April 20, 1943. A. P. GAGNEBIN 2,316,948

ALUMINUM-TREATED CAST STEELS

Filed July 17, 1941

Fig. 1.

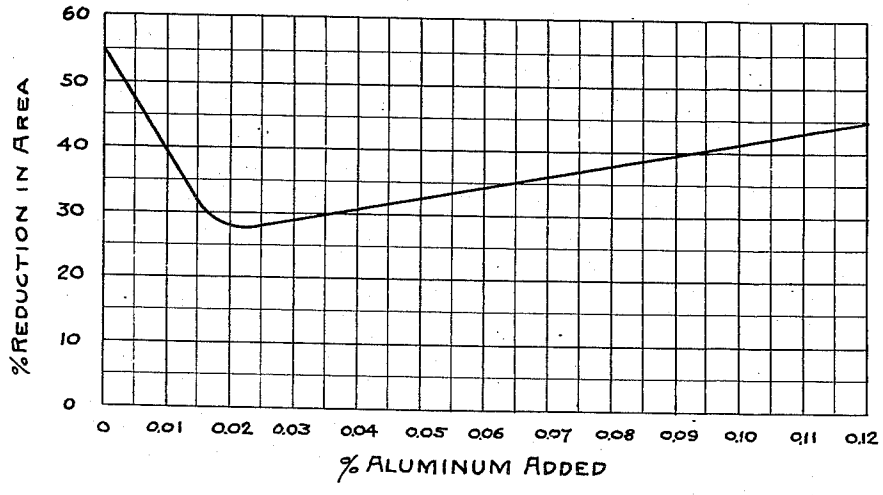
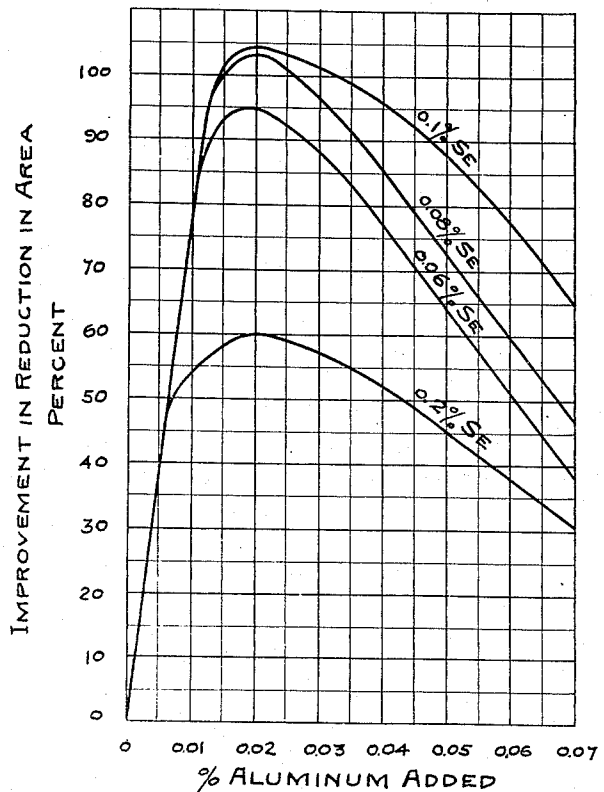


Fig. 2.



INVENTOR.
ALBERT P. GAGNEBIN
BY A. P. Gagnebin
ATTORNEY

Patented Apr. 20, 1943 2,316,948

UNITED STATES PATENT OFFICE

2,316,948

ALUMINUM-TREATED CAST STEEL

Albert Paul Gagnebin, Fair Haven, N. J., assignor to The International Nickel Company, Inc., New York, N. Y., a corporation of Delaware

Application July 17, 1941, Serial No. 402,752
In Canada May 18, 1940

12 Claims. (Cl. 75—58)

The present invention relates to steels and to a method of producing steel possessing an improved combination of properties, and more particularly to aluminum-treated cast steels and to a method of consistently producing fine grained aluminum-treated cast steels possessing good ductility combined with soundness of metal.

It is well known that in the industrial production of cast steels of similar composition and heat treatment, castings were often defective because of excessive porosity and/or because of low ductility. Heats of similar composition sometimes yielded cast steel which possessed low ductility when solid (and properly heat treated), while at other times the metal possessed good ductility but tended to be unsound. This erratic production of cast steels resulted in products which were sometimes defective and sometimes satisfactory, but which could not be consistently duplicated. The production of good steel castings was an art requiring considerable skill and good fortune in order to obtain metal which did not possess the above mentioned shortcomings and which were characterized by freedom from porosity combined with good ductility. The properties of the resulting castings appeared to be influenced by numerous variables, including the type of charge used, the type of furnace used, the amount of boil, the furnace conditions, the slag, the amount and kind of deoxidants used, and many others which those skilled in the art could not control to consistently produce castings which were sound and possessed good ductility and other satisfactory properties required by the trade.

