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NONAUSTENITIC STAINLESS STEEL

Oscar E. Harder, Columbus, Ohio, assignor to Inland Steel Company, Indiana Harbor, Ind., a corporation of Delaware

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This invention relates to nonaustenitic stainless steels. It has to do, particularly, with the improvement of the machinability of stainless steels and is more particularly directed to the chromium stainless steels which are predominantly ferritic in character. However, it is applicable to those steels which are known in the industry as ferritic stainless steels and to other chromium steels which are sometimes referred to as martensitic chromium steels. More broadly, it may be said that this application is directed to stainless steels which may be designated as nonaustenitic.

In the prior art, there are a number of chromium steels which belong in the above-mentioned classes. In most of these steels, the chromium content commonly falls within the range of 10 to 30 per cent chromium. Common chromium ranges are such as 10 to 14 per cent, 14 to 18 per cent, 18 to 24 per cent and 24 to 30 per cent. Within the chromium range from 10 to 30 per cent, it is customary to refer to steels of the lower chromium content, such as within the range of 10 to 20 per cent chromium, as heat-treatable; that is, they can have their hardness increased by heat-treating processes which are well-known in the steel industry. The range of steel which responds to these well-known heat treatments for increasing the hardness and strength depends upon the carbon content because the extent of the gamma iron field for a given chromium content increases as the carbon content increases while, on the contrary, the extent of this field is decreased for any given carbon content as the chromium content increases. For example, the extent of the gamma field with .1 per cent carbon is about 12 per cent chromium and for the field which may contain some of the gamma phase it is about 18 per cent chromium, whereas with 1 per cent carbon the field in which some hardenability can be effected is up to 20 per cent chromium and with 1½ per cent carbon it may be up to as high as about 25 per cent chromium.

One of the objects of my invention is to provide a stainless steel of any of the various types indicated in which the machinability of the steel is improved.

Another object of my invention is to provide a stainless steel of the type indicated in which this improved machinability is attained without detracting from the mechanical properties of the steel.

Various other objects of this invention will appear as this description progresses.

My invention relates particularly to the improvement of machinability of stainless steels of the type in question by the additon of lead thereto. In particular, I preferably introduce the lead in percentages ranging from .03 to .478 per cent. Moreover, it is important that this lead be so introduced that it is uniformly dispersed in the steel and that at least a major portion of it is in sub-microscopic form at a magnification of about 100 diameters. I have found that this is attainable and that machinability is thereby improved without harmful effect on the mechanical properties of the steel or the response of the steel to the usual heat-treating processes.

While steels of many compositions have been prepared in the course of this research and development work, only a limited number will be used to illustrate the advantages of this invention.

In a series of heats containing approximately .35 per cent carbon, .55 per cent manganese, .45 per cent silicon, .025 per cent sulfur and 14 per cent chromium, steels with lead contents of .06 and .09 per cent were compared with other samples to which no lead was added. Tensile tests and hardness tests were made on these steels using specimens which had been heated for one hour at 1600° F. and furnace-cooled. The strength properties, including tensile strength, elongation and reduction of area, were essentially the same in the steels to which no lead was added and those which contained .06 and .09 per cent lead. The Charpy impact resistance and the Brinell hardnesses were essentially the same.

Machinability tests on these steels which had a Brinell hardness of approximately 200, showed an improvement of 13 per cent for the alloy containing .06 per cent lead and of 22 per cent for the alloy containing .09 per cent lead.

Another series of heats was made up containing approximately .17 per cent carbon, .58 per cent manganese, .46 per cent silicon, .025 per cent sulfur and 17.20 per cent chromium. One of these samples contained .08 per cent lead whereas no lead was added to the other. Tests on these steels after annealing at 1400° F. showed no essential difference in the strength properties, the impact resistance and the alloys with and without lead had the same hardness. Machinability tests showed that the steel containing only .08 per cent lead had 14 per cent better machinability than the one to which no lead was added.

In another series of tests, with essentially the same analyses, except that the carbon was approximately .10 per cent and the lead content

was .11 per cent, the steels were tested at a hardness of 176 Brinell and the lead containing steel was found to have 29 per cent improved machinability. Again, the mechanical properties were essentially identical.

Comparison tests were made on steels containing approximately 27 per cent chromium with .10 per cent carbon with normal contents of Mn, Si, P and S so that the two steels were essentially the same except that one contained .15 per cent lead while no lead was added to the other. The mechanical properties of the two alloys were essentially the same and when machinability tests were made on specimens having a Brinell hardness of about 215, the alloy containing .15 per cent lead showed 39 per cent improvement in machinability as compared with the alloy to which no lead was added.

The cooperative effect of lead with sulfur and with phosphorus in improving the machinability of ferritic stainless steels is illustrated by tests on steels of the compositions given in Table I and by the machinability data given in Table II.

