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STAINLESS STEELS CONTAINING BORON

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My application for patent is a continuation-in-part of my co-pending application Serial No. 238,593, filed July 25, 1951, now abandoned, and entitled Melting Process and Product, and the invention relates to metals and alloys having satisfactory hot-working qualities, and to the hot-worked products fashioned of the same, as well as to a method of producing these metals and alloys.

One object of my invention is to provide a method of producing metals and alloys, such as stainless steel, and various hot-worked products of the same, which method imparts to the metals and alloys qualities which effect appreciable savings in cost of processing or conversion and serve to minimize conversion loss of metal.

Another object is to provide metals and alloys, such as stainless steels, of improved ingot surface and better quality of metal, and displaying improved hot-ductility, and as well, possessing improved hot-workability, including hot-pressing, extrusion, hot-forging, hot-rolling and even hot-piercing, all with substantial enhancement in recovery of metal from the ingot and with appreciable reduction in necessity for intermediate heating during processing to final, finish dimensions, wherein grinding required between intermediate heatings is appreciably reduced, surface tearing and checking are materially decreased, and scrapping of the metal as rejects is minimized.

Still another object is the provision of hot-rolled high-alloy stainless steel plate, sheet, strip, structural shapes, bars, rods and wire at minimum conversion cost and maximum metal recovery, all in the substantial absence of severe hot-checking in hot-working the same, as well as hot-pierced seamless tubes of good quality.

Yet another object is the provision of certain high-alloy stainless steel forgings which previously, because of hot-working difficulties, were available only as castings and other high-alloy stainless steel hot-rolled products which previously were only available as castings or forgings, and still others in the form of seamless tubing which were available previously only as cast or fabricated products.

Other objects of my invention in part will be obvious and in part pointed out during the course of the following description.

My invention accordingly consists in the combination of elements and composition of ingredients, and in the several operational steps and the relation of each of the same to one or more of the others as described herein, all as particularly set forth in the claims at the end of this specification.

To permit a more thorough understanding of certain aspects of my invention, it is advantageous at this point to note that the high chromium alloys and stainless steels of the high-alloy grades inherently possess many highly advantageous properties. These high-alloy compositions contain high percentages of chromium and usually a substantial quality of nickel. Increasing attention has been given over a period of years to the production of these compositions, due largely to the unique and advantageous characteristics thereof.

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My invention is particularly directed to those alloys with chromium content ranging from say about 10% to about 35% or more by weight, with or without nickel up to about 50%. It is contemplated that certain other alloying additives may be present, illustratively carbon up to 1.50%, silicon up to 5.0%, manganese up to 20%, molybdenum and/or tungsten up to 10.0%, cobalt up to 50%, any one or more of the ingredients vanadium, zirconium, tantalum, columbium, and titanium up to 5.0%, copper up to 10.0%, aluminum up to 5.0%, nitrogen up to 0.50%, phosphorus and/or sulfur up to 0.50% and the remainder iron.

Many of these alloys, especially those of high-alloy content, however despite their admirable qualities displayed in service, characteristically have been found to be difficult to hot-work, displaying only limited ductility, and being highly resistant to successful piercing, quiet resistant to successful hot-rolling and some being difficult to forge. In the austenitic stainless steels these difficulties are somewhat unexpected, since it was anticipated that these alloys would display fairly good hot-ductility.

Thus, it developed in the prior art practice that when it was required to hot-work these alloys, for example the high-alloy stainless steels, they were first subjected to careful and prolonged preliminary heating and soaking, before being pierced, hot-rolled, or forged, as the case may have been. Despite these preliminary precautions, however, the highly alloyed metal was found to tear or check severely after but slight reduction. With this the metal had to be set off the mill and ground down to good surface, or scrapped in whole or in part. Removal of surface defects was both costly and time-consuming. Intermediate anneal, subsequent to grinding, was followed by further conversion. Frequently two or three such intermediate steps of grinding and annealing were required before final reduction to finished dimension was had.

Thus it will readily be seen that low or erratic yields have heretofore been considered inevitable, with considerable loss in time, in plant investment, and in labor cost. Moreover, a high percentage of rejects were encountered, with attendant scrapping of substantial quantities of this highly critical and expensive alloy metal, this due to the metal checking or tearing beyond possible reconditioning. And the foregoing has direct applicability, not only to the production of stainless steel and other chromium alloy tubing but to the processing of ingots into plate, sheet or strip, or the processing of billets to bars, rods and wire, and even to the production of forgings in many of the highly alloyed grades.