In view of the erratic production of cast steels and in view of frequent production of castings with low ductility and/or excessive porosity, those skilled in the art were aware of the vexatious nature of the problem facing the art and were diligently attempting to solve it. Many deoxidizers and degasifiers were proposed. The use of strong deoxidizers tended to promote low ductility when used in amounts sufficient to thoroughly degasify the steel. This was particularly true when attempts were made to produce castings treated with small amounts of aluminum. The use of a regular deoxidation treatment such as a manganese and silicon deoxidation also presented some problems. The biggest obstacle to the production of good quality cast steel, deoxidized in the regular manner with manganese and silicon, was the necessity for very accurate control of the iron oxide content of the molten steel. A high oxygen or oxide content often resulted in porosity, and a low oxygen or oxide content promoted low ductility. Furthermore, no sufficiently rapid method for measuring the oxygen or oxide content of a molten steel bath was known. Thus, the assurance of soundness by the use of strong deoxidizers such as aluminum and silicon promoted low ductility and the use of manganese and silicon deoxidation did not assure the production of cast steel which was consistently sound and ductile in commercial practice. The use of strong deoxidizers were sometimes considered necessary to secure freedom from subsurface porosity. Although many attempts were made to remedy the aforementioned shortcoming, none as far as I am aware, was entirely successful when put in commercial operation on an industrial scale in consistently producing satisfactory results.

I have discovered a method of producing cast steel free from the disadvantages and defects noted hereinabove which consistently makes sound steel castings having improved physical properties, e. g., high ductility, etc., and devoid of porosity and which is capable of being carried into practice satisfactorily and economically when operated on an industrial scale for the manufacture of commercial steel castings. I have also discovered that selenium and/or tellurium not only desensitize the effect of sulfur but also produce pronounced grain refinement in steels which in the absence thereof would be coarse grained. Both elements are weak deoxidizers so that it is possible to produce a partially killed fine grained steel whereas the usual grain refining elements, such as aluminum, titanium, vanadium and the like, have always been strong reducing elements or strong carbide formers or both. The term "fine grained steel" as used herein is in accordance with general metallurgical usage and means that the grain size is small after cooling through the transformation temperature, as in normalizing; other types of tests such as the McQuaid-Ehn test similarly show the grain refining effect of selenium and/or tellurium. The terms "desensitizing" or

"sulfur-desensitizing agent" as used herein refers to the ability of selenium and of tellurium to counteract or otherwise decrease the detrimental effect of sulfur upon ductility, particularly in low oxygen or oxide melts treated with aluminum and/or other strong deoxidizers. The terms also refer to the ability of selenium and of tellurium to cause the sulfur, or sulfides, to occur globularly and randomly distributed rather than in the chain-like, intergranular occurrence which is associated with low ductility in cast steels.

It is an object of the present invention to provide a method of producing deoxidized cast steel which is simple, practical and economical and which is capable of being operated consistently and successfully on an industrial scale to produce satisfactory and commercially acceptable products.

It is another object of the present invention to provide a method of manufacturing aluminum-treated cast steel whereby castings can be consistently produced not only free from porosity but also with high physical properties, especially high ductility particularly with respect to reduction of area.

It is a further object of the invention to provide a method of producing steel which consistently yields fine grained cast steels substantially free from porosity and chain-like intergranular distribution of inclusions, particularly chain-like sulfide inclusions, and which consistently produces sound cast steels wherein the sulfide inclusions are globular and randomly distributed.

The invention also provides a melting process for producing cast steels which involves a novel combination of operations and which permits the use of strong deoxidizers to thoroughly kill the steel, which produces random distribution of inclusions, particularly sulfides, and which consistently makes a sound cast steel having good ductility, etc.

The invention further provides a method of producing sound and ductile cast steels over a broader range of oxygen or oxide content in molten steel than has been possible heretofore.

It is also within the contemplation of the present invention to provide a method of desensitizing the steel to the adverse effect of sulfur and to produce fine grained cast steels possessing randomly dispersed, globular sulfides independent of the oxygen or oxide content of the molten steel and the kind of deoxidizer used.

It is further within the contemplation of the present invention to provide fine grained cast steels characterized by freedom from blowholes combined with high ductility and containing small controlled amounts of selenium and/or tellurium.

