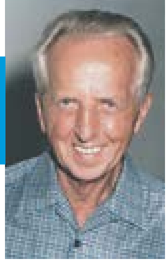

ACADEMIC STUDY
Dr. David Kirk | Coventry University

Shot Peeners' Magic Steel MANGALLOY

INTRODUCTION

Mangalloy works magically! As shot particles it is austenitic and tough but develops a very hard martensitic skin if cold-worked by peening. When the surface wears away, very very slowly, the skin automatically repairs itself. For peening cabinet components the same applies.

Mangalloy, also called "manganese steel" or "Hadfield steel", is an alloy steel containing an average of around 13% manganese. Invented in the nineteenth century it found many applications such as railway line intersections.

This article includes elements of the alloy's history, properties, martensite formation and applications.

HISTORY

Mangalloy was invented by Sir Robert Hadfield in 1882. It was the first commercially successful alloy steel and had properties different from those of plain carbon steels. Hadfield had been searching for a steel composition that would have both hardness and toughness which plain carbon steels did not have. In the nineteenth century, steelmaking was more of an art than a science. Hadfield became interested in the addition of manganese and silicon to carbon steel. This was because ferromanganese had become available being made cheaply from manganese ores.

As the manganese content of carbon steel is raised it becomes increasingly brittle. At 4% manganese, it shatters on impact. Hadfield was interested in why this occurred. Why he produced a steel with a manganese content of about 12% is, however, unclear. The following apocryphal tale was related to the author, when he was a child, by his steelmaker father:

"Hadfield ordered a steel to be made, in his own steelworks, that contained 4% manganese. A pile of ferromanganese was delivered to the furnaceman. He added enough to produce the specified 4% manganese content—then went off for a break. The foreman came to the unmanned furnace, saw the pile of ferromanganese and wrongly assumed that none had been added. He therefore added enough to produce 4%, though actually raising it to about 8%—then went off for his break. During that break Hadfield himself came along, saw the ferromanganese and also wrongly assumed none had been added, so he did so himself. As a result the steel, when cast, had about 12% manganese."

Hadfield's hundreds of tests on his 12% manganese steel gave results that surprised him. Cast bars could not be machined, filed or sawn. On heating and quenching the steel became both hard and tough. With plain carbon steels heating and quenching increases hardness but at the expense of toughness. Hadfield's patent of 1883 was for steel alloys containing 12 to 14% manganese and 1.0% carbon. These were the very first steel alloys that were commercially viable.

MECHANICAL PROPERTIES

The variation of its mechanical properties, ductility, tensile strength, toughness and wear resistance, is basic to an understanding of why the magic alloy Mangalloy became so important. Fig.1 shows how ductility varies with manganese content. Ductility falls from about 30% to 0% with increase of manganese between 0 and 7%. Thereafter ductility rises rapidly, reaching a peak of almost 50% about 13% manganese content. Beyond 13% manganese ductility falls equally rapidly.

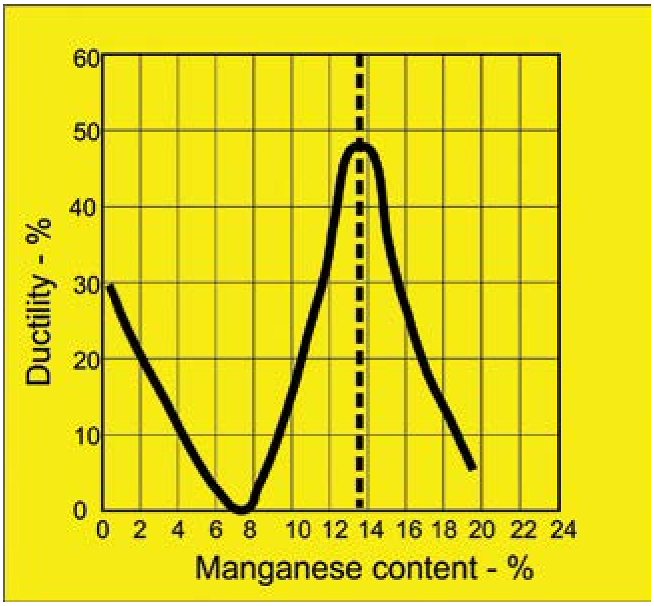

Fig.1. Effect of manganese content on ductility of carbon steel.

Fig.2 shows how the tensile strength of plain carbon steels is affected by manganese addition.