An important object of my invention, therefore, is to overcome in substantial measure, the difficulties heretofore confronting the art, and provide stainless steel and other alloys and a method of making the same whereby the hot-working qualities of the alloys, particularly the hot-ductility, are importantly improved so that the metal readily lends itself to hot-forging and hot-rolling in the substantial absence of intermediate anneal, and some grades even to hot-piercing, all with important savings in processing time, and minimizing loss of metal as by grinding and by splitting, tearing and the like in processing.

Now I have found that upon the addition of a very small quantity of a suitable boron-containing material to the alloy melt, either in the furnace in finishing the metal, or preferably to the ladle, important and highly desirable advantages are obtained, substantially minimizing the detrimental qualities just discussed. Particularly good results are had where the boron-containing ingredient is added along with or in the presence of a deoxidizing agent. I find that for satisfactory results this boron-containing material can be present in the alloy only in

quantity just sufficient to achieve the qualities hereinafter described, at the same time falling safely below that highly critical concentration where embrittlement of the metal is observed, sufficient to destroy all usefulness thereof. For, with but slight excess of boron, the metal will fall to pieces during working. Properly employed, preferably along with a deoxidizing agent, highly important increase is observed in hot-ductility and other hot-working properties of the metal.

As an illustrative example of the practice of my invention, I produce high-alloy grades of stainless steel according to the practice of any one or more of a number of well-known and presently conventional methods. Illustratively, and not by limitation, I frequently employ the electric arc furnacing techniques disclosed by Field (U. S. Letters Patent 1,925,182) and by Arness (U. S. Letters Patent 1,954,400).

At an earlier point I have outlined certain composition ranges within which my invention has especial application giving rise to highly advantageous results. Within this range it is recognized that the highly alloyed grades of stainless steel, of which type 310 (25 chromium-20 nickel), type 314 (25 chromium-20 nickel-2 silicon), type 309 (25 chromium-12 nickel), type 308 (20 chromium-10 nickel), type 307 (20 chromium-10 nickel-4 manganese), type 316 (18 chromium-12 nickel-2 molybdenum), type 317 (18 chromium-12 nickel-3 molybdenum), type 330, (15 chromium-30 nickel), 17-7 PH (17 chromium-7 nickel-1 aluminum), and 20-28-3-3 (20 chromium-28 nickel-3 molybdenum-3 copper) are illustrative and are difficult to hot-work, either by rolling or by forging; piercing of these grades to form seamless tubing is particularly difficult. By example, where ingots are rolled or forged to blooms or billets, as for later rolling into bars or wire, a common practice is to cast a ten inch or thirteen inch ingot which, after proper heating and soaking, is rolled on a suitable mill, such as a 28"-20" fixed-pass rolling mill, to billet which is 3" or 4" square. In rolling highly-alloyed grades such as type 310, it is common experience that when the ingot has been partly reduced in size, say to 6" square, the metal will start to tear or check severely. As previously noted, such material thereupon must be set off the mill, subjected to expensive grinding to remove surface defects, then reheated and re-rolled, or else scrapped in whole or in part. Often the material will hot-check or hot-tear in re-rolling, with accompanying necessity for further grinding and reheating, all with high grinding losses. Not infrequently a substantial amount of material requires scrapping because it is torn too badly to be reconditioned.

A somewhat similar situation exists where larger ingots are rolled into slabs or sheet bar preparatory to final rolling to plate, sheet or strip. For in this case, illustratively, ingots 17 x 42 inches or 16 x 35 inches are rolled to slabs 2½ inches thick. Here again, the grades of metal which do not hot-work satisfactorily may have to be set off the mill at much greater thicknesses than desired; ground to remove surface flaws, and reheated. Scale formed during reheating must first be removed, and the metal thereupon subjected to further passes. Several re-rollings may be required before the desired final dimensions are achieved.