The invention also contemplates fine grained cast steels containing fractional percentages of the strong deoxidizer aluminum and small controlled amounts of selenium and/or tellurium to eliminate the adverse effect of aluminum upon the sulfide distribution which would occasion a serious loss of ductility.

The invention also contemplates fine grained cast steels containing fractional percentages of a strong deoxidizer, such as aluminum, and small controlled amounts of selenium and/or tellurium, and characterized by soundness of metal combined with high physical properties, especially high ductility.

Other objects and advantages of the invention will become apparent to those skilled in the art from the following description and the accompanying drawing in which:

Fig. 1 is a graph showing the effect of aluminum on the ductility of cast steel; and

Fig. 2 is a graph showing the improvement in ductility obtained in aluminum treated cast steel in accordance with the present invention.

In general, the present invention involves a novel combination of operations which comprises establishing or producing a molten mass of steel or ferrous alloy in the customary manner but without regard to the accurate oxygen or oxide control which has been required heretofore, treating said molten mass of steel, for example, in the ladle, with about 0.01% to about 0.07% or 0.08% aluminum, in elemental or alloy form and with about 0.05% to about 0.6% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium, and casting the molten steel thus treated whereby aluminum treated cast steels are consistently produced which posses improved ductility regardless of the oxide content of the steel. I have discovered that small but effective amounts of selenium and tellurium have a powerful desensitizing effect on the sulfur present in the steel and promote high ductility in the final cast steel despite the use of aluminum. Heretofore it was believed that selenium and/or tellurium, like sulfur, produced inclusions which caused degradation of mechanical properties and that if co-present their effect would be additive so that the addition of selenium and/or tellurium to a steel containing sulfur would further lower its ductility. I have made the astonishing discovery that quite the reverse is true and that the addition of selenium and/or tellurium to steel has the remarkable effect of rendering sulfur quite innocuous and that selenium and/or tellurium behave like oxygen in coalescing sulfides and make it possible to produce a cast steel of very high ductility despite the presence of sulfur and the use of aluminum. I have also made the astonishing discovery that selenium and tellurium act as grain refiners thereby further improving the properties of the cast steels.

At least about 0.05% of selenium and/or tellurium appears to be required in order to obtain appreciable beneficial effect in aluminum-treated steels. In general, as the sulfur-content increases above normal values, i. e., above about 0.05%, the minimum selenium and/or tellurium content required to obtain a beneficial effect should also be increased accordingly, and, preferably, the manganese content should also be increased.

Low ductility is consistently associated with intergranular, chain-like sulfides while good ductility is obtained when the sulfides are globular and randomly dispersed. The type of sulfide inclusion is normally related to the oxygen or iron oxide content of the steel, intergranular sulfides being obtained with low oxygen and iron oxide contents and randomly distributed sulfides being characteristic of high oxygen and iron oxide contents. A characteristic and consistent relationship exists between low ductility and intergranular sulfides. Intergranular sulfide condition may occur with any melting process, including the acid electric, basic electric and basic open hearth processes. A relatively high oxygen or oxide content has been required for good fluidity and ductility but unfortunately this frequently led to excessive porosity in the casting. Porosity may develop because of insufficient deoxidation prior to casting. Low ductility will result because of

the production of chain sulfides due to the absence of sufficient oxygen in the melt promoted by reducing conditions during melting, by the use of strong deoxidizers, etc. The desire for soundness, a primary requisite of good metal, has led to the use of strong deoxidizers such as aluminum, especially in converter and acid electric steel. It has been noted that aluminum-killed steels possess low ductility. Aluminum is an excellent deoxidizer, for example in amounts of 0.01% to 0.07% or 0.08% or more, which assures soundness in cast steels but so lowers the oxygen content as to cause the sulfur to precipitate intergranularly and results in low ductility when cast. Its normal use is precluded in cast steels, particularly alloy cast steels, with high ductility requirements. In some instances, small amounts of aluminum are even more detrimental than larger amounts. Thus, it has been observed that additions of about 0.02% aluminum appears to lower the ductility of cast steels to lower levels than do smaller or larger amounts. Fig. 1 is a graph depicting the average shape of a curve showing the effect of aluminum additions on the reduction of area and plotted from data obtained on nickel-manganese cast steels containing about 0.3% carbon, 1.5% nickel, 1.5% manganese, 0.35% silicon, 0.035% sulfur, 0.03% phosphorus, and treated with various amounts of aluminum. The injurious effect of aluminum on the ductility of the cast steel as indicated by the reduction in area is brought out by the curve, particularly for aluminum additions within the range of about 0.01% to 0.07% or 0.08%. Small additions of aluminum of the order of about 0.015% to 0.03 or 0.04% cause particularly sharp losses in ductility in cast steel while larger quantities up to about 0.1% are also detrimental and the ductility never reaches that of cast steel not treated with aluminum. Sims and Dahle in Transactions of American Foundrymen's Association, volume 38, 1938, page 76, presented data for plain carbon cast steel which showed precisely the same effect. The present invention enables the art to use strong deoxidizers such as aluminum and the like in cast steels with none of its detrimental effects, such as low ductility. Silicon, a fairly strong deoxidizer, also promotes low ductility and intergranular sulfides when used in amounts sufficient to completely deoxidize the steel and assure sound metal when cast. I have found that manganese appears to be an inadequate desulfurizer under reducing conditions as it forms sulfides that appear in the grain boundaries.

