals selected from the group of ferrite strengtheners or the carbide formers or a combination of metals selected from these two groups. For example, in the nickel alloy steels (S. A. E. 2000, 2100, 2300 and 2500) the nickel is a ferrite strengthener although it has other functions in alloy steels. In the chromium steel (S. A. E. 5100), the chromium is a strong carbide former although it has other functions in alloy steels. In the nickel-chromium steels (S. A. E. 3100, 3200, 3300 and 3400), use is made of both a ferrite strengthening metal and a carbide forming metal and there are certain advantages which result from such combinations. In the chromium-vanadium steel (S. A. E. 6100) use is made of two carbide forming metals. It will be understood that all carbide formers serve to strengthen steel and are in part dissolved in the ferrite. Therefore, the term "strength-giving alloying metals" which appears in the claims is intended to include carbide formers as well as ferrite strengtheners.

In the composition cited in Table II, use has been made of one ferrite strengthening metal and two carbide forming metals. It has been shown that, for many purposes and to some extent, one ferrite strengthener may be substituted for another and likewise one carbide former may be substituted for another without greatly modifying the serviceability of the resulting alloy steel.

The choice of ferrite strengtheners or carbide formers, or combinations of these, depends in part upon fabrication requirements and the intended use of the alloy steels. Cost of the alloying elements is also a factor which has to be given consideration. Ferrite strengtheners, as a class, are used to enhance toughness and cold formability while carbide formers favor increased hardness and resistance to wear. These relations may not hold for all ranges in compositions, however. The general principle used in selecting alloying elements for making alloy steels is to use a combination of ferrite strengtheners and carbide formers such that the resulting alloy steel is said to have a balanced composition and to confer upon the steel the desired characteristics and properties.

My invention is applicable to certain other special ferrous alloys. For example, I contemplate the use of from .03 to 1.00 per cent of lead in an alloy containing carbon within the range of .07 to .25 per cent, manganese from .30 to .70 per cent, silicon from traces to .30 per cent, phosphorus from .10 to .15 per cent, sulfur from traces to .06 per cent, copper from .75 to 1.25 per cent and nickel from .40 to .70 per cent. Though alloys of this type are frequently used under conditions where machining is not required, there are occasions when machining is desirable and such an alloy containing lead is within the scope of my invention.

In the course of the development of my invention I have prepared numerous heats of steels other than those previously enumerated. Some of these are set forth in Table III.