It is to these high alloy steels that the minute boron addition is introduced. While it is within the purview of my invention that the boron addition be in the form of various boron-containing materials such as ferro-boron, or other boron pre-alloys such as silicon-boron, manganese-boron, aluminum-boron with and without silicon, manganese, vanadium or zirconium; or boron oxides; dehydrated borates such as boric acid and pyrobor; I find it satisfactory to add it as rasorite or other naturally occurring borate such as borax. Rasorite is a boron-containing material, also known as kernite, having the chemical formula $\text{Na}_2\text{O} \cdot 2\text{B}_2\text{O}_3 \cdot 4\text{H}_2\text{O}$. Closely related to borax ($\text{Na}_2\text{O} \cdot 2\text{B}_2\text{O}_3 \cdot 10\text{H}_2\text{O}$) resorite differs therefrom only in

the quantity of water of hydration. As found it may contain small quantities of chlorides, carbonates and sulphates of sodium and calcium, as well as clay. A chemical analysis of rasorite concentrate typically shows the following:

	Percent
Loss on ignition-----	27.9
SiO_2 -----	3.2
Al_2O_3 -----	1.5
MgO -----	1.9
Na_2CO_3 -----	5.9
$\text{Na}_2\text{B}_4\text{O}_7$ -----	55.8

Containing 8.8% boron by calculation, the rasorite is received as a concentrate and is a grayish, white-colored granular material of about 10 to 20 mesh size.

I find that the quantity of boron which advantageously may be included in the melt is highly critical, this varying with the total alloy content. It is imperative that the boron content shall not exceed 0.008% for type 310, having a total alloy content of about 45%, this being scaled down to a maximum figure of 0.004% for type 304 (19 chromium-9 nickel) having a total alloy content of about 28%; the minimum boron content being about 0.00005% for all of the alloys and the maximum being increased somewhat above the 0.008% figure for alloys having total alloy contents substantially higher than in the type 310. For should the alloys be made without a boron addition the desired good qualities will not be imparted to the metal, while should the boron exceed the upper limit of the range the metal is completely ruined, as by embrittlement and other hot-short properties, rendering it impossible to work. And in addition, such metal is subject to objectionable carbide precipitation which renders it wholly unfit for many classes of service. In these types best results are had where the amount of contained boron in the steel is about 0.0001% to 0.0008%. For the extra low carbon grades of stainless steel, such as types 304L and 316L (carbon contents of 0.03% maximum but the remainder of the analyses the same as for the standard grades as given above) the desired boron content is 0.0003% to 0.0008%.

Following my usual practice I add the boron-containing substance, illustratively, rasorite, direct to the ladle, preferably along with a strong deoxidizing agent selected, for example, from the group consisting of ferro-titanium, calcium-silicon, aluminum, ferro-silicon, and silicon-manganese-aluminum alloy. These deoxidizers are selected from the group which perform the function of combining with the oxygen in the metal. Other deoxidizers which are satisfactory include aluminum-silicon, chromium-silicon, manganese-silicon, magnesium-silicon, magnesium-manganese-silicon, ferro-zirconium, silicon-zirconium, nickel-zirconium and calcium metal.

In making the preferred additions to the metal, rasorite is in the form of a sand, while the ferro-titanium is in the form of lumps up to about 1½ to 2-inch, and the calcium-silicon is in lumps of about ½ inch to ¾ inch size. These ingredients are added one after the other, it being immaterial which is added first, or they may be mixed and added as briquettes if desired. Preferably it is added to the ladle, but if added to the furnace the addition is poked through the slag with an iron rod. The rasorite and the calcium-silicon melt before reaching the top of the bath. The ferro-titanium, however, sinks into the bath. These ingredients may also be added to the ingot mold.

The proportions per ton of stainless steel to be produced are 4 pounds of ferro-titanium, 2 pounds of calcium-silicon and 1½ pounds of rasorite, this for the type 310 steel. It is to be noted as indicated above that for other types of stainless steel as the alloy content decreases the permissible amount of boron decreases, thus the rasorite requirement is correspondingly decreased. The amount of ferro-titanium employed, however, remains the same.

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Illustratively, where 1½ pounds of rasorite are used for the type 310 (25 chromium-20 nickel), for the type 309 (25 chromium-12 nickel) 1¼ pounds of rasorite are employed. Similarly for the type 308 (20 chromium-10 nickel) and for type 316 (18 chromium-12 nickel-2 molybdenum) one pound of rasorite is employed. And for type 304 (19 chromium-9 nickel) three-quarters of a pound is employed per ton of steel.

While I do not know exactly the reason why the boron imparts these advantageous properties to the metal, I find the boron addition, particularly in combination with the strong deoxidizing agent, imparts greatly improved hot-ductility and greatly improved hot-working properties.