Selenium and/or tellurium are able to nullify the detrimental effect of sulfur, or sulfides, apparently by coalescing the sulfides, particularly in an aluminum-treated or low oxygen or oxide steel, to produce globular randomly dispersed sulfides and high ductility in the final cast steel instead of the intergranular, chain-like sulfides and low ductility normally obtained in aluminum-treated low oxygen or completely deoxidized steels. Selenium and tellurium have two other useful and unexpected attributes in that they are mild deoxidizers and that they refine the normalized and McQuaid-Ehn grain size of the steel. The average McQuaid-Ehn grain size of selenium and/or tellurium treated steels is about No. 6 to 7, although some No. 4 and No. 5 grains have been observed occasionally. Usually, over about 50% of the selenium and/or tellurium remains in the final product, although in one instance a recovery as low as about 10% was observed. Under certain conditions substantially full recovery may be obtained in the product. Thus, where about 0.1% selenium was added to one steel, upon analysis 0.09% remained in the product. In general, the recoveries will depend upon many factors, including the state of oxidation of the molten metal, the efficiency of the method of addition, for example the form of the addition material or the thoroughness with which the material is incorporated below the surface of the molten metal, the holding time before casting, etc.

It has been found that the present invention is particularly beneficial in the treatment of steels subjected to deoxidation with a powerful deoxidizer such as aluminum in amounts of about 0.01% to about 0.07%, particularly about 0.015% to 0.03% or 0.04%, in conjunction with the sulfur-desensitizing treatment with selenium and/or tellurium in amounts of about 0.05% to 0.6%, preferably about 0.05% to 0.2%, for example, about 0.1%. Table I lists several nickel-manganese steels and the various treatments to which portions of the heats were subjected. Table II gives the properties of the resulting steels and sets forth the improvement in reduction in area, in percent improvement, compared with the reduction in area of the same aluminum-treated steel not treated with selenium and/or tellurium as plotted in Fig. 1. The improvement in reduction of area of the high sulfur steel, i. e., the 0.07% sulfur steel, is in comparison to the reduction of area of the same steel treated with aluminum but without selenium or tellurium (steel No. 12). All steels were subjected to treatment with aluminum, a powerful deoxidizer, prior to treatment in accordance with the present invention. As pointed out hereinbefore, treatment with aluminum has been considered detrimental where high ductility was required, and small amounts of the order of 0.02% are frequently more detrimental than larger amounts. Steels Nos. 2 to 11 and 14 which were treated in accordance with the present invention all showed a notable improvement in reduction in area and/or elongation, particularly the former, compared with the properties of the same steels after treatment with aluminum alone as illustrated in Fig. 1 and by steel No. 12 or aluminum and insufficient amounts of selenium as illustrated by high sulfur steel No. 13. It will be noted that steels Nos. 12 to 14 contained much more than the usual amount of sulfur found in steel and illustrate the effectiveness of the present invention in desensitizing sulfur or sulfides.

Table I

Composition: 1.5% Ni, 1.5% Mn, 0.4% Si

Steel No.	C	S	Treatment of molten steel [1]
	Percent	*Percent*	
1	0.30	0.035	0.1% Se.
2	0.3	0.035	0.02% Al, then 0.06% Se.
3	0.3	0.041	0.06% Al, then 0.06% Se.
4	0.3	0.035	0.02% Al, then 0.08% Se.
5	0.3	0.041	0.06% Al, then 0.08% Se.
6	0.3	0.035	0.02% Al, then 0.1% Se.
7	0.3	0.041	0.06% Al, then 0.1% Se.
8	0.3	0.035	0.12% Al, then 0.1% Se.
9	0.3	0.035	0.02% Al, then 0.2% Se.
10	0.3	0.035	0.06% Al, then 0.2% Se.
11	0.3	0.035	0.10% Al, then 0.2% Se.
12	0.25	0.07	0.06% Al.
13	0.25	0.07	0.06% Al, then 0.05% Se.
14	0.25	0.07	0.06% Al, then 0.1% Se.