TABLE I.—*Chemical compositions of stainless steels*

Heat No.	C, %	Mn, %	Si, %	P, %	S, %	Cr, %	Ni, %	Mo, %	Pb, %
5034	(.46)	(.39)	(.37)	.02	.025	16.0	.25	1.00	*
5035	(.39)	(.42)	(.35)	.02	.025	16.0	.25	1.00	(.15)
5036	.40	.40	(.37)	.10	.025	16.0	.25	1.00	*
5037	.40	.40	(.41)	.02	.12	16.0	.25	1.00	*
5038	(.39)	.40	(.40)	(.101)	.025	16.0	.25	1.00	(.08)
5039	.40	.40	(.33)	.02	.12	16.0	.25	1.00	(.12)

*No lead added.
( ) Actual analysis. All other intended analyses.

TABLE II.—*Results of machining tests on ferritic steels*[a]

Heat No.	Pb, %	P, %	S, %	Brinell hardness	Machinability index		Percent improvement in machinability
					Saw	Drill	
5034	*	.02	.025	197	1.00	1.00	Standard
5035	.15	.02	.025	198	.784	.631	41
5036	*	.10	.025	217	.724	.664	44
5037	*	.02	.12	201	.656	.534	55
5038	.08	.102	.025	215	.573	.472	92
5039	.12	.02	.12	197	.541	.496	93

*No lead added.
[a] Compositions given in Table I.

It will be noted that the steels are of the 16 per cent chromium type with about 0.40 per cent carbon and that they contained about ¼ per cent of Ni and 1 per cent Mo. The variables are lead, sulfur and phosphorus. All of these steels are ferritic in character but they are hardenable or responsive to the usual heat treatments. Heat No. 5034 which was low in sulfur and phosphorus and to which no lead was added served as a standard or base line in the machinability test.

The machinability tests were made by sawing and drilling tests. In the saw tests the average time required to saw off bars of the standard (heat No. 5034) was given the value 1.00 and an index calculated for the other steels by dividing the average time required to saw off bars of the same size by the time required for the standard. Obviously then values less than 1.00 represent improved machinability. Similarly, by noting the average time required to drill holes to a given depth in the standard and the other steels, a drillability index could be calculated. The improvements in percentages of machinability given in the last column in Table II were calculated from the indices obtained in the above-mentioned sawing and drilling tests.

The data in Table II show that lead, sulfur and phosphorus are effective in improving the machinability of this type of stainless steel. The data also show that combinations such as lead and phosphorus (heat 5038) cooperate to further improve the machinability. Likewise, the combination of lead and sulfur (heat 5039) combined to improve the machinability above what was obtained when one of these elements was used alone. It is considered as highly significant that the addition of only .08 per cent lead and increasing the phosphorus from about .02 per cent to about .10 per cent (heat 5038) should reduce the average index to nearly one-half, or, stated another way, reduce the machining time to about one-half of that of the same steel with no lead and a normal low phosphorus content. It will be noted also that the addition of only .12 per cent lead and increasing the sulfur from about .025 per cent to about .12 per cent reduced the machining time to about one-half that of the same steel to which no lead was added and which had a normal low sulfur content.

The data in Table II show the hardnesses of the steels used in the machinability tests. Tests on specimens of the steels listed in Table I after they had been heated one hour at 1700° F. and cooled in the furnace showed that lead had essentially no effect on the tensile strength, yield strength, elongation, reduction of area, Charpy impact resistance or Brinell hardness. On the other hand, the amount of phosphorus used strengthened and hardened the steel somewhat and reduced the Charpy impact resistance when used alone or when used with lead. Sulfur in the amount used had little or no effect on these properties when used alone or with lead.

The advantages of using combinations of slightly increased amounts of sulfur and phosphorus with lead are indicated from the results of tests on heats No. 4584 and 4853 of the following analyses:

Heat No.	Chemical composition, percent								
	C	Mn	Si	P	S	Cr	Ni	Mo	Pb
4584	.40	.50	.50	.015	(.055)	16.0	.25	1.00	(.05)
4853	.40	.50	.50	.10	.12	16.0	.25	1.00	(.12)

It will be observed that the only difference in the compositions of these steels are the increases in the phosphorus from .015 to .10 per cent, sulfur from .055 to .12 per cent and lead from .05 to .12 per cent. However, machinability tests showed an improvement of 71 per cent for heat 4853 compared with heat 4584 as a standard. The steel of heat 4853 was slightly higher in strength and hardness and slightly lower in ductility as shown by elongation, reduction of area and by impact resistance.

In another series of tests the effect of a small addition of lead on the machinability of an alloy steel containing principally chromium and silicon as alloying elements was studied. The compositions of these two steels are given below:

Heat No.	C, %	Si, %	Cr, %	Pb, %
4590	.41	3.69	8.5	.....
4591	.42	3.83	8.5	.08

mechanical properties of the steel represented

by the above heats, when tests were made on specimens normalized from 1900° F., were essentially the same.