So that the general nature of my invention as heretofore disclosed may be more particularly understood, I now disclose certain specific applications thereof in the following table:

TABLE I(a)

The steel

Heat No.	Type	C	Cr	Ni	Additions to Melt	Ingot Size
101053	308	.044	20.59	9.92	4#/T FeTi, 2#/T CaSi only.	13" square.
101050	308	.046	20.32	10.02	4#/T FeTi, 2#/T CaSi, 1.25#/T rasorite.	13" square.
30061	310	.119	26.68	22.71	3#/T FeTi only	10" square.
11219	310	.105	26.50	22.05	3#/T FeTi, 1.68#/T rasorite.	10" square.

TABLE I(b)

Hot-rolling tests

Heat No.	Total Heating Time, hrs.	Rolling Temperature, ° F.	Rolling Results	Wt. Scrapped Because of Checks, #	Final Percent Yld. of Ground, 4" Sq. Blooms
101053	20¾	2,200	13" rolled to 6" Sq., heavily checked; 6" Sq. rolled to 4" Sq., slight check.	95	72.7
101050	20½	2,200	13" rolled directly to 4" Sq. with excellent surface.	Nil	77.9
30061	32¾	2,300	10" Sq. rolled to 6" Sq., heavily checked; 6" Sq. rolled to 5" Sq., heavily checked; 5" Sq. rolled to 4" Sq., heavily checked.	2,503	57.5
11219	60¾	2,300	10" Sq. rolled directly to 4" Sq. with excellent surface.	Nil	79.0

Considering for a moment the test data pertaining to heat No. 101050 (as compared with heat No. 101053), it is apparent that by adding to the melt only 1¼ pounds of rasorite per ton of type 308 steel (20 chromium-10 nickel) substantially all loss to scrap because of surface-checking is avoided, and that as well, no intermediate anneal is required and a 5.2% increase in yield is achieved in the final metal carried into the 4-inch billet, all with radically improved metal surface.

Similarly, upon comparison of heat 30061 with heat 11219, I find that the small boron addition to type 310 (25 chromium-20 nickel) obviates the necessity for the intermediate anneals, brings about appreciable reduction in working time and in labor costs, and gives a vastly improved surface to the finished metal. As well, a saving is achieved of something over 1¼ tons in loss of metal heretofore scrapped because of checking, together with a saving of some 21.5% in final yield from the ingot.

In Table II I give the results of further tests according to the practice of my invention, at higher rolling temperatures, which establish the advantageous results attending upon my new practice:

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TABLE II(a)

The steel

Heat No.	Type	C	Cr	Ni		
31065	310	.067	24.50	20.45	FeTi 4#/T, CaSi 2#/T.	11-16" x 35" 11-17" x 42"
31073	310	.063	24.39	19.48	FeTi 4#/T, CaSi 2#/T, Rasorite 1, 60#/T.	11-16" x 35" 11-17" x 42"

TABLE II(b)

Hot-rolling tests

Heat No.	Rolling Temperature, ° F.	Rolling Results	Total Grinding Loss, percent	Net Yld., percent of Ground Slabs
31065	2,380	Both ingots rolled to 5" slabs, heavy check; 5" slabs rolled to 2½" slabs, moderate check.	7.3	75.6
31073	2,380	Both ingots rolled directly to 2½" slabs, very light edge check.	5.3	80.0

Table II(a) (b) establishes the advantageous results had in hot-rolling large ingots to 2½" slabs. Illustratively, the necessity for an intermediate anneal is eliminated, and substantial improvement in surface detail is had. Grinding loss is appreciably reduced, along with appreciable increase in the net yield of metal carried over from ingot to finished slab.

I have emphasized the importance and great improvement in hot-ductility inherent in my new steel. This affords an accelerated test for hot-workability and can best be evidenced by a hot-bending test wherein a series of 90° bends are rapidly imparted to the metal under high temperature condition until fractured. In this connection it is important, for accuracy of test data, that the metal be first brought to a predetermined high temperature, then quickly withdrawn from the furnace, placed in a vise, and rapidly bent back and forth through 90° bends until fracture occurs; hot-ductility, and hot-workability, are gauged by the comparative number of bends.

