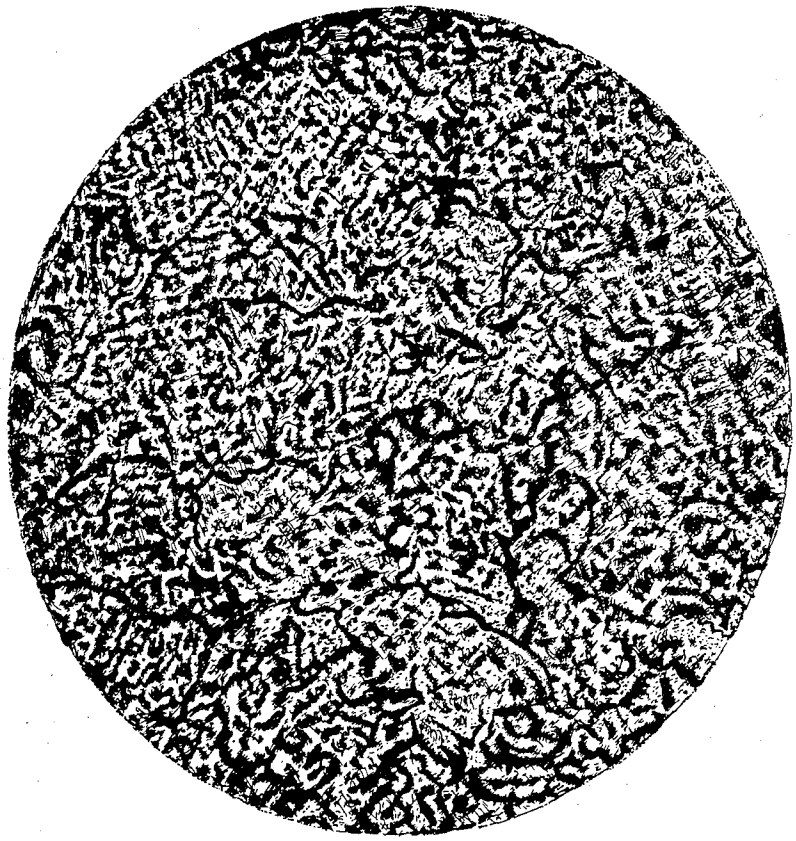
Oct. 2, 1934. J. H. HALL 1,975,746

METHOD OF TRANSFORMING MANGANESE STEEL

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FIG. 1



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INVENTOR

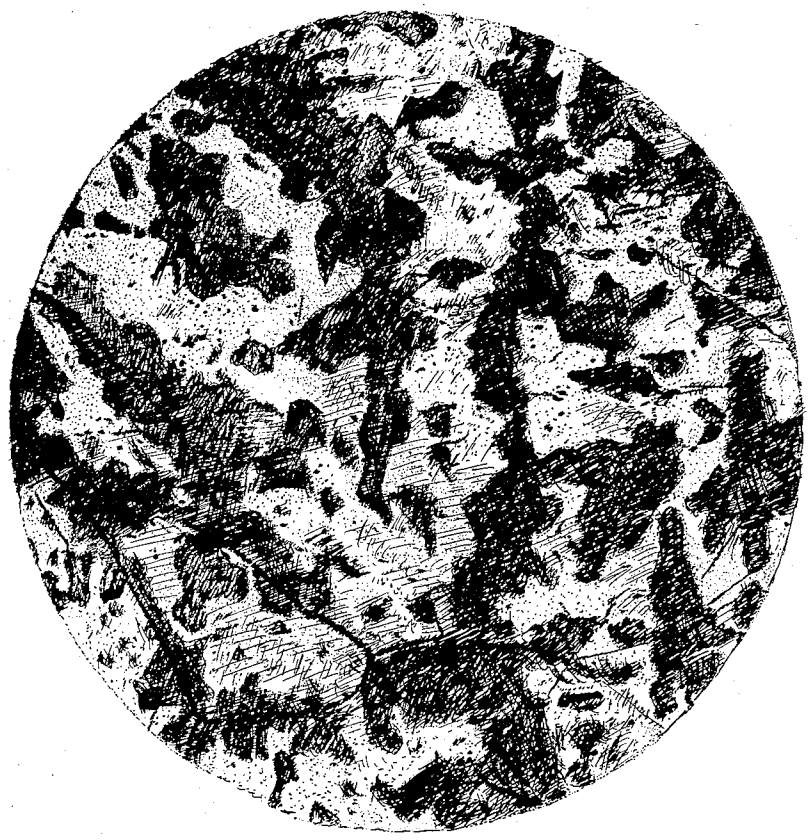
BY Jas. A. Richmond
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FIG. 2



