

Sept. 10, 1940.

R. H. BANCROFT

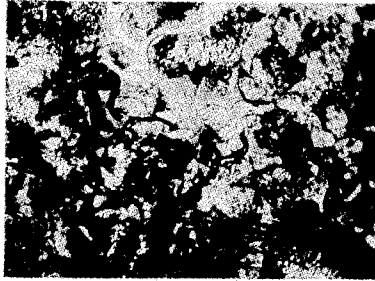
IRON ALLOY

Filed June 28, 1940

2,214,652

2 Sheets-Sheet 1

Fig. 1.



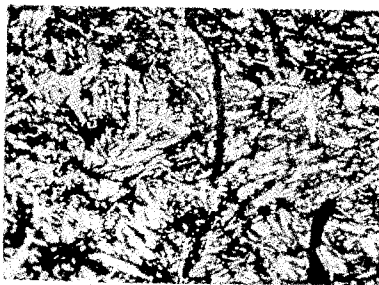
SORBITE STRUCTURE - (ORDINARY CAST IRON)

Fig. 2.



INSTANT IRON - MARTENSITIC AS CAST

Fig. 3.



INSTANT IRON - STILL MARTENSITIC AFTER DRAWING

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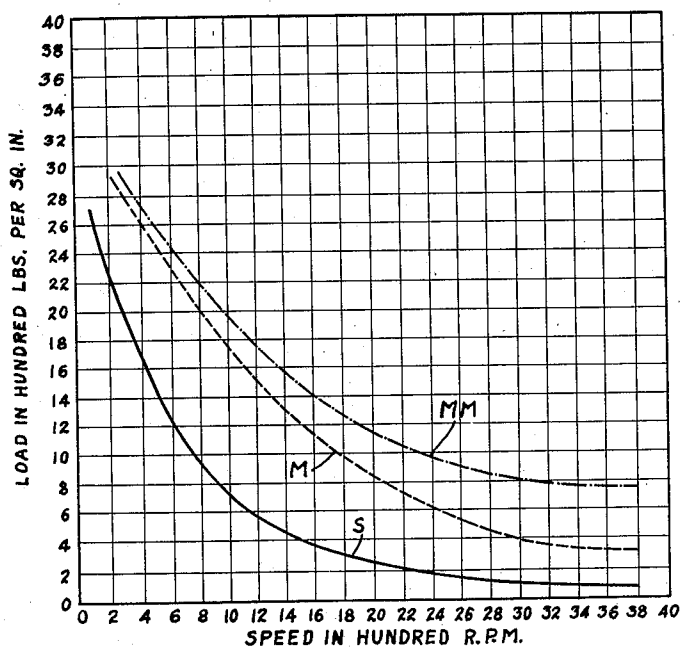
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Fig. 4.



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UNITED STATES PATENT OFFICE

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IRON ALLOY

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Application June 28, 1940, Serial No. 343,031

8 Claims. (Cl. 75—125)

This invention relates to ferrous metals, and more particularly to improvements in iron alloys adapted to provide a desirable bearing surface with increased wear resistance in articles made of such alloys.

More specifically, the invention relates to martensitic gray iron alloys particularly well adapted for making machine elements or parts normally subject to wear under load, such as piston rings, pistons, cylinder liners, bearings, gears, etc.

The ferrous alloys forming the subject matter of the present invention provide gray iron castings having a stable and substantially martensitic structure, as cast, in common molding sand. The martensitic castings thus formed are too hard to permit machining by ordinary tools or equipment, and accordingly, the invention contemplates "drawing" the martensitic castings at a temperature which will render the same readily machinable without destroying the desirable martensitic structure during the drawing operation. The castings may be reheated if desired to relieve any strains.

The alloys disclosed herein have been found to be particularly well adapted for piston rings designed for use in internal combustion engines, and while the following description deals largely with piston rings, it will be understood that the same is given by way of illustration and not limitation, and that the disclosed alloys have been found useful for machine elements other than piston rings.

Prior to my invention, piston rings usually have been made of cast iron, although some attempts have been made to produce piston rings of steel. The speed and power of internal combustion engines have been greatly increased during the past decade or two. Accordingly, piston rings are subjected to much higher temperatures, pressures and increased wear, while at the same time more efficient or exacting performance of rings has been necessarily demanded—but not successfully attained—by reason of these conditions. Temperatures of 500° F. or higher are attained in the cylinders of modern internal combustion engines. It is well known that many cast iron piston rings, prior to the advent on the market of rings embodying my invention, rapidly distorted in shape, lost some of their tension or re-

silience after a relatively short period of use, wore out quickly, and, in some cases, scuffed, that is, abraded the cylinder walls. These cast iron rings usually had a structure of a sorbite or pearlite nature, which has the advantage of being easily machined but has the disadvantage of being relatively soft and, hence, subject to too rapid wear. Prior attempts to produce steel rings capable of withstanding the rigorous conditions of modern internal combustion engines and efficiently performing their intended functions have not been successful for various reasons. In most instances, such steel rings, among other defects, became scuffed or they soon scuffed the cylinder walls.