Saw and drill tests on these steels showed that the machinability was improved 14 per cent by the presence of .08 per cent lead. Drill life tests were made on these two steels, heat treated so that the steel containing lead had a Brinell hardness of 280 and the one to which no lead was added had a hardness of 275. The tests showed that the time to drill holes to a given depth was only about 70 per cent as great for the steel of higher hardness but containing lead at the beginning of the test and after a number of tests had been made the time required to drill holes in the steel containing no lead increased so that it required approximately twice as long as for the steel of somewhat higher hardness but containing .08 per cent lead, that is, the drill dulled more rapidly when lead was absent.

The steel used in this test is illustrative of the type of stainless steel in which the Si supplements the Cr to make the steel stainless. In this case the silicon plus chromium amounts to somewhat over 12 per cent and for many purposes the steel is as stainless as a steel containing twelve or more per cent of chromium and this is a ferritic steel.

While the examples which have been given for illustrative purposes have shown relatively low lead contents, such as .05 to .15 per cent, larger amounts of lead further improve the machinability of the steels disclosed. A novel feature of the discovery that the machinability of steels could be improved, by the addition of lead in finely dispersed form, is that the mechanical properties of the resulting steels and their response to the usual heat treating processes are not impaired which generally is not the case when other means, which have been known in the prior art, are used for this purpose.

The method of adding the lead to my steel to improve machinability is important, but the important features are that the lead in the steel shall be mainly in fine uniformly dispersed form and that the lead content shall be within certain limits as will be disclosed in the appended claims. Satisfactory steels have been obtained when the lead was introduced according to the disclosures in my co-pending application, Serial No. 205,364, filed April 30, 1938, and in the application of J. H. Nead, Serial No. 205,505, filed May 2, 1938.

My tests have shown that the presence of the lead in the steels of this invention has no detrimental effects from the standpoint of corrosion resistance. As a matter of fact, in many cases the corrosion resistance of the steel is improved by the presence of lead.

While my invention is primarily directed to chromium steels, other alloying elements within certain percentage ranges may be present without causing the steels to become austenitic in character and my invention applies to such steels. Likewise, while I have referred to the steels as being chromium steels, there are certain alloying elements which function much in the same way as chromium in that they tend to make the steels ferritic and these elements may be used to within certain percentage ranges to supplement or replace the chromium in the steels of my invention. For example, as indicated, silicon in certain percentage ranges tends to supplement the chromium in making a stainless steel or improving the corrosion and heat resistance of the steel and also tends to make the steel ferritic.

Molybdenum for some purposes improves the corrosion and heat resistance of the steel and also tends to make the steel more ferritic. For this reason, molybdenum may be used within certain percentage ranges to supplement the chromium or to replace the chromium. Tungsten also functions to some extent as does chromium. Molybdenum and tungsten may be used in stainless steels when they are employed in service involving elevated temperatures and may serve to increase the strength of the steels.

Certain alloying elements are generally recognized in the industry as tending when present in sufficient percentages to produce austenitic steels and outstanding examples of these are nickel and manganese. However, nickel and/or manganese may be present in my steels within certain limited percentages to contribute special properties or to improve certain properties. Industry has recognized the beneficial effects of adding certain limited percentages of nickel and of manganese to the chromium stainless type of steel and there are recognized specifications which cover such compositions. For example, it is stated in certain specifications such as The Steel Products Manual of the American Iron and Steel Institute that certain chromium alloys contain up to 2 per cent maximum nickel. In certain compositions the nickel improves the corrosion resistance. Manganese may have a similar function.

Copper is another alloying element which may be used in the type of steel to which this application is directed to improve or to impart desirable properties. Copper has little effect on the structure of the steels so that it does not tend to modify their ferritic condition in any significant way.

While my invention relies principally on the addition of lead within certain percentage ranges to improve the machinability of the steel, in certain compositions, it is desirable, as indicated, to use a combination of lead with other elements such as sulfur and/or phosphorus. It is well-known in the art that sulfur may be used to improve the machinability of a great variety of steels and it is used in the chromium stainless steels to improve the machinability. On the other hand, it is recognized that sulfur in higher percentages detracts from some of the mechanical properties of the steels and for that reason I restrict the amount of sulfur to be used in improving the machinability of my steels to much smaller values than the maximum percentage which is used in steels when sulfur alone is relied upon to improve the machinability. For example, in some of the commercial steels which are now on the market sulfur contents up to .30 per cent and even higher have been used. I prefer to limit the sulfur content to about .15 per cent as a maximum when it is used in combination with lead. Selenium and/or tellurium, especially selenium, have been used to improve the machinability of steels and may be used in combination with lead as has been shown for sulfur. Since sulfur, selenium and tellurium are all members of group VI of the periodic chart and have many related properties, the use of "sulfur" in this specification and the appended claims is intended to include the similar and related elements selenium and tellurium.