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FIG. 3



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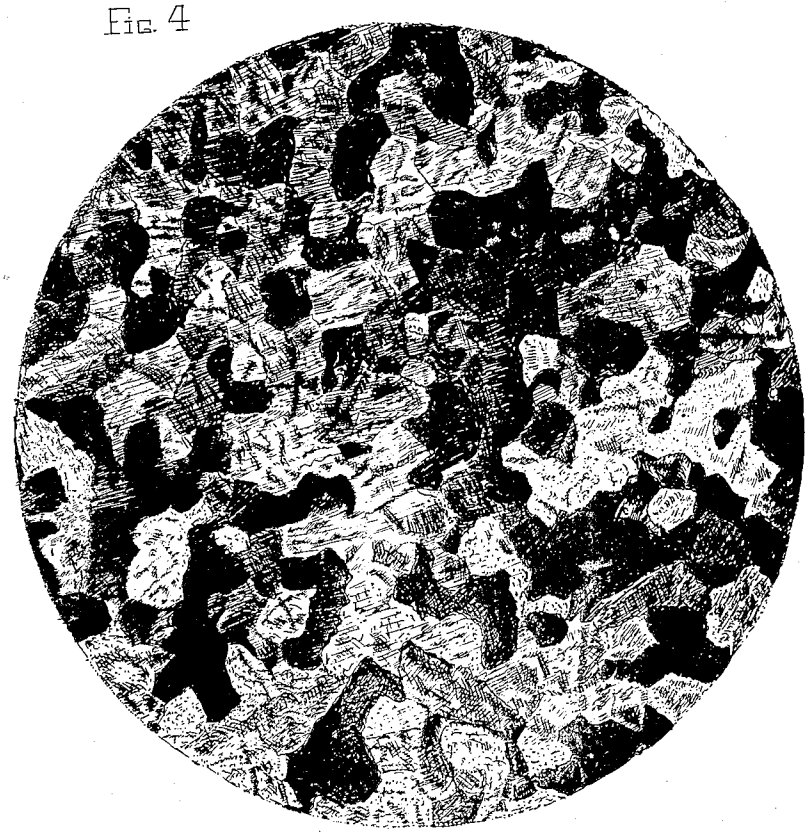
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Fig. 4



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FIG. 5



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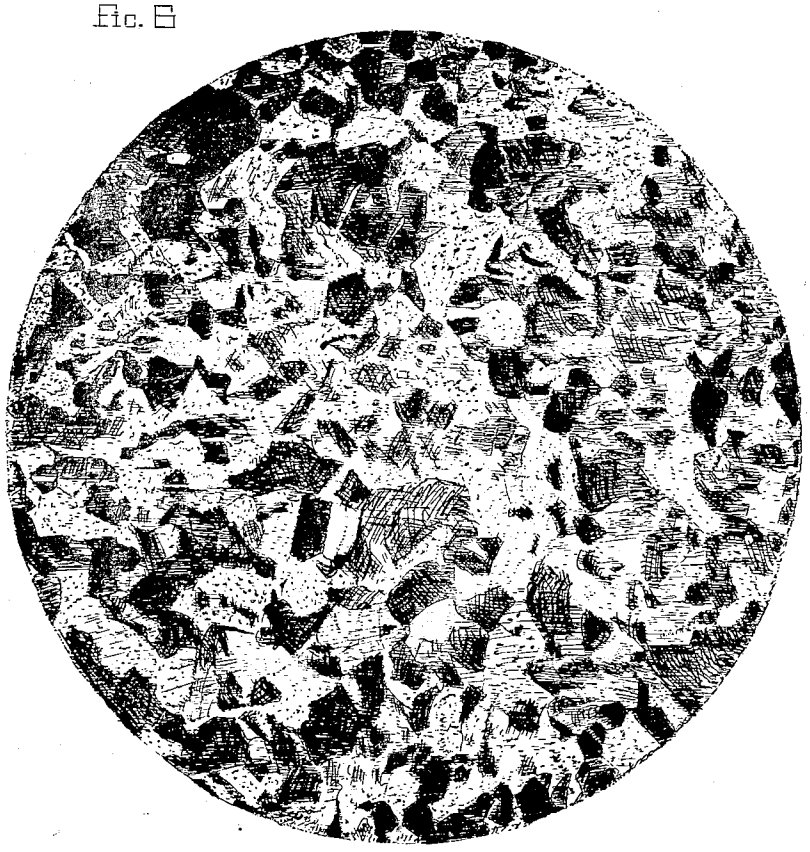
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Fig. 6