Illustratively, the 310 type steel of heats Nos. 31073 and 31065 were shaped into small 3-inch square test ingots, forged to 1-inch square test bars and then machined to a ¾ inch round specimens. These round specimens were heated in a laboratory furnace to 2200° F., quickly withdrawn, placed in a vise, and quickly bent back and forth until fracture. I found the introduction of rasorite to the melt to increase the ductility of the No. 310 type steel greatly, 49 bends as compared to 28 bends.

While in my process, as previously noted, I prefer to add to the metal rasorite and the deoxidizing agent ferro-titanium and calcium silicide, improved hot-ductility is had with other boron-contained ingredients and other deoxidizing agents as previously noted. To this end I prepared a series of type 310 (25 chromium-20 nickel) stainless steel ½-inch bar specimens and conducted a series of hot-bend tests thereon at 2300° F. While all the samples were of the fundamental 25-20 grade, five of them contained special addition agents.

Thus sample E6856 as shown in the following Table III included additions of ferro-titanium, ferro-silicon, and rasorite. Sample E6859 included an addition of ferro-boron alone, while sample E6860 included an addition of rasorite alone. Sample E6861 included additions of ferro-titanium and calcium-silicide, together with ferro-boron instead of the rasorite of sample E6856. Sample E6862 included calcium-silicide and rasorite with aluminum instead of with ferro-titanium as in sample E6856. As a standard of comparison with the variously-treated steels, two samples were made without addition agents, namely the samples E6847 and E6850.

TABLE III

Hot-bend tests on 25-20 chromium-nickel stainless steel ($\frac{1}{2}$ " diameter bars heated at 2300° F. for $\frac{1}{2}$ hour and promptly tested)

Heat No.	No. Bends	Average	Addition
E6847-----	23-22	22.5	Control—None.
E6850-----	21-24		
E6856-----	54-62	58	FeTi—CaSi—rasorite Std.
E6859-----	52-59	55.5	FeB.
E6860-----	40-40	40	Rasorite.
E6861-----	46-46	46	FeTi—CaSi—FeB.
E6862-----	32-33	32.5	Al+CaSi+rasorite.

In the heats here reported the particular addition agents, where employed, were employed in the amounts: FeTi—4#/T, CaSi—2#/T, rasorite—1 $\frac{1}{2}$ #/T, FeB—to give .004% B, Al—approx. 2#/T.

Consideration of Table III again establishes the hot-ductility of the high alloy steel to be more than doubled and in some instances increased nearly two-and-a-half times, through the inclusion of boron to the metal within the critical range which I have heretofore specified.

Actually, I find improved hot-ductility and improved hot-workability where the amount of boron introduced is very low indeed, the amount of contained boron approximating 0.00005%. Test results on hot-rolled slab ingots of the 18-8 chromium-nickel grade, with and without boron treatment, and the 19-9 chromium-nickel grade with and without boron, are given in Table IV below.

TABLE IV(a)

The steel

Heat No.	B, Per cent	C, Per cent	Cr, Percent	Ni, Per cent	Additions to Melt	Ingot Size
82668...	.0003	.10	17.64	7.42	$\frac{1}{4}$ # Borosil ¹ per ton.	17 x 42 and 16 x 29.
82515...	none	.079	17.98	9.37	No boron.....	17 x 42, 16 x 29.
82715...	.0004	.059	18.72	8.96	$\frac{1}{4}$ # Borosil per ton.	17 x 42, 16 x 29.
82518...	none	.070	18.06	9.79	No boron.....	17 x 35.

¹ Borosil is a boron-silicon ferro-alloy manufactured and sold by Ohio Ferro-Alloys Co. and contains about 3-4% boron, 40D silicon and the remainder, iron.

TABLE IV(b)

Hot-rolling tests

Heat No.	Rolling	Further Conversion
82668-----	Nine 17 x 42 ingots and five 16 x 29 ingots rolled to 2 $\frac{1}{2}$ " slabs showing little or no defects during rolling.	15-ton slabs ground with 5.5% loss. 42-ton slabs scarfed with 5.0% loss. No coil grinding required.
82515-----	Eleven 17 x 42 ingots rolled to 2 $\frac{1}{2}$ " slabs with three ingots showing light to medium scales and two ingots light check.	45-ton slabs, grinding loss 7.6%. 22 coils or 40-ton showed edge slivers, seams and scale pattern and 87% required coil grinding.
82715-----	Twenty 16 x 29 ingots rolled to sheet bar showing little or no defects.	
82518-----	Fourteen 17 x 35 ingots rolled to 2 $\frac{1}{2}$ " slabs with one ingot showing light back and all ingots with scattered light to medium scales.	52 tons of slabs ground with loss of 8%. 28 coils or 52 tons showed light to heavy slivers, seams and scales, 34% required coil grinding.