Phosphorus is also an element which has been used to improve the machinability of steel and it is effective for this purpose to a certain extent but when used in higher percentages tends to impair the mechanical properties of the steels and particularly the ductility of the steels. For

this reason, I limit the amount of phosphorus in the steel when it is used in combination with lead to improve the machinability and I prefer to limit the phosphorus content to about .15 per cent maximum. The choice of using increased amounts of sulfur and/or phosphorus depends upon the properties desired in the steel. If the maximum machinability is the principal requirement, then it may be desirable to use both of these elements which function to break up the chip and to improve the machinability. If, on the other hand, good retained ductility is of major importance, then less use can be made of these elements to improve the machinability and I rely more upon the lead which within the preferred percentage range is essentially without effect on the mechanical properties of the steel. The use of sulfur and/or phosphorus in these steels for the improvement of machinability has better application in those steels which are relatively soft and relatively low in strength but which have good ductility. These steels tend to drag and smear in the machining operation and the elements sulfur and phosphorus harden the steel somewhat and cause the chip to break more freely and are advantageous in these low carbon compositions. These relations will be brought out more in detail later in this specification.

Aluminum as an alloying element in these steels like chromium tends to make them ferritic and for certain applications, particularly for scaling resistance at elevated temperatures, improves the steels and the aluminum may therefore be considered as a supplementary element for chromium and may be used within certain percentage ranges in these steels to replace chromium. Aluminum in small percentages is a grain refining element and may function to prevent excessive grain growth in certain heat treating operations.

Other elements which may be used to refine the grain and control grain growth in part are titanium, vanadium and zirconium. Nitrogen is an element which has been used in these steels for the purpose of refining the grain and for increasing the strength and hardness. Nitrogen, however, is an effective austenizing element and the amount of nitrogen which can be used in these steels without tending to make them austenitic in character is somewhat limited. Nitrogen, by increasing the hardness and strength in certain compositions, especially those which are relatively soft, tends to improve the machinability and for that reason it is within the scope of my invention to use small percentages of nitrogen such as up to about .10 to .20 per cent. The maximum permissible amount of nitrogen must be held to the lower limits for steels of higher hardness and higher strength. On the other hand, with the softer steels the higher nitrogen content may be used in some applications.

Having thus described my invention, what I claim is:

1. A nonaustenitic stainless steel containing carbon in the range of effective amounts to 1.7 per cent, from 8 to 30 per cent chromium and from .03 to .478 per cent lead, the major portion of said lead being substantially uniformly dispersed throughout the steel and the steel having improved machinability as a result of such lead.

2. A nonaustenitic stainless steel containing carbon in the range of effective amounts to 1.7 per cent, from .05 to .15 per cent sulfur, from .02 to .15 per cent phosphorus, from 8 to 30 per cent chromium and from .03 to .478 per cent lead, the major portion of said lead being substantially uniformly dispersed throughout the steel and the steel having an improved machinability as a result of its combined lead, sulfur and phosphorus contents.

3. A nonaustenitic stainless steel containing carbon in the range of effective amounts to 1.7 per cent, from 8 to 30 per cent chromium, up to 4 per cent copper, from traces to 4 per cent of at least one modifying element selected from the group of ferrite promotors consisting of molybdenum, tungsten, aluminum, silicon, titanium, cobalt and columbium, the total of such modifying ferrite promotors not exceeding 10 per cent, from traces to about 3 per cent of at least one of the modifying elements from the group consisting of nickel and manganese, and from .03 to .478 per cent lead, the major portion of said lead being substantially uniformly dispersed throughout the steel and the steel having improved machinability as a result of such lead.

4. A stainless steel containing carbon in the range of effective amounts to 1.7 per cent, from 8 to 30 per cent chromium, up to 4 per cent copper, from traces to 4 per cent of at least one modifying element selected from the group of ferrite promotors consisting of molybdenum, tungsten, aluminum, silicon, titanium, cobalt and columbium, the total of such modifying ferrite promotors not exceeding 10 per cent, from traces to about 3 per cent of at least one of the modifying elements from the group consisting of nickel and manganese, not more than .15 per cent of any one nor more than .30 per cent total of embrittling elements selected from the group consisting of sulfur, phosphorus and nitrogen, said steel being further characterized by a lead content the major portion of which is in finely dispersed form with the lead ranging from .03 to .478 per cent and having its machinability improved by the presence of said lead and having substantially the same mechanical properties and response to heat treatment as a steel of the same composition with a lead content of less than .03 per cent, the remainder of the steel being essentially iron and said steel being predominantly nonaustenitic.

OSCAR E. HARDER.