It has long been well known that a ferrous metal may be made martensitic by heating the metal above the critical temperature and then quench-cooling it. (The martensitic structure is characterized microscopically by its needle-like or acicular form, easily recognized by metallogrists.) Piston rings so formed would be wholly impractical. They would be not only too brittle and badly distorted from quenching shock for their intended functions and too hard to machine or finish, but the martensitic condition would, in contrast with the present invention, be unstable when subjected to heat. In use in engines, the unstable martensite would decompose, because of the heat, into softer forms such as troostite, sorbite or pearlite, and the ring would distort or deform and wear rapidly.

Accordingly, one of the principal objects of the present invention is to provide iron alloys adapted for use in manufacturing various machine elements in which good wearing qualities are desired with freedom from warping or distortion in use.

An important but more specific object of the invention is to provide a piston ring of a suitable alloy which will overcome the above-mentioned defects of prior piston rings. To attain this objective, I provide a resilient gray iron piston ring which is martensitic as cast and which in finished form has a substantial or pseudo-martensitic structure, and which structure remains stable and permanent without distortion of the ring when the same is subjected to the high temperatures and pressures present in an internal combustion engine; the ring at the same time being tough and highly wear resisting, very durable, efficient

throughout its life, and readily machinable during manufacture.

Another object of the invention is to provide alloys suitable for forming a martensitic structure, as cast, in articles of different given thicknesses.

Another object of my invention is to provide a novel process of manufacturing machine elements or parts in which a stable martensitic gray iron structure is desired in the finished article.

Other objects and advantages of the invention will be apparent to those skilled in the art from the following description, taken in conjunction with the accompanying drawings, in which:

Figures 1 to 3 constitute photomicrographs, all taken at the same magnification, i. e., 1100 diameters. More specifically:

Figure 1 is a photomicrograph of a cross section of an article made of ordinary cast iron in a sand mold and exhibiting a highly sorbitic structure without any evidence of martensite;

Figure 2 is a photomicrograph of a cross section of an article illustrating the form of structure that is obtained with the alloys of the present invention when cast in a sand mold, the structure being martensitic as cast in the mold;

Figure 3 is a photomicrograph of a cross section of the article shown in Figure 2 after having been drawn to render the same machinable without destroying the martensitic structure; and

Figure 4 represents wear test curves plotted from data obtained in comparative load capacity tests of piston rings made in accordance with the present invention and piston rings of conventional sorbitic cast iron.

The alloys of the present invention are especially adapted for casting articles, which are of thin section, in sand molds to produce a martensitic structure as cast.

In practicing the invention, cast iron and suitable alloying materials are melted into a molten mass and then poured into and rapidly cooled or chilled in molds which may be of the usual conventional sand type employed in casting, for example, individual piston rings, which are articles of relatively small cross section. Different alloying elements or metalloids may be utilized and their proportions varied. These are so selected and proportioned as to extend the critical hardening range both downward and upward. The critical temperature may be fairly defined as the point where the metal hardens or as the point of transition from the austenitic state to the martensitic state, or as the temperature where alpha iron changes to the gamma state, as is understood in the metallurgical science. Examples of elements serving as critical depressants are molybdenum, copper, nickel and manganese. On the other hand, silicon or chromium, for example, are elevants and raise the critical hardening temperature. The amount of such elements used depends largely on the rate of cooling in the mold, which, in turn, depends on the cross sectional size of the article being cast, as will be apparent hereinafter. As a generality, the critical depressing elements may be less than 2% of the mass, and the critical elevating elements less than 4% of the mass. It will be understood that the primary purpose of the latter elements is to prevent changes or decomposition of the ultimate martensitic structure when the article is subjected to high temperatures, for example, as when a piston ring is exposed to the temperatures normally existing

in the cylinder of an internal combustion engine, or to even higher temperatures.