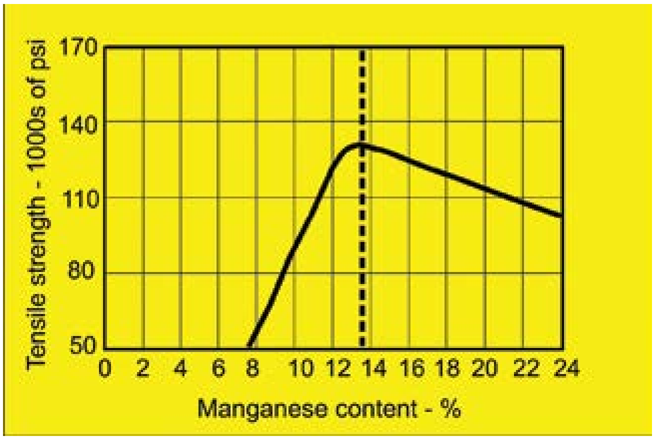

Fig.2. Effect of manganese content on tensile strength of carbon steel.

As with its effect on ductility, tensile strength reaches a peak with about 13% of added manganese.

Toughness is strength multiplied by ductility. Hence if a material is to be tough, it must be both strong and ductile. Ceramics may be strong but they lack ductility and are therefore brittle. Mangalloy is superbly tough because it has both very high strength as well as high ductility.

Wear resistance is defined simply as resistance to wear. Wear is so very important that it is a subject in its own right —tribology. A brief account was presented as "Wear and Its Reduction", TSP Winter, 2016. Suffice it to say that Mangalloy has very high wear resistance which adds to its usefulness.

AUSTENITE TO MARTENSITE

Mangalloy in its austenite form is an unstable arrangement of iron and manganese ions. The arrangement is called face-centered-cubic, (f.c.c.), and is illustrated in fig.3. Just one face of a cube is highlighted with ions at each corner and at the center of the face. These can be either iron or manganese ions. The much smaller carbon atoms randomly occupy spaces in the lattice.

Transformation from the unstable austenitic structure to a body-centered-tetragonal (b.c.t.) martensitic structure requires energy to be applied. As an analogy, consider a row of dominoes separated by less than their height. The row is unstable and only needs one end domino to be pushed over to set off the familiar chain reaction.

Martensite has a different crystal structure as illustrated in fig.4. Cold-working of Mangalloy provides enough energy to cascade the ions and atoms to their new positions.

SURFACE SKIN OF MARTENSITE

During peening with Mangalloy shot, a surface layer of martensite is induced as illustrated by fig.5. With extended peening this surface layer wears away but is automatically replaced.

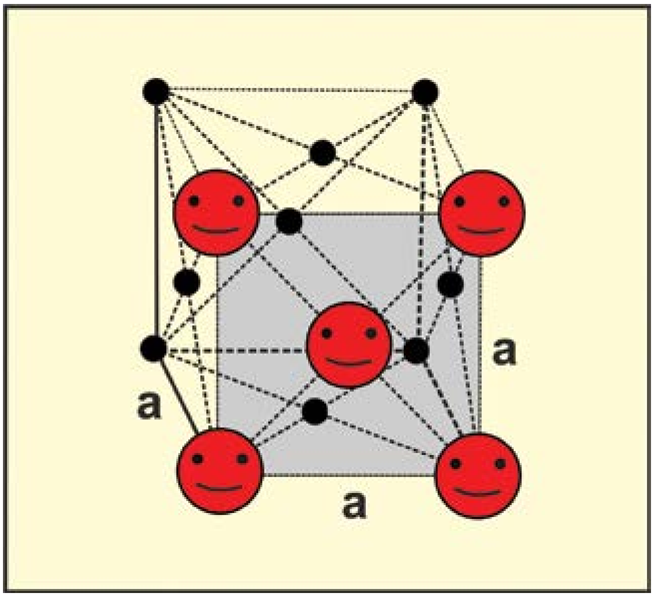

Fig.3. Face-centered-cubic arrangement of ions.

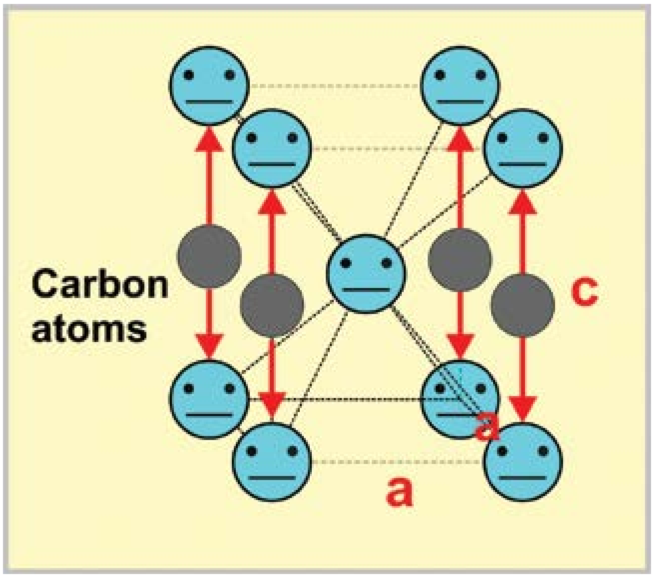

Fig.4. Body-centered-tetragonal arrangement - Martensite.