JOHN H. HALL,
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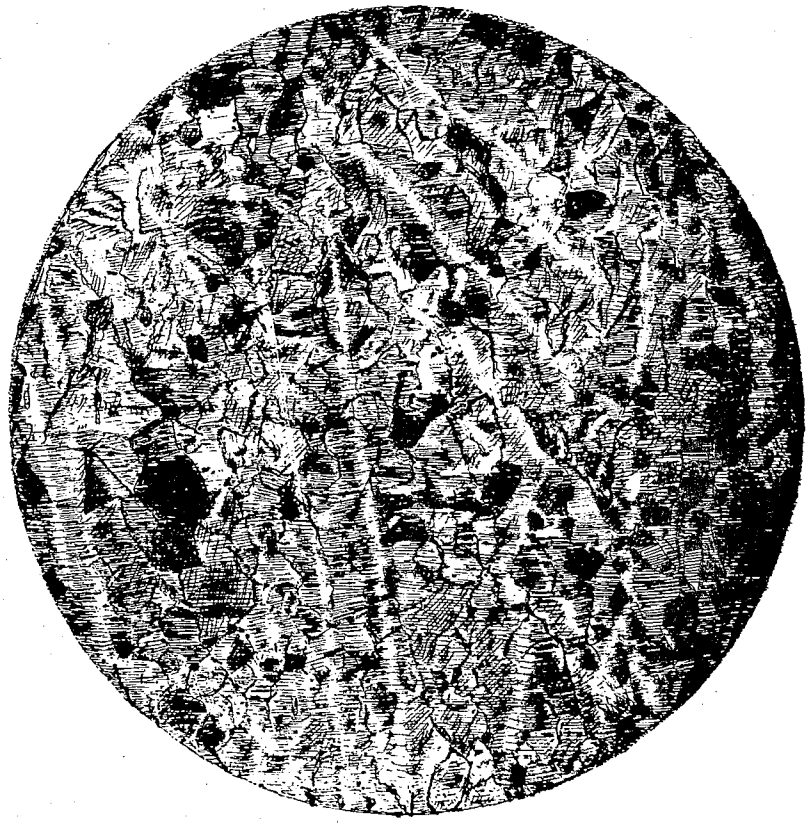
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Fig. 7



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Patented Oct. 2, 1934 1,975,746

UNITED STATES PATENT OFFICE

1,975,746

METHOD OF TRANSFORMING MANGANESE STEEL

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Application November 11, 1929, Serial No. 406,375

11 Claims. (Cl. 148—21.5)

The principal object is to improve the physical properties of iron or steel alloys containing from ten to fifteen per cent manganese or what is generally known as "austenitic" or "twelve per cent" manganese steel.

The nature of the invention consists in transforming manganese steel in order to improve its physical properties and particularly to refine its grain structure.