Alloys falling within the following range have been found suitable for making martensitic gray iron castings of a thickness up to approximately one-half inch:

	Per cent	
Carbon	3.25 to 3.75	
Silicon	2.25 to 3.30	
Sulfur	.10 maximum	10
Phosphorus	.20 to .50	
Manganese	.50 to 1.00	
Molybdenum	.45 to 1.00	
Chromium	.20 to .50	
Copper	.50 to 2.50	15
Iron	Balance	

Within the range specified above, I have found that the following composition is particularly well adapted for making martensitic gray iron castings of a thickness of about one-eighth of an inch and under:

	Per cent	
Carbon	3.65 to 3.75	25
Silicon	2.90 to 3.30	
Sulfur	.10 maximum	
Phosphorus	.20 to .50	
Manganese	.50 to 1.00	
Molybdenum	.45 to .65	30
Chromium	.20 to .35	
Copper	.50 to 1.50	
Iron	Balance	

A particularly good alloy within the foregoing range for making martensitic gray iron piston rings as cast is as follows:

	Per cent	
Carbon	3.65 approx.	
Silicon	3.0 to 3.07	40
Sulfur	.08	
Phosphorus	.30	
Manganese	.55 to .75	
Molybdenum	.50 to .55	
Chromium	.25 to .31	45
Copper	.85 approx.	
Iron	Balance	

Martensitic gray iron piston rings having highly desirable qualities of elasticity and wear resistance have been cast of alloys having the following specific compositions:

	Per cent	
(1) Carbon	3.65	55
Silicon	3.07	
Manganese	.55	
Molybdenum	.50	
Chromium	.31	
Copper	.86	
Iron	Balance	60
(2) Carbon	3.65	
Silicon	3.00	
Sulfur	.08	65
Phosphorus	.30	
Manganese	.75	
Molybdenum	.55	
Chromium	.25	
Copper	.85	
Iron	Balance	70

The latter composition is the preferred composition for piston ring castings of about one-eighth of an inch in axial width.

For castings having a thickness of about one-eighth to one-quarter of an inch, I have found the following composition to be particularly useful in providing a martensitic gray iron structure as cast:

	Per cent
Carbon.....	3.55
Silicon.....	2.85
Sulfur.....	.08
Phosphorus.....	.30
Manganese.....	.75
Molybdenum.....	.65
Chromium.....	.30
Copper.....	2.00
Iron.....	Balance

For providing a martensitic gray iron, as cast, in articles having a thickness of about one-quarter to one-half inch, an alloy having the following limits has been found useful:

	Per cent
Carbon.....	3.25 to 3.50
Silicon.....	2.25 to 2.75
Sulfur.....	.10 maximum
Phosphorus.....	.20 to .50
Manganese.....	.50 to 1.00
Molybdenum.....	.75 to 1.00
Chromium.....	.30 to .50
Copper.....	1.00 to 2.50
Iron.....	Balance

A preferred composition for martensitic gray iron piston ring castings within the above range is as follows:

	Per cent
Carbon.....	3.35
Silicon.....	2.50
Sulfur.....	.08
Phosphorus.....	.25
Manganese.....	.75
Molybdenum.....	.90
Chromium.....	.40
Copper.....	2.00
Iron.....	Balance

In the manufacture of piston rings, for example, the ferrous alloys selected will depend upon the cross sectional dimensions of the piston ring.

The mass of iron and selected elements may be melted in any suitable or standard furnace at a temperature of, say, 2700° F. or more and then poured. Upon cooling in the sand, the rings are found to be intensely martensitic as shown in the illustrative photomicrograph of Figure 2. This has been accomplished without resort to any extraneous quenching or liquid cooling operation. The hard martensitic structure results from the use of the alloy material which has so extended the critical hardening range as to utilize the heat of the melted metal as it cools normally in the mold.

The castings, as taken from the molds, are too hard for subsequent machining operations. (By "machining operations," I mean the usual mechanical operations performed on a piston ring such as cutting the gap or joint, rough turning or grinding, boring and finishing turning or grinding.) The castings being too hard, I next reheat or "draw" at a temperature below the critical temperature but higher than 500° F. and allow the castings to cool. This draw, which may be at a temperature of from around 900°

F. to around 1200° F., makes the metal soft enough to be readily machinable and increases the tension of the ring. However, the metal retains a substantial or pseudo-martensitic structure due to the effect of the contained critical elevating elements. This structure is clearly manifest in the illustrative photomicrograph of Figure 3. After drawing, the castings may have a hardness of from 42 to 48D Rockwell, the Rockwell scale being a well known standard scale for hardness. A hardness of 46D Rockwell is preferred.

The rings are then machined or semi-machined. I find it desirable to finish machining the flat edges of the ring, bore it, turn the periphery and cut the gap, and then reheat the ring to a lower temperature than that of the "draw" but above the temperature to which the rings may be subjected in use in an internal combustion engine. This last or secondary heating operation is preferably performed at a temperature between 500° F. and 800° F. The secondary heating tends to relieve the strains and stresses which have been set up in the ring during the machining operations and it also improves somewhat the tension of the ring. It does not, however, alter the stable pseudo-martensitic structure which has been permanently fixed during the prior high temperature. The maintenance of the substantial martensitic structure is essential to insure the resistance to abrasion or wear. I then finally finish turning the outer periphery of the ring, although this operation may be performed prior to the secondary heating operation, if desired.