Peening cabinet components that receive impacts will also develop a protective martensitic surface skin. Fig.6 shows one example where Mangalloy plates are arranged to guide shot onto a long rod. The plates themselves develop protective surface martensitic skins.

CONCLUSION

Although Mangalloy was discovered in the nineteenth century it has taken more than a century and a half for its usefulness in shot peening to be generally recognized. Sir Robert Hadfield was necessarily protective of his inventions and published several patents. The following on page 30, downloaded using Google, is a relevant patent for Mangalloy.

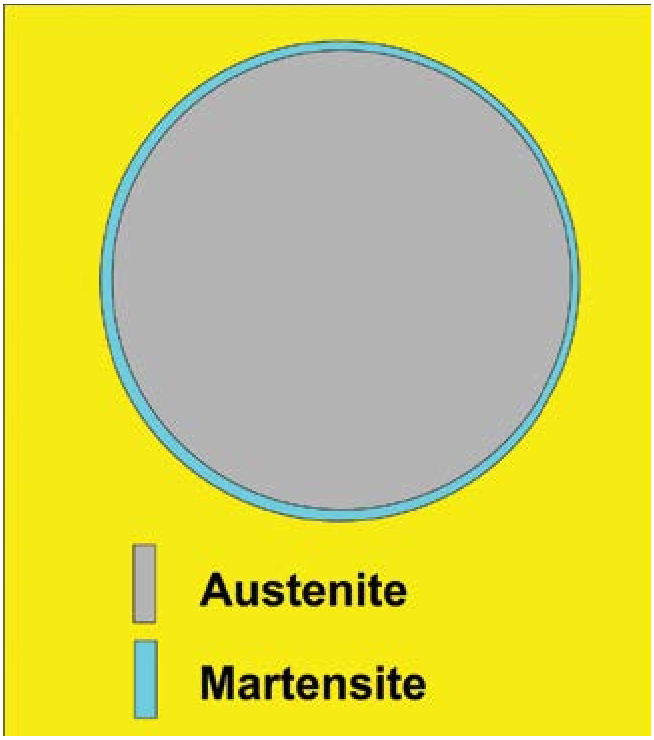

Fig.5. Surface martensitic skin.

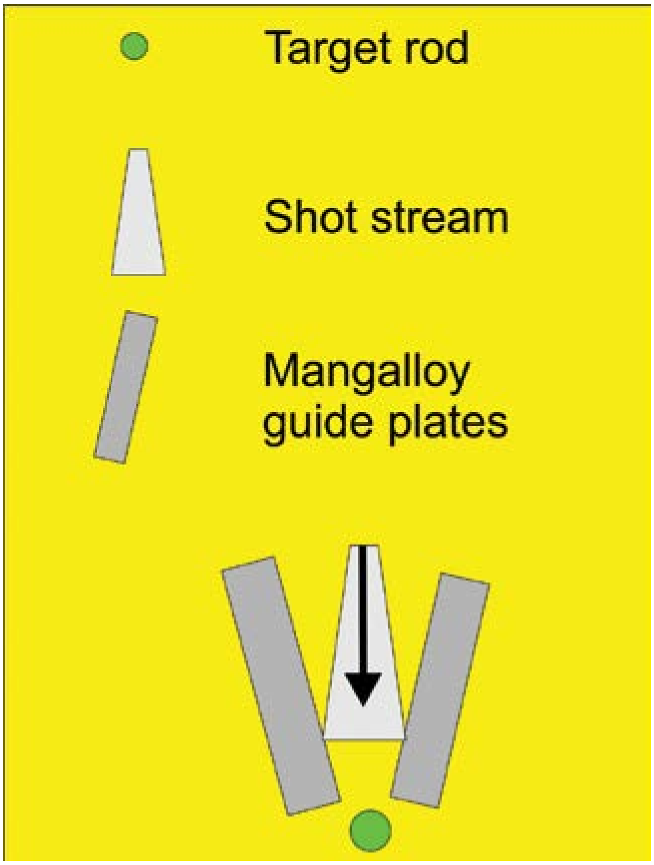

Fig.6. Mangalloy plates guiding shot stream.

Description
UNITED STATES PATENT Office,
ROBERT HADFIELD, OF SHEFFIELD, COUNTY OF YORK, ENGLAND.
STEEL.
SPECIFICATION forming part of Letters Patent No. 303,151, dated August 5, 1884.

Application filed May 5, 1884. (No specimens.) Patented in England January 12, 1983, No. 200.