In certain investigations, by Hadfield and others, in connection with the development of the magnetic properties of manganese steel, they reported a condition of partial transformation after prolonged heating at temperatures around 500 to 600° C., but this in no way disturbed the current belief that manganese steel could not be transformed by any process of heat treatment. There was more or less apparent reason for this. When manganese steel is poured into moulds at a low temperature, its austenite crystals are comparatively small, but when it is cast very hot it has relatively large austenite grains, largely in the form of elongated prisms extending at right angles to the surfaces of the piece. This columnar structure is clearly revealed in the microstructure of the metal, and on the fracture of a bar, broken in the untreated state, is seen as an aggregate of columnar fibers resembling the pulp of an orange. Moreover, the austenite grain size, that the metal assumes on cooling from the casting temperature, persists after the usual heat treatment, which consists of heating the steel to 1000° C., or somewhat over and quenching in water. The columnar structure may be obscured in the fracture of a heat-treated bar, but the microscope reveals the true grain size to be what it was before heat-treatment. This is what would naturally be expected for ordinarily the metal in cooling never passes below its critical point, but even when cold is still above the critical range. Hence, the usual heat-treatment has no effect on the grain size except possibly to increase the same, for manganese steel, unlike carbon steel, does not transform in cooling. In the case of carbon steel the grain size is changed when the steel is heated through the transformation range and thus all annealing and heat-treatments of carbon steel confer upon the metal the benefits arising from a refinement of the grain. This is especially true of cast carbon steel and of carbon steel that has been rolled or forged at high temperatures. At ordinary rates of cooling the transformation point AC^1 of manganese steel is below atmospheric temperature. In fact, it cannot be made to transform even when immersed in liquid air. Hence, when manganese steel is heat-treated by heating it to over 1000° C. and quenching it in water, it does not transform because it never has passed through the transformation point AR^1. In rolling or forging manganese steel parts out of cast ingots, blooms or billets, the grain size is reduced by the working to which the piece is subjected, so that the grains of such parts are usually much smaller than those of cast articles of manganese steel. Such parts are heat-treated by heating them to 1000° C. or slightly higher and quenching them in water. In this operation no further refinement of the grain size occurs. In fact, the grains are often increased in size by the heat-treatment.

I have discovered and have demonstrated that manganese steel can be transformed and can have desirable benefits conferred upon it, particularly a great reduction of the grain size, if it be annealed at a proper temperature for a comparatively long period so that a partial transformation from austenite to martensite, troostite, and even to sorbite and pearlite, ensues, and thereafter be reheated so that there results a transformation in the reverse order, that is to say,

a return to austenite. The effect of this is greatly to improve the physical properties of the steel, including a reduction in grain size of several hundred per cent.

In practicing the invention, manganese steel is annealed at a temperature of from 400 to 600° C. for a period of from twelve to ninety-six hours. For example, excellent results have been achieved following an annealing period of seventy-two hours with the temperature lying between 450 to 525° C. The annealing period and the temperature may vary, however, within the ranges specified, according to circumstances.

After the preliminary heating, as stated, the temperature is allowed to fall gradually to bring about slow cooling. In the cool state, the steel is very brittle, much harder than in its normal state, and very magnetic. Under the microscope the structure will be found to consist substantially of sorbite, troostite, martensite, and some untransformed austenite, with the usual free cementite when the carbon is above 0.90.

After the process of letting the metal transform by subjecting it to a prolonged heating and a slow cooling, I re-heat it to a temperature above the transformation point. For example, I heat to about 1060° C. and then follow with quenching in water, or otherwise. The effect of this is to establish a reversal of the transformation and to put the steel in a uniformly austenitic state, and possessed of great toughness and strength, freedom from magnetic properties, and marked refinement of grain structure compared to austenitic steel cast, rolled or forged and treated in the usual way, that is to say by heating it to 1000° C. or over and quenching it in water.

The accompanying drawings are reproductions of microphotographs by F. F. Lucas, undisputed leader in work with the high power microscope. The microphotographs were taken from specimens of cast manganese steel. The appearance of the rolled or forged steel is similar, but the grain size is relatively smaller.

Figure 1 shows the steel before heat-treatment.

Figs. 2 and 3 show the steel after prolonged holding at temperatures below its critical point followed by slow cooling.

Figs. 4 and 5 show the steel after the usual heat-treatment, consisting of heating it to 1060° C. and quenching it in water.

Figs. 6 and 7 show, respectively, cast steel that has been "cold poured" and "hot poured" and heat-treated according to my invention.