Table III.—*Experimental alloy steels with and without lead (100# split heats)*

| Heat No. | Chemical composition—percent | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | S | P | Ni | Cr | Mo | Pb |
| 4222 | .18 | .64 | .26 | .027 | .014 | 3.45 | | | .01 |
| 4223 | .17 | .66 | .28 | .027 | .014 | 3.49 | | | .17 |
| 4224 | .46 | .92 | .28 | .026 | .012 | 3.47 | | | .02 |
| 4225 | .48 | .93 | .32 | .025 | .015 | 3.45 | | | .20 |
| 4226 | .16 | .58 | .24 | .022 | .011 | 1.25 | .65 | | .00 |
| 4227 | .16 | .60 | .26 | .025 | .010 | 1.26 | .65 | | .14 |
| 4228 | .45 | .83 | .29 | .027 | .012 | 1.24 | .66 | | .03 |
| 4229 | .46 | .84 | .29 | .027 | .012 | 1.26 | .66 | | .18 |
| 4230 | .30 | .75 | .19 | .028 | .012 | | .67 | .20 | .00 |
| 4231 | .31 | .76 | .19 | .029 | .012 | | .64 | .19 | .12 |
| 4232 | .20 | .53 | .14 | .023 | .013 | 1.75 | .65 | .32 | .03 |
| 4233 | .20 | .54 | .13 | .023 | .012 | 1.75 | .64 | .33 | .11 |
| 4234 | .41 | .74 | .22 | .023 | .013 | 1.73 | .65 | .33 | .03 |
| 4235 | .42 | .75 | .21 | .022 | .012 | 1.74 | .65 | .36 | .17 |
| 4236 | .15 | .61 | .21 | .022 | .012 | 1.75 | | .25 | .05 |
| 4237 | .16 | .64 | .20 | .023 | .012 | 1.78 | | .24 | .18 |
| 4238 | .40 | .74 | .21 | .026 | .013 | 1.80 | | .24 | .05 |
| 4239 | .40 | .75 | .22 | .024 | .012 | 1.76 | | .24 | .18 |
| 4240 | .19 | .56 | .20 | .024 | .010 | | .75 | | .02 |
| 4247 | .20 | .57 | .21 | .023 | .010 | | .75 | | .12 |
| 4252 | .51 | .85 | .21 | .030 | .012 | | .93 | | .04 |
| 4253 | .53 | .87 | .22 | .030 | .012 | | .95 | | .17 |
| | | | | | | | | V | |
| 4244 | .14 | .57 | .21 | .026 | .009 | | .91 | .18 | .00 |
| 4245 | .15 | .59 | .22 | .026 | .011 | | .91 | .18 | .16 |
| 4246 | .51 | .83 | .22 | .031 | .010 | | .93 | .19 | .03 |
| 4247 | .53 | .86 | .22 | .032 | .009 | | .93 | .18 | .21 |
| 4248 | .30 | 1.77 | .23 | .032 | .015 | | | | .03 |
| 4249 | .31 | 1.78 | .24 | .030 | .016 | | | | .15 |
| | | | | | | | | Cu | |
| 4250 | .19 | .53 | .10 | .028 | .119 | .53 | | 1.01 | .04 |
| 4251 | .20 | .56 | .10 | .029 | .120 | .51 | | 0.98 | .18 |

These heats were prepared in a high frequency induction furnace. Then, half of the steel was poured into an ingot mold, whereupon lead in finely divided form was added to the molten steel remaining in the furnace. After a short interval of time during which the steel was agitated by the induced current, the lead-containing steel was poured into a second ingot mold. The resulting 50 lb. ingots were forged and rolled into bars. About half of each ingot was rolled into one inch round bars and the other half into ¾ inch round bars. No noticeable difference was observed between the lead-free and the lead-containing steels in the forging and rolling operations. The compositions given in Table III are the results of chemical analyses taken from said ingots. Steels of the type listed in Table III are also within the scope of my invention.

Another illustration of the advantages of additions of lead to improve the machinability of alloy steel is provided by a steel containing about 1.00 per cent carbon, .90 per cent manganese, .30 per cent silicon, .025 per cent sulfur, .025 per cent phosphorus, .12 per cent molybdenum and .18 per cent lead. This steel was drawn into wires of .060 and .030 inch diameter and used in the production of small watch parts in automatic machines. Plant tests showed that this steel had better machinability than any prior art steels which had been tested. The mechanical properties of this lead-containing steel were excellent as shown by the fact that the wire of .060 inch diameter showed a tensile strength of 169,000 lb./sq. in. and a reduction of area of 25 per cent while the .030 inch diameter wire had a tensile strength of 188,000 lb./sq. in. and a reduction of area of 15 per cent. This steel of high strength has been found to have good machinability and to be superior in this respect to similar steels not containing lead.

My invention is also applicable to that type of steel containing constituents designed to aid in controlling the grain size of the steel. Thus, it is within the scope of my invention to embody from .03 to 1.00 per cent lead in a steel containing from effective amounts to 1.70 per cent carbon together with ferrite strengthening elements and carbide formers or either of them and also containing a grain defining element such as aluminum or titanium in the amounts of one-half to six pounds per ton.

The use of lead in alloy steels to improve their machinability does not require increasing the sulfur content of these steels above normal specifications although for certain purposes further improvement in machinability may be effected by slightly increasing the sulfur content. This, however, is only permissible in certain parts where the increased sulfur content does not harmfully affect the mechanical properties or where the desired mechanical properties can be obtained by heat treatment.