[1] Percentages given are amounts added.

Table II

Heat treatment: Normalized and drawn

Steel No.	Mechanical properties					
	Y. P.	T. S.	El.	R. A.	Impact	Improvement
			Percent	*Percent*		*Percent*
1	68.7	91.5	29.0	54.7	----	----
2	61.0	83.6	26.5	54.5	----	95
3	63.7	86.5	27.0	49.2	----	45
4	61.0	83.2	26.5	57.6	----	103
5	61.0	88.0	27.7	52.2	----	54
6	61.6	81.5	28.5	58.3	----	104
7	60.0	84.0	30.5	60.1	----	77
8	65.7	88.2	27.5	52.5	----	19
9	67.0	92.0	26.0	44.9	----	60
10	67.5	90.7	26.0	48.0	----	41
11	67.7	90.7	27.5	47.2	----	15
12	65.2	83.2	16.5	15.9	13.5	----
13	66.5	82.3	13.2	14.5	11	----
14	60.7	79.5	31.2	47.2	27	197

Y. P.=yield point in thousand pounds per square inch.
T. S.=tensile strength in thousand pounds per square inch.
Percent El.=percent elongation.
Percent R. A.=percent reduction in area.
Impact=Charpy inpact in foot-pounds (V notch).
Percent improvement=improvement in reduction of area, in percent.

In Fig. 2 curves have been plotted showing the approximate proportionate improvement in ductility, i. e., in reduction of area, for nickel-manganese cast steel treated in accordance with the present invention as compared to the same steel treated with aluminum but not with selenium or tellurium. A marked improvement in ductility is obtained in cast steels treated with aluminum and selenium and/or tellurium when the aluminum-treatment comprises adding about 0.01% to about 0.07% aluminum in conjunction with a sulfur-desensitizing treatment with selenium and/or tellurium.

It is to be observed that the present invention provides a method of producing aluminum-treated cast steels possessing improved ductility which comprises deoxidizing or killing the molten steel with aluminum and treating the molten steel with about 0.05% to about 0.5% or 0.6% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium and casting the thus-treated steel whereby aluminum-treated cast steel is obtained having improved ductility over a similar steel treated with aluminum alone. Particularly improved results are obtained when the aluminum-treatment comprises killing the steel with about 0.01% to about 0.07% aluminum. It is preferred to treat the molten steel with about 0.06% to about 0.15% or 0.2% selenium and/or tellurium. Very satisfactory results have been obtained by deoxidizing the steel with about 0.015% to 0.04% aluminum and about 0.08% to 0.1% selenium and/or tellurium.

Tellurium, like selenium, also has a markedly beneficial effect upon the properties of cast steels treated with a powerful deoxidizer such as aluminum. Although an equal fractional percentage of selenium appears to be slightly more effective than tellurium, the addition of about 0.1% of either or both to normal steels has produced satisfactory results in actual practice. Tables III and IV contain data showing the notable improvement in ductility resulting from the treatment of aluminum-killed nickel-manganese steels with various amounts of a tellurium sulfur-desensitizing agent. Steels Nos. 17 to 21, treated in accordance with the invention, exhibit superior reduction in area and/or elongation than similar aluminum-treated steels not treated with tellurium or with insufficient amounts of tellurium. It will be noted that steels No. 15 to 17 contain more sulfur than is normally found in high grade cast steels.

Table III

Composition: 1.51% Ni; 1.43% Mn; 0.3% Si; 0.27% C

Steel No.	S	Treatment of molten metal
	Per cent	
15	0.077	Partly oxidized, then 0.06% Al added.
16	0.077	Same as 15, then 0.05% Te added.
17	0.077	Same as 15, then 0.15% Te added.
18	0.035	0.06% Al and 0.06% Te added.
19	0.035	0.06% Al and 0.1% Te added.
20	0.035	0.06% Al and 0.2% Te added.
21	0.035	0.06% Al and 0.3% Te added.