Fig. 1, etched with nitric acid, is a view at 50 diameters of a bar of cast manganese steel that has not been re-heated after casting it. The austenite crystals, with carbides separating them and distributed throughout their area, are typical of the untreated cast steel.

Fig. 2 is a view, at 400 diameters, etched with nitric acid, of a specimen bar of cast 12% manganese steel, which was heated for 48 hours at 500° C. The structure consists of a ground mass of austenite, with areas of troostite, sorbite and pearlite, and ribs of cementite.

Fig. 3 is a view at 3500 diameters, of the same specimen as is illustrated in Fig. 2. Austenite, cementite, troostite and pearlite, make up the structure.

Rolled or hammered specimens of manganese steel that have been heated for long period at about 500° C., show structures similar to those of Figs. 2 and 3; the size of the grains, of course, is smaller than those shown in Figs. 2 and 3.

Figs. 4, 5, 6 and 7 are from a heat of cast manganese steel analyzing

Carbon	1.22
Silicon	.73
Manganese	11.5

These microphotographs were magnified 35 diameters.

Fig. 4 shows a test bar cast "cold", etched with nitric acid, and which has been heat-treated in the usual manner, which consists simply of heating it to 1060° C. and quenching it in water. The grain count is 22 grains per square millimeter.

Fig. 5 shows the structure with nitric acid etch of a bar from another coupon of the same heat, cast very "hot", which has been heat-treated in the same manner as Fig. 4, by heating it to 1060° C. and quenching in water. The grain count is 9 per square millimeter.

Fig. 6 shows the structure with nitric acid etch of a bar which was cast attached to the bar from which Fig. 4 was taken. This bar was heat-treated by annealing for 48 hours at 500° C. cooling in the air, re-heating to 1060° C. and quenching in water. The grain count is 46 per square millimeter.

Fig. 7 shows the structure with nitric acid etch of a bar which was cast attached to the bar from which Fig. 5 was taken. This bar was annealed for 48 hours at 500° C., cooled in air, reheated to 1060° C. and quenched in water. The grain count is 48 per square millimeter.

It is evident from these micrographs that the prolonged heating at 500° C. has brought about a transformation of part of the austenite of the manganese steel to troostite, or troostite mixed with martensite, and even to sorbite and pearlite. Like the effect of quenching in suppressing the transformation of carbon steel, the effect of manganese in these steels is normally to prevent transformation of the austenite at all ordinary rates of cooling, though carbide is liberated on cooling manganese steel slowly through the temperature range commonly indicated in the carbon-iron diagram by the line "SE", just as it is in carbon steels. Increasing the pressure, as it were, that tends to bring about transformation, as for instance by immersion in liquid air, does not cause transformation of the austenite of 12% manganese steels. On the other hand, if the resistance to transformation is decreased, or, better perhaps, if more time is allowed for transformation to occur, by holding the steel for many hours at a temperature below its transformation point, partial transformation does take place. Could the steel be cooled from a high temperature at an exceedingly slow rate, the same thing would undoubtedly occur, and sufficiently delicate apparatus, were such in existence, would almost certainly detect a critical point in cooling, probably a little below the well marked critical point found by Hadfield and Hopkinson to occur at 700° C., on heating this partially transformed steel.

The illustrations are conclusive of the transformation and that a change in the grain size results from a heat-treatment which consists of a prolonged annealing at or near 500° C. followed, after slow cooling, by a second heating to about 1060° C. and quenching.

The effect of the changes in grain size, produced by my method of heat treatment, upon the tensile properties of cast manganese steel is shown in Table 1, which gives the results of tests of

bars of manganese steel cut from cast coupons so designed as to produce perfectly sound bars. In each heat bar "C" and bar "CR" were cut from a single coupon, and bars "H" and "HR" were also cut from a single coupon.