Piston rings constructed in accordance with the present invention have, in comparative wear tests, shown an appreciable improvement in load carrying capacity over conventional sorbitic cast iron piston rings. These tests were made under identical conditions. Curves S and M of Figure 4 are based upon the following data obtained by running a plain or sorbitic cast iron ring, and my martensitic cast iron ring, respectively, against a cylinder section made of sorbitic cast iron:

Table I

Test speed, R. P. M.	Scuffing pressure, lbs. per sq. in.		Increase in load capacity attained with martensitic ring
	Regular sor- bitic iron ring (curve S)	Martensitic gray iron ring (curve M)	
			Percent
500.....	1450	2370	63
1000.....	700	1800	157
1500.....	400	1290	181
2000.....	360	850	136
2500.....	175	540	208
3000.....	100	400	300

As will be apparent, curve S of Figure 4 graphically indicates the loads and corresponding speeds at which a sorbitic iron ring scuffed, and curve M indicates the comparative increase in load that the martensitic rings withstood before finally scuffing. The last column of Table I expresses this increase in load capacity in percent.

Even greater improvement in results was obtained when a martensitic gray iron ring was run against a cylinder section formed of like martensitic iron. The data of Table II below forms the basis for curve MM of Figure 4, which illustrates the improvement in load carrying capacity for this combination.

Table II

5	Test speed, R. P. M.	Scuffing pressure, lbs. per sq. in., martensitic gray iron ring engag- ing cylinder sec- tion of like ma- terial (curve MM)	Increased load capacity over plain iron ring and cylinder of like material
10			Percent
	500.....	2600	79
	1000.....	2040	191
	1500.....	1550	287
	2000.....	1170	225
	2500.....	900	414
	3000.....	700	660

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It will be noted from Tables I and II, and Figure 4, that with a martensitic piston ring and a martensitic cylinder member, the load capacity of the ring before scuffing at 3000 R. P. M. was almost doubled, that is, increased from 400 lbs. per sq. in. to 760 lbs. per sq. in., which is truly remarkable.

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This application is a continuation in part of my copending application Serial Nos. 139,891, filed April 30, 1937.

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While the aforescribed compositions and heat treatment have been found highly satisfactory in the production of piston rings, it will be understood that some variations in the composition and/or processing may be made, and that the compositions and heat treatment may be employed in making machine elements other than piston rings, without departing from the spirit of the invention.

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I claim:

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1. A ferrous alloy for forming martensitic gray iron as cast, comprising: total carbon 3.25% to 3.75%, silicon 2.25% to 3.30%, sulfur 0.10% maximum, phosphorus .20% to .50%, manganese .50% to 1.00%, molybdenum .45% to 1.00%, chromium .20% to .50%, copper .50% to 2.50%, and iron—balance.

2. A ferrous alloy for forming a martensitic

gray iron as cast, comprising: total carbon 3.65% to 3.75%, silicon 2.90% to 3.30%, sulfur .10% maximum, phosphorus .20% to .50%, manganese .50% to 1.00%, molybdenum .45% to .65%, chromium .20% to .35%, copper .50% to 1.50%, and iron—balance.

3. A ferrous alloy for forming martensitic gray iron as cast, comprising substantially: total carbon 3.65%, silicon 3.00%, sulfur .08%, phosphorus .30%, manganese .95%, molybdenum .55%, chromium .25%, copper .85%, and iron—balance.

4. A ferrous alloy for forming martensitic gray iron as cast, comprising substantially: total carbon 3.65%, silicon 3.07%, manganese .55%, molybdenum .50%, chromium .31%, copper .86%, and balance iron.

5. A ferrous alloy for forming martensitic gray iron as cast, comprising: total carbon 3.50% to 3.05%, silicon 2.75% to 3.00%, sulfur .10% maximum, phosphorus .20% to .50%, manganese .50% to 1.00%, molybdenum .55% to .75%, chromium .25% to .40%, copper 1.50% to 2.50%, and iron—balance.

6. A ferrous alloy for forming martensitic gray iron as cast, comprising substantially: total carbon 3.55%, silicon 2.85%, sulfur .08%, phosphorus .30%, manganese .75%, molybdenum .65%, chromium .30%, copper 2.00%, and iron—balance.

7. A ferrous alloy for forming martensitic gray iron as cast, comprising: total carbon 3.25% to 3.50%, silicon 2.25% to 2.75%, sulfur .10% maximum, phosphorus .20% to .50%, manganese .50% to 1.00%, molybdenum .75% to 1.00%, chromium .30% to .50%, copper 1.00% to 2.50%, iron—balance.

8. A ferrous alloy for forming martensitic gray iron as cast, comprising substantially: total carbon 3.35%, silicon 2.50%, sulfur .08%, phosphorus .25%, manganese .75%, molybdenum .90%, chromium .40%, copper 2.00%, and iron—balance.

RICHARD H. BANCROFT.