Table IV

Heat treatment: Normalized and drawn

Steel No.	Mechanical properties					
	Y. P.[1]	T. S.	El.	R. A.	Impact	Improvement
			Per cent	*Per cent*		*Per cent*
15	65.7	85.3	17.0	20.2	10	----
16	63.8	83.9	14.5	22.7	17	----
17	64.2	83.3	24.5	39.1	23	93
18	48.7	85.7	28.0	49.7	----	46
19	60.5	90.5	25.7	48.6	----	43
20	56.5	90.5	30.2	51.7	----	52
21	54.5	90.5	27.0	44.7	----	31

[1] See footnote to Table II for key to symbols.

When cast steels which possess good properties in light sections are poured into heavier sections, the properties are frequently detrimentally affected. The property most adversely affected appears to be the ductility. There is reason to believe that this may be attributed, at least in part, to poor sulfide distribution. Treatment of steels in accordance with the present invention has been found to have beneficial effect upon the ductility of steels cast in heavy sections. Tables V and VI give the treatments and the resulting properties of a nickel-manganese steel cast into heavy sections 3 inches by 5 inches by 5.5 inches. The marked beneficial effect of the selenium and/or tellurium treatment on strongly deoxidized steels cast in heavy sections is shown by comparing the properties of steel No. 22 with steel No. 23. Steel No. 22 is a nickel-manganese steel deoxidized with both silicon and manganese and with aluminum, whereas steel No. 23 is another heat of the same composition deoxidized with silicon, manganese and aluminum plus further treatment with selenium in accordance with the present invention. The recovery in reduction in area and elongation in the heavy section after the selenium treatment is very pronounced as shown in Table VI.

Table V

Composition: 1.5% Ni; 1.5% Mn; 0.3% C; 0.35% Si; 0.035% S

Steel No.	Treatment of molten metal[1]
22	Regular Si-Mn deoxidation, then 0.06% Al.
23	Regular Si-Mn deoxidation, then 0.06% Al and 0.1% Se.

[1] Percentages given are amounts added.

Table VI

Heat treatment: Double normalized and drawn

Steel No.	Mechanical properties				
	Y. P.[1]	T. S.	El.	R. A.	Improvement
			Per cent	*Per cent*	*Per cent*
22	64.2	72.1	4.5	7.4	
23	66.7	87.2	22.0	30.9	317

[1] See footnote to Table II for key to symbols.

I have discovered that increased impact values at low temperatures can be secured by applying the present invention to aluminum-containing steels, for example, a steel treated with up to about 0.07 or 0.08% aluminum.

It will be observed that the present invention provides aluminum-treated cast steels and a method of treating aluminum-treated cast steels, including plain carbon steel, alloy steels, and other iron-base alloys subject to the difficulties and disadvantages mentioned hereinbefore. Cast steels normally contain about 0.025% to about 0.05% sulfur, but steels containing 0.07% to 0.09% sulfur have also been successfully treated, and steels containing even larger quantities as high as about 0.15% sulfur will be usefully improved. Cast steels finished in accordance with the present invention can tolerate larger quantities of sulfur with better ductility than steels finished only with silicon and manganese and/or aluminum. In general, as the sulfur content increases above about 0.06% it is preferred to increase the manganese content above normal values, for example, above about 0.65%. Increased amounts of selenium or tellurium also tend to compensate for increased sulfur contents. Should the sulfur exceed the upper limit of the range normally found in steel, i. e., about 0.05% a larger amount of sulfur-desensitizing agent should be added than is normally added, as will be apparent to those skilled in the art. Steel baths containing below about 0.015% or 0.02% sulfur which can only be achieved with greater difficulty and at much higher cost, apparently do not contain sufficient sulfur to markedly affect the ductility and such steels are fairly successfully treated by prior art methods, e. g., killing with aluminum, a treatment which cannot consistently produce satisfactory results with higher sulfur contents, although the present invention may also be used in treating such low sulfur steels. Cast steels containing less than about 0.015% sulfur are comparatively rare and are not usually met with in ordinary cast steel practice. When I refer herein to "small but detrimental" amounts of sulfur I include within the scope of the expression amounts of sulfur which when present in well killed steel castings lower the ductility as compared to a casting of similar composition but containing less sulfur, or amounts which tend to produce intergranular sulfides, or amounts which when present in a steel casting will possess higher ductility when treated in accordance with the present invention than when not so treated or not otherwise specially treated to decrease the deleterious effect of the sulfur.