Table 1

Heat	C	Si	P	Mn	State	T. S.	L. P.	Ext. 2" %	R. A. %	Grains per figure	
										Sq. mm.	No.
A	1.22	.73	.085	11.5	C	95750	42500	27.0	35.4	22	4
					Cr	130000	45000	43.5	31.2	46	6
					H	78000	37500	17.8	27.9	9	5
					Hr	97500	42500	19.75	34.4	48	7
B	1.16	.54	.079	12.9	C	134750	42500	54.35	42.5	47	
					Cr	148000	45000	60.4	45.7	76	
					H					6–67	
					Hr	147750	45000	62.0	44.9	90	
C	1.17	.72		13.6	H	126000	43750	59.2	45.4		
					Hr	143000	42500	71.2	46.3		
D	1.13	.78		13.6	C	130500	45000	52.0	37.9		
					Cr	136000	45000	66.7	44.3		
E	1.29	.74		13.7	C	115750	45000	40.4	33.4		
					Cr	146000	47500	55.8	40.7		
					H	120000		50.5	41.6		
F	1.17	.77		13.9	C	140000		50.9	41.3		
					C	128500		46.7	40.3		
G	1.18	.76		13.3	C	136750		53.0	41.0		
					C	132500		50.25	47.2		
H	1.24	.84	.086	13.0	C	133250	46250	47.4	45.1		
					Cr	148250	47500	52.4	37.6		
					H	112000	41250	47.0	33.1		
					Hr	152750	48750	63.6	44.3		
I	1.27	.63		12.5	C	101000		28.3	38.8		
					Cr	137500		48.8	43.1		
					H	98500		47.0	34.7		
					Hr	125500		37.8	34.1		

T. S.=Tensile strength in lbs. per square inch.
L. P.=Limit of proportionality in lbs. per sq. in.
Ext. 2" %=Extension before fracture in 2" %.
R. A. %=Reduction of area, %.

The symbols "C" and "H" represent "cold poured" and "hot poured" steel, heated to 1060° C. and quenched in water; "Cr" and "Hr" denote the companion bars that were heated for a long time at 500° C., cooled slowly and then re-heated to 1060° C. and quenched in water. The limit of proportionality in tension is given for only certain of the tests. It was determined with an Olsen strain gauge type of extensometer reading to 0.00006667". This property varied so little, however, that it was not thought worth while to determine it in all my tests.

It will be seen that in practically every case the tensile strength, elongation, and reduction of area of the steel have been improved by my improved method of heat treatment, the improvement being more marked in the metal poured "hot", which is generally weaker and less ductile than the "cold poured" steel.

In Table 2 are given the average tensile strengths and extensions of the different classes of steels shown in Table 1.

Table 2

State	No. tests	T. S.	Ext. % 2"
C	10	124875	45.03
Cr	6	140960	54.6
H	5	106900	42.3
Hr	5	133300	50.87

In this table one sees at a glance the considerable improvement in these properties caused by my improved method of heat-treatment.

In tensile test bars cast roughly to shape, and in some small castings, improvements in the tensile properties, comparable in amount to those illustrated in these tables, are not always produced by my improved method of heat-treatment. The reason for this is not entirely clear, though it appears to be due in part to the fact that the centers of these bars or castings often contain an area of spongy metal, which is considerably more extensive in the bars poured "hot" than in those poured "cold", and is sufficiently large to mask the effect of improvement in the strength of the outside portion of the bars.

That my improved method of heat-treatment improves certain properties of bars cast to size, however, is shown by the results of repeated bending tests of cast manganese steel bars summarized in Table 3.

Table 3

Size of bar	Throw	State	No. tests	Revolutions to break
¾" round	5/16"	H	20	13800
¾" round	5/16"	C	15	20325
¾" round	5/16"	Hr	9	22600
¾" square	¼"	H	10	14663
¾" square	¼"	Hr	11	25212

These tests were made in an Olsen machine in which ¾" round or square bars are clamped tightly at one end, while the free end is moved back and forth by a cross-head 6½" from the vise that holds the bar. The "throw" shown in the table is the total motion of the end of the bar from its lowest to its highest position, and is probably sufficient to give the bar a very slight permanent set. It will be seen that the "hot poured" bars H, which have been given the ordinary heat treatment, break after about half the number of bends that are endured by the "cold poured" bars C that have been given the ordi-

nary heat-treatment, or by the "hot poured" bars Hr that have been heat-treated by my improved method.