To all whom it may concern:
Be it known that I, ROBERT HADFIELD, of Sheffield, in the county of York, England, have invented a new and useful Improvement in Steel; and I do hereby declare the following to be a full, clear, and exact description thereof.

In my British Patent No. 200, of January 12, 1883, and my pending application No. 120,640 for Letters Patent of the United States, I describe an improved process, which consists in the admixture of a large percentage of manganese with molten iron in a decarburized or nearly decarburized condition, or to molten steel, whereby I produce a new description of steel of great toughness and hardness, and possessing several peculiar and valuable distinguishing characteristics. The use of manganese in the manufacture of steel has been known and practiced, but only in proportions not generally exceeding one to one and one half per cent, it having always been supposed previous to my invention that the presence of any larger percentage of manganese would be injurious to the steel and result in an utterly worthless product. I have discovered, however, as the result of extensive experiments, that when manganese is added to the metal or to melted steel in the process of manufacture in any proportions not less than about seven per cent. nor more than thirty per cent. of manganese the most beneficial effects are produced and a new product results, which has the valuable qualities of ordinary steel, while differing from it in several important respects, so that my new manufacture of steel is distinguishable from the grades of steel produced by any of the ordinary processes heretofore known in the following particulars: first, in its freedom from honey-comb and other similar defects; second, in its great toughness and extreme hardness, by reason of which the hitherto indispensable processes of rolling, forging, hammering, hardening, and tempering become unnecessary and may be in many cases entirely dispensed with, though of course this material can, if desired, be rolled or forged in the usual manner third, in its great thinness and fluidity, whereby fine steel castings can be made without misrunning, and which will be nearly, if not quite, as smooth as the so-called metal castings; fourth, that when cast it does not settle much and does not draw like ordinary castings, particularly at the junction of the thin and thick parts of the casting. These characteristics of my improved steel render it specially adapted for the manufacture of steel rolls to be used in place of chilled rolls; also, for casting guns and armour-plates, and for wheels for railroad-cars and streetcars, and for the railway plant generally; also, for the manufacture of various implements and parts of machinery, and for making articles known in the trade as steel toys, and for the larger edged tools, which, when cast of my improved steel, need only to be ground, as they can be used without forging or tempering.

In making my improved steel the ordinary manganese of commerce may be used; but I prefer in all cases a rich ferro-manganese as high as possible in manganese, containing about eighty per cent. of manganese, and as low as possible in carbon, silicon, and other foreign bodies. And here I may remark that my invention renders the presence of silicon unnecessary for producing soundness.

In making my improved steel by the process described in my said application I proceed as follows, viz: The ferro-manganese is, if desired, first carefully melted or treated in a reverberating or other suitable furnace before adding it to the molten decarburized iron or steel, into which it is poured in a melted or highly-heated state, or the molten iron or steel is added to the melted or highly-heated ferromanganese. The iron or steel for receiving or being added to the manganese is prepared in any of the known processes of melting and decarburizing cast-iron or making steel in reverberating or other furnaces, and by the Bessemer process, or that known as the open-hearth process. when the metal is decarburized, or nearly so, or the steel melted, as the case may be, in any desired manner, the melted or heated ferro-manganese is poured into it, or vice versa. The mixed molten mass is then well stirred by any known means, so as to incorporate the manganese thoroughly with the molten decarburized iron or the steel. When this has been effected, nothing remains but to pour out my improved steel thus percent. of manganese. More or less ferro-manganese into ingot or other suitable moulds, when, after cooling, it is ready for use without tempering, rolling, forging, or hardening, though it may be rolled or forged in the usual manner.

It remains only to state the proportions in which the manganese should be mixed with the iron or steel to produce the desired result. This will depend on the purpose for which the steel is desired to be used. To produce a steel suitable for armour-plates, I add such a quantity of rich ferro-manganese (containing about eighty per cent. of manganese) as to obtain in the steel, decarburized iron, &c., under treatment about ten per cent. of manganese. If the steel is to be used for making car-wheels or railway plant, I add such a quantity of ferro-manganese which yields a steel containing about eleven per cent. of manganese. In edge-tools and steel toys I add such a quantity of ferro-manganese as to obtain a steel containing about twelve percent manganese may be used, according to the hardness of steel required. The range of proportions which I have found to produce beneficial results, and which I desire to include in my invention, is from about seven to thirty per cent of manganese.

The steel thus produced I have found to be harder, stronger, denser, and tougher than steel now made, even when the latter has been forged and rolled.

Having thus described my improvement, what I claim as my invention, and desire to secure by Letters Patent, is—

As a new article of manufacture, steel containing a proportion of from about seven to thirty per cent. of manganese.

In testimony whereof I have hereunto set my hand this 23d day of June, A. D. 1884.

ROBERT HADFIELD.
Witnesses:
IIAYR. RONSON, BENJ. FREEBOROUGH.