The cast steels contemplated by the present invention may contain various amounts of carbon, say about 0.05% to about 0.75% or even up to about 1.7%, frequently about 0.1% to about 0,6%, and usually about 0,25% to about 0.45%, and may contain various amounts of alloying elements such as nickel, chromium, manganese, silicon, molybdenum, vanadium, copper, and other strengthening elements, say from an effective percentage or 0.01% to about 7% or 9%, or more, and I desire that the amounts of these strengthening elements shall fall within the practical range within which the sulfide distribution has an important influence upon ductility. Usually the cast steels will contain incidental elements and impurities commonly present as a result of good steel making practice, for example, phosphorus, magnanese, silicon, etc., as those skilled in the art will readily understand. The iron content normally will exceed about 90% and will usually be less than about 99% or 98%. The present invention is applicable to a wide range of plain carbon cast steels and alloy cast steels containing the usual incidental elements, deoxidizing elements, and impurities. It has been found that certain special deoxidizers such as titanium or apparently zirconium impair response to the present invention and are preferably avoided or used very sparingly.

In addition to the above-mentioned elements normally found in steels, the cast steels produced in accordance with the present invention contain, in the final product, about 0.02% to about 0.5% of selenium and/or tellurium, preferably about 0.05% to about 0.1%. The aluminum-treated steels contemplated by the present invention may contain in the final product from a small but effective amount, say 0.003%, up to about 0.07% of aluminum and the like, for example about 0.01% to about 0.05% aluminum. In commercial practice, aluminum-treated steels are usually defined by the amounts of aluminum added in finally treating the molten steel rather than by the residual amounts of aluminum in the final product. Furthermore, I have found that the present invention is described more practicably by the amounts of aluminum added in finally treating the molten steel and that the improvement obtained in accordance with the present invention is related to the amounts of aluminum added to molten steel which in the final stages is in the conventional slightly oxidized condition or which is in an unoxidized condition such as results from final processing under reducing conditions. Of course, it will be apparent that if the bath is excessively oxidized larger amounts of aluminum may be used in order not only to finally deoxidize the molten steel to remove the last traces of oxygen but also to reduce the oxygen to that usually present in the molten steel at the time aluminum is added and which is usually accomplished by a silicon-manganese deoxidation. The present invention is concerned with aluminum-killed cast steels. By "aluminum-killed" cast steels I mean steels treated in the final stage with amounts of aluminum sufficient to at least substantially deoxidize the molten steel. The injurious effects of aluminum which are overcome by the present invention are particularly pronounced when sufficient aluminum is added to at least substantially deoxidize the steel and to leave not more than about 0.07% aluminum or, preferably, not more than the amount resulting from adding about 0.07% or 0.08% aluminum in the final cast product.

In order that those skilled in the art may have a better understanding of the present invention, illustrative examples of steels to which the pres-

ent invention is applicable are given in Table VII. Plain carbon steel, nickel steel, nickel-manganese steels, nickel-molybdenum steels, nickel-chromium steel, nickel-vanadium steel, nickel-silicon steels and copper steel are given as examples.

Table VII

Composition				
C	Mn	Si	Ni	Others
Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
0.3	0.75	0.35	--------	--------
0.1	0.65	0.35	3.6	--------
0.27	1.4	0.3	1.5	--------
0.4	1.5	0.35	1.5	--------
0.3	1.5	0.35	1.5	--------
0.3	1.25	0.25	1.35	--------
0.22	0.9	1.2	1.5	--------
0.28	0.75	0.35	1.75	0.25 Mo
0.35	0.75	0.35	1.5	0.75 Cr
0.3	0.75	0.35	1.5	0.1 V
0.55	0.5	0.8	----	1.75 Cu

In carrying the invention into practice the selenium or tellurium may be added in the elemental form or as an alloy, for example as 50% ferro-selenium or nickel-selenium. If pure or elemental selenium be used, it should be forced into the molten metal because it volatilizes so readily. Ferro-selenium is much the better form for direct addition because it dissolves readily when in contact with the melt and apparently with lower loss than when added in elemental form.

While the invention has been described with particular reference to steel castings and products which are cast substantially in the shape or size in which they are to be ultimately used, it is applicable to centrifugal castings, rolls and cast gear blanks and other products whose properties reflect the properties of the metal as cast. It is to be observed that the present invention is applicable to a wide variety or articles of manufacture made from steel castings well known to those skilled in the art. For example, the invention is applicable to such articles as pressure castings made of ferritic cast steels. Illustrative pressure castings include valve bodies and the like, such as cast valve bodies, cast valves, cast casings and fittings, cast turbine nozzles and diaphragms, cast turbine casings, cast pressure vessels and similar cast articles subject to pressure and/or to thermal or mechanical shock.

The present application is a continuation-in-part of my co-pending application Serial No. 340,839, filed on June 15, 1940.