In these tests, of course, the determining factor is the strength of the outside fibres of the test bars, for once a crack starts on the outside of a bar, it breaks after being subjected to but a few hundred more bends. The effect of sponginess at the center, therefore, which appears to affect the result of tensile tests of bars cast to size, is practically nil in bars subjected to repeated small bends, so that the number of bends they endure in this test is roughly proportional to the strength of the metal of the outside layers.

The physical properties of rolled or forged manganese steel articles are improved by my new process of heat-treatment, to an extent more or less proportional to the amount of change in their grain size that results from this heat-treatment process.

I am aware that it has been proposed to anneal manganese steel castings following their removal from the sand and before treating. The purpose and effect of such annealing was simply to relieve casting stresses so as to obviate ultimate cracking of the castings. The annealing was not carried out at definite temperatures, and in no case was a grain refinement sought.

Having described my invention, I claim

1. The method of greatly reducing the grain size of manganese steel and otherwise improving its physical properties, which consists in heating it to a temperature below its critical point for upwards of twelve hours, followed by slow cooling, for the definite purpose and with the result of transforming it, and then restoring the austenitic structure with marked refinement of the grain by heating the transformed steel to about 1060° C. and quenching.

2. The method of treating manganese steel in order to transform it and thereby refine the grain, which comprises transforming the steel by heating it for a protracted period of not less than twelve hours and at a temperature below its critical point and then slowly cooling it, to effect a transformation from austenite, and thereafter heating it to a temperature above the transformation point and quenching.

3. The method of refining the grain structure of manganese steel, which comprises passing manganese steel through its transformation range by heating it to a temperature below its critical point, for not less than twelve hours and then slowly cooling it, and ultimately effecting a transformation in the reverse order by heating it to a temperature above the transformation point and quenching.

4. The method of refining the grain structure of manganese steel, which comprises subjecting manganese steel to preliminary heating below the critical point to effect a transformation from austenite to sorbite, cooling, heating to a temperature above the transformation point, and quenching.

5. The method of refining the grain structure of manganese steel, which comprises subjecting manganese steel to an annealing treatment for an effective time up to 72 hours and at an effective temperature within the range of 400 to 600° C. to cause a transformation from austenite to sorbite, allowing the steel to cool, and then re-heating to substantially 106° C. to effect a re-transformation in the reverse order.

6. The method of refining the grain structure of manganese steel, which comprises holding manganese steel for a period of from twelve to ninety-six hours at a temperature of from 400 to 600° C., to effect a transformation from austenite to sorbite, slowly cooling the steel, and then re-heating to substantially 1060° C. to effect a re-transformation in the reverse order.

7. The method of treating manganese steel, which comprises subjecting manganese steel to two definite heat-treatments, whereof the first consists in holding the steel at a temperature of about 500° C., for an effective period for the purpose and with the result of transforming it to a state manifested by the appearance of little or no austenite, and whereof the second, following comparative slow cooling, consists in obtaining an uniformly refined austenitic grain structure by heating the transformed steel to about 1060° C. and quenching.

8. The method of producing manganese steel of refined austenitic grain structure and free from magnetic properties, which comprises passing it through its transformation range by heating it below its critical point to change it from the austenitic state, and, after gradual cooling, returning it to an uniformly refined austenitic state by giving it a second heating up to about 1060° C., and quenching it.

9. The method of producing manganese steel of greatly improved physical properties, which comprises subjecting manganese steel to an initial heating at a temperature of from 400 to 600° C. and holding it at that temperature until transformation ensues from the austenitic through the sorbitic state, cooling it by gradual declination, and then reheating to substantially 1060° C. and quenching the reheating temperature being effective to return the grain to its austenitic state but characterized by its marked refinement.

10. The method of producing manganese steel of greatly improved physical properties, which comprises subjecting manganese steel to an initial heating at a temperature of from 475 to 525° C., and holding it at that temperature until at least partial transformation ensues from the austenitic state through the sorbitic state, cooling it, and then re-heating to about 1060° C., and quenching.

11. The method of refining manganese steel which consists in first partially transforming it by subjecting it to heating for a period of about sixty hours, more or less, at a temperature of from about 400° to about 600° C. and tapering off the heat by slow process, and then restoring the austenitic state by heating the transformed steel to about 1060° C. and quenching.

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