Consideration of the results given above, particularly a comparison of the heat No. 82668 having the boron addition, with the heat No. 82515 of like analysis but without the boron addition, reveals the improvements in ingot surface had in the steels with the small boron addition, in processing the slabs into coils, no grinding is required of those coils containing the boron addition as compared to the necessity for grinding 87% of the

coils containing no boron, this because of the edge slivers, seams and scale pattern.

Attention also is directed to the reduction in grinding loss and in scarfing loss, with corresponding increase in yield, which is had with the boron-containing steel. Thus, in the stainless steel with the boron, addition the yield of dressed ingots amounts to 94.5 to 95.0%, while that for the steel without the addition the yield of dressed ingots only amounts to 92.4%.

The very real improvements in the hot-rolling characteristics which are had with the boron addition are further illustrated in a series of heats of type 304-L stainless-steel (.03 maximum carbon, 18-20 chromium, 8-11 nickel). In rolling 17 x 42 and 17 x 53 slab ingots to a scheduled 3-6" thickness only one heat out of 23 in which no boron addition had been made possessed good hot rolling properties. The ingots of the others checked or tore after a reduction to some 6-11" and the partially-converted slabs required grinding or scarfing prior to further reduction. This is an expensive operation.

As contrasted with the above, I find that the heats in which boron is present in certain small amounts possess good hot-working qualities. Thus, of five heats of type 304-L stainless-steel having a boron addition of .0002%, three had good rolling characteristics and two had poor characteristics. Of twelve heats of type 304-L containing .0003% boron, eight had good characteristics, three had fair, and one had poor characteristics and of nine heats with .0004% boron, seven had good hot-rolling properties and two had properties which would be considered only fair. One heat of the series had .0005% boron and its hot-rolling properties were good.

The foregoing test data clearly shows that the yield from hot-working is definitely improved where boron is added to the steel; the amount of metal that has to be scrapped from the ingots is less, and the amount of metal recovered is correspondingly greater. And, there is a further point of extreme importance, that the ingots roll easier and therefore may be rolled a longer time with the result that to achieve a certain finished size, less re-heatings are required. In other words, with the present method and steel an ingot may be rolled down to a required size without any intermediate re-heating treatment at all, whereas before, at least one intermediate annealing was required, together with a grinding of the partially rolled material to free it of scale resulting from the anneal.

In addition to the various types of steel which I have heretofore referred to wherein the boron has given rise to substantially improved hot-working qualities there may be listed several others. Illustratively, type 446, a 27% chromium steel, is especially improved by boron additions, and when thus treated and made into large ingots, displays highly advantageous hot-rolling qualities. Moreover, type 410, a 12% chromium grade, when produced with boron inclusion within the permissible range, is found to overcome substantially all normal tendency towards detrimental star-segregation commonly found in this grade. This advantageous phenomenon is highly important in the production of turbine bladings. Quality is better, with less non-metallic inclusions.

From the foregoing it will be seen that by the addition of a boron-containing material within the prescribed limits to high-alloy stainless steel, particularly with a deoxidizing agent as well, the hot-ductility and the hot-working properties thereof are vastly improved. Where these metals heretofore could not be advantageously employed under severe hot-working conditions, being attended by necessity for many intermediate anneals with consequent severe increase in operational costs and loss of materials, accompanied by a high percentage of rejects, when my new method of steel manufacture and the resulting products are employed, important improvement was observed in the hot-working qualities of the metal. Because of the good hot-ductility many grades of high-alloy stainless steel tubing can be produced advantageously. And

other grades heretofore available in cast form may be had in the form of hot-rolled plate, sheet, strip, bars, rods and wire. Others may be had in the form of forgings.

From a practical standpoint, even in those grades previously available in hot-rolled form, important savings in time, labor and plant investment are achieved, due to the shortening of the manufacturing operation by increasing the hot-reduction had in a single operation. These savings in efficiency are accompanied by substantially minimizing the number of rejects, and in the loss of metal to grinding, all with substantial improvement in the recovery of metal therefrom.

All these, as well as many other highly practical objects and advantages attend upon the practice of my invention.