It will be seen from the above that my invention results in certain important advantageous characteristics in alloy steels. In the first place, my invention results in marked improvement in machinability of alloy steels of the type described. In addition, there is an improvement in the grain structure of such steels. Furthermore, these steels containing lead possess lower frictional resistance or coefficients of friction than other steels of otherwise similar compositions but not containing lead. Other advantages will appear from the previous description and the appended claims.

Having thus described my invention, what I claim is:

1. An alloy steel of the class containing strength-giving alloying metals in proportions within the range of 0.50 to 6.00 per cent, and characterized by good machining properties, said steel consisting essentially of said alloying metals within the range specified, carbon in effective amounts up to 1.70 per cent, silicon from a trace to 2.50 per cent, phosphorus from a trace to 0.15 per cent, sulfur from a trace to 0.30 per cent, lead in the range between 0.03 and 1.00 per cent, and the balance being substantially all iron, at least a major portion of the lead being uniformly dispersed throughout the steel and serving to improve the machinability thereof.

2. An alloy steel of the class containing strength-giving alloying metals in proportions within the range of 0.50 to 6.00 per cent, and characterized by good machining properties, said steel consisting essentially of said alloying metals within the range specified, carbon in effective amounts up to 1.70 per cent, silicon from a trace to 2.50 per cent, phosphorus from a trace to 0.15 per cent, sulfur from a trace to 0.30 per cent, lead in the range between 0.03 to .478 per cent, and the balance being substantially all iron, at least a major portion of the lead being uniformly dispersed throughout the steel and serving to improve the machinability thereof.

3. An alloy steel of the class containing strength-giving alloying metals in proportions within the range of 0.50 to 6.00 per cent, and characterized by good machining properties, said steel consisting essentially of said alloying metals within the range specified, carbon in effective amounts up to 1.70 per cent, silicon from a trace to 2.50 per cent, phosphorus from a trace to 0.15 per cent, sulfur from a trace to 0.06 per cent, lead in the range between 0.03 to 1.00 per cent, and the balance being substantially all iron, at least a major portion of the lead being uniformly dispersed throughout the steel and serving to improve the machinability thereof.

4. An alloy steel of the class containing strength-giving alloying metals in proportions within the range of 0.50 to 6.00 per cent, and characterized by good machining properties, said steel consisting essentially of said alloying metals within the range specified, carbon in effective amounts up to 0.60 per cent, silicon from a trace to 2.50 per cent, phosphorus from a trace to 0.15 per cent, sulfur from a trace to 0.30 per cent, lead in the range between 0.03 to 1.00 per cent, and the balance being substantially all iron, at least a major portion of the lead being uniformly dispersed throughout the steel and serving to improve the machinability thereof.

5. An alloy steel of the class containing strength-giving alloying metals in proportions within the range of 0.50 to 6.00 per cent, and characterized by good machining properties, said steel consisting essentially of said allowing metals within the range specified, carbon in effective amounts up to 1.70 per cent, silicon from a trace to 2.50 per cent, phosphorus from a trace to 0.05 per cent, sulfur from a trace to 0.06 per cent, lead in the range between 0.03 to .478 per cent, and the balance being substantially all iron, at least a major portion of the lead being uniformly dispersed throughout the steel and serving to improve the machinability thereof.

6. An alloy steel of the class containing strength-giving alloying metals in proportions within the range of 0.50 to 6.00 per cent, and characterized by good machining properties, said steel consisting essentially of said allowing metals within the range specified, carbon in effective amounts up to .60 per cent, silicon from traces to .50 per cent, phosphorus from a trace to 0.05 per cent, sulfur from a trace to .06 per cent, lead in the range between .03 to .478 per cent, and the balance being substantially all iron, at least a major portion of the lead being uniformly dispersed throughout the steel and serving to improve the machinability thereof.

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CERTIFICATE OF CORRECTION.

Patent No. 2,182,759. December 5, 1939.

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It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 4, first column, line 36, for the word "defining" read refining; and second column, lines 50 and 64, claims 5 and 6 respectively, for "allowing" read alloying; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 6th day of February, A. D. 1940.

Henry Van Arsdale,
Acting Commissioner of Patents.

(Seal)