Although the present invention has been described in conjunction with preferred embodiments, it is understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Thus when I use the term "balance substantially all iron" I do not exclude minor constituents and impurities which may be present in such amounts as occur in commercial practice or in amounts not adversely affecting the desired properties of the product. Such variations and modifications apparent to those skilled in the art are considered to be within the purview and scope of the appended claims.

I claim:

1. A method of decreasing the deleterious effect of aluminum upon the ductility of cast steels which comprises deoxidizing a molten mass of steel with aluminum, treating the molten mass of steel with about 0.05% to 0.6% of at least one desensitizing agent from the group consisting of selenium and tellurium, and casting the thus-treated molten steel whereby aluminum-treated cast steels characterized by improved ductility are produced.

2. A method of producing ductile aluminum-treated cast steels which comprises killing a molten mass of steel containing sulfur with aluminum in amounts up to 0.07% and with a small but effective amount up to about 0.6% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium, and casting the thus-treated molten steel whereby aluminum-treated cast steels characterized by improved ductility are produced.

3. A method of decreasing the deleterious effect of aluminum upon the ductility of sulfur-containing cast steels which comprises treating a molten mass of steel containing at least about 0.015% sulfur with about 0.01% to 0.07% aluminum and about 0.05% to 0.6% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium, and casting the thus-treated molten steel whereby aluminum-treated cast steels characterized by improved ductility are produced.

4. A method of producing ductile aluminum-treated cast steels which comprises establishing a molten mass of steel containing at least 0.015% sulfur, deoxidizing said molten mass with a fractional percentage of aluminum, treating said molten mass with about 0.05% to 0.6% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium, and casting the thus-treated molten steel whereby aluminum-treated cast steels characterized by improved ductility are produced.

5. A method of producing ductile aluminum-treated cast steels containing randomly distributed globular sulfide inclusions which comprises establishing a molten mass of steel containing small but detrimental amounts up to about 0.15% of sulphur, treating said molten mass with about 0.01% to 0.07% aluminum and about 0.05% to 0.6% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium, and casting the thus-treated molten steel whereby ductile aluminum-treated cast steels containing randomly distributed globular sulfide inclusions are obtained.

6. A method of producing ductile aluminum-treated cast steels which comprises treating a molten mass of steel containing about 0.02% to 0.05% of sulfur with about 0.01% to 0.07% aluminum and about 0.06% to 0.2% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium, and casting the thus-treated molten steel whereby ductile aluminum-treated cast steels are produced.

7. A method of consistently producing ductile aluminum-treated cast steels which comprises establishing a molten mass of steel containing small but detrimental amounts up to about 0.08% sulfur, treating said molten mass with about 0.01% to 0.07% aluminum and with a small but effective amount up to about 0.2% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium, and casting the thus-treated molten steel whereby ductile aluminum-treated cast steels are produced.

8. A ductile aluminum-treated cast steel containing small amounts up to 0.15% sulfur, small but effective amounts up to 1.7% carbon, a small

amount up to about 9% of at least one alloying element, aluminum in the amount resulting from adding about 0.01% to 0.07% aluminum, a small but effective amount up to about 0.5% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium, and the balance substantially all iron.

9. A ductile aluminum-treated cast steel characterized by randomly distributed globular sulfide inclusions which contains about 0.015% to 0.08% sulfur, about 0.05% to 0.75% carbon, up to about 9% of alloying elements, a small amount up to about 0.07% of aluminum, about 0.02% to 0.5% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium, and the balance substantially all iron.

10. As an article of manufacture, a ductile aluminum-killed cast steel containing sulfur up to about 0.05%, carbon up to 0.6%, a small amount up to about 9% of alloying elements, aluminum in an amount resulting from adding about 0.01% to 0.07% aluminum, about 0.02% to 0.2% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium, and the balance substantially all iron.

11. As an article of manufacture, a ductile aluminum-treated steel casting containing a small amount of sulfur, about 0.05% to 1.7% carbon, up to about 9% of alloying elements, aluminum in an amount up to about 0.07%, about 0.02% to 0.5% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium and the balance substantially all iron.

12. As an article of manufacture, a casting made of aluminum-treated steel characterized by a microstructure comprising globular, randomly distributed sulfide inclusions and containing sulfur up to about 0.15%, a small but effective amount up to about 1.7% carbon, aluminum in an amount resulting from adding about 0.01% to 0.07% aluminum, a small but effective amount up to about 0.5% of at least one sulfur-desensitizing agent from the group consisting of selenium and tellurium, said casting being characterized by soundness of metal and improved ductility compared to a similar casting not containing said sulfur-desensitizing agent.

ALBERT PAUL GAGNEBIN.