It is apparent from the foregoing that once the broad aspects of my invention are disclosed, many embodiments thereof will readily suggest themselves to those skilled in the art to which my invention relates, all falling within the scope of my disclosure. Accordingly, I desire my disclosure to be considered solely as illustrative and not by way of limitation.

I claim as my invention:

1. Alloy steel ingots of at least about 16" x 35" size and of improved hot-rolling characteristics containing chromium up to about 35%, nickel up to about 35%, up to about 20% manganese, up to about 5% silicon, up to about 50% cobalt, up to about 10% molybdenum, up to about 10% copper, up to about 5% aluminum, up to about 5% columbium, tantalum, vanadium, zirconium and titanium, the total alloy content being at least 45%, about 0.00005% to 0.008% boron, and remainder substantially all iron.

2. Stainless steel ingots of at least about 10" x 10" size and of improved hot-rolling characteristics containing about 10% to 35% chromium, up to about 35% nickel, up to about 20% manganese, up to about 5% silicon, up to about 50% cobalt, up to about 10% molybdenum, up to about 10% copper, up to about 5% aluminum, up to about 5% of columbium, tantalum, vanadium, zirconium and titanium, about 0.00005% to 0.004% boron, the total alloy content amounting to at least 35% and remainder substantially all iron.

3. Alloy steel ingots blooms and billets at least about 10" x 10" size and of improved hot-rolling characteristics containing chromium up to about 35%, nickel up to about 35%, up to about 20% manganese, up to about 5% silicon, up to about 50% cobalt, up to about 10% molybdenum, up to about 10% copper, up to about 5% aluminum, up to about 5% columbium, tantalum, vanadium, zirconium and titanium, the total alloy content being at least 25%, about 0.00005% to 0.0010% boron, and remainder substantially all iron.

4. Hot-rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 10% to 35% chromium, up to about 35% nickel, up to about 20% manganese, up to about 5% silicon, up to about 50% cobalt, up to about 10% molybdenum, up to about 10% copper, up to about 5% aluminum, up to about 5% of columbium, tantalum, vanadium, zirconium and titanium, about 0.0001% up to 0.0008% boron, the total alloy content amounting to at least 25% and remainder substantially all iron.

5. Hot-pierced stainless steel tubes containing about 10% to 35% chromium, up to about 35% nickel, up to about 20% manganese, up to about 5% silicon, up to about 50% cobalt, up to about 10% molybdenum, up

to about 10% copper, up to about 5% aluminum, up to about 5% columbium, tantalum, vanadium, zirconium and titanium, about 0.0001% up to 0.0008% boron, the total alloy content amounting to at least 25%, and remainder substantially all iron.

6. Hot-rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 27% chromium, about 0.00005% up to 0.0010% boron, and the remainder substantially all iron.

7. Turbine blading stock free of star-segregation containing about 12% chromium, about 0.00005% up to 0.0010% boron, and the remainder substantially all iron.

8. Hot-rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 19% chromium, about 12% nickel, about 3% molybdenum, about 0.0003% to 0.0010% boron, and the remainder substantially all iron.

9. Hot-rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 0.03% maximum carbon, about 18% chromium, about 12% nickel, about 2% molybdenum, about 0.0003% to 0.0010% boron, and the remainder substantially all iron.

10. Hot rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 19% chromium, about 9% nickel, about 0.00005% to 0.0008% boron, and the remainder substantially all iron.

11. Hot rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 18% chromium, about 8% nickel, about 0.00005% to 0.0008% boron, and the remainder substantially all iron.

12. Hot rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 25% chromium, about 20% nickel, about 0.00005% to 0.008% boron and the remainder substantially all iron.

13. Hot rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 25% chromium, about 12% nickel, about 0.00005% to 0.004% boron and the remainder substantially all iron.

14. Hot rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 20% chromium, about 10% nickel, about 0.0001% to 0.0010% boron and the remainder substantially all iron.

15. Hot rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 15% chromium, about 30% nickel, about 0.0001% to 0.008% boron, and the remainder substantially all iron.

16. Hot rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 20% chromium, about 10% nickel, about 4% manganese, about 0.0001% to 0.004% boron, and the remainder substantially all iron.

17. Hot rolled stainless steel plate, sheet, strip, structural shapes, bars, rods and wire containing about 20% chromium, about 28% nickel, about 3% copper, about 2% molybdenum, about 0.0001% to 0.008% boron, and the remainder substantially all iron.

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