WROUGHT IRON

ITS MANUFACTURE
CHARACTERISTICS
AND APPLICATIONS

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ITS MANUFACTURE, CHARACTERISTICS AND APPLICATIONS

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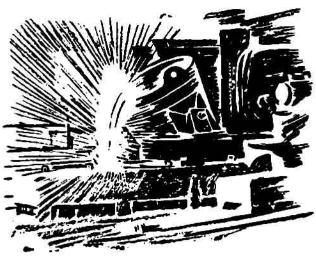

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PREFACE TO SECOND EDITION

DURING *the past decade there has been a rapidly growing demand for wrought iron in many different products. This demand has been accompanied by a need for information on the qualities of the material and their application to present day problems. This handbook is dedicated to that need.*

The manufacture of wrought iron is the oldest branch of the ferrous metal industry, and until recent years the details concerning the methods employed were not generally known because a high degree of individual skill was required to produce good quality material. Thus, in many cases, users of wrought iron had available very little reliable information on which to base their decisions.

This book has been written to serve as a source of up-to-date information on wrought iron for all who are interested in problems of material selection as well as for those students in colleges and universities who may someday become responsible for engineering specifications. In order to make the subject matter both clearly understandable and concise, no attempt has been made to go into minute details concerning the history of wrought iron manufacture, since that covers a period of several thousand years and much of it has no direct bearing on present day or future problems. For the sake of clarity, numerous photographs have been employed to better illustrate the various phases of the subject.

The wide acceptance accorded the first edition of this volume has been a source of inspiration and gratification to the authors. Many comments on the text have been received which contained helpful suggestions or criticisms. Many of these comments have formed the basis for revisions in the text of this second edition. Also, some new material has been added which it is felt will serve to enhance the value of this volume to all members of the engineering and educational professions.

The successful completion of this work has been made possible through the friendly cooperation of many individuals whose contributions, constructive criticisms, and practical suggestions are acknowledged with thanks.

J. A.
E. B. S.

Pittsburgh, Penna.
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Chapter I

WROUGHT IRON

WROUGHT iron is best described as a two-component metal consisting of high purity iron and iron silicate—a particular type of glass-like slag. The iron and the slag are in physical association, as contrasted to the chemical or alloy relationship that generally exists between the constituents of other metals. Wrought iron is the only ferrous metal that contains siliceous slag.

Many different processes have been employed in the manufacture of wrought iron during the thousands of years it has been made and used by man. Naturally, vast improvements have been made in manufacturing methods as well as in the quality of the finished wrought iron, but, peculiarly, the characteristics of the metal and the metallurgical principles used in producing it have remained unchanged. With any method of manufacture, the initial product, which is subsequently squeezed and rolled, is always composed of a pasty or semi-fused mass of cohering, slag-coated granules of refined iron.

Until comparatively recent times, the slag content of wrought iron was considered as an undesirable impurity. It was present because the maximum temperatures obtainable in the furnaces used were not sufficiently high to keep the iron in the molten or liquid state after the greater portion of the metalloid impurities, principally carbon, had been eliminated. In other words, during the final stages of the refining operations, the fusion temperature of the iron was equal to or above the temperature of the furnace, thus causing the refined iron to solidify and, in so doing, to entrain some of the molten siliceous slag in which it was partially immersed. Today, of course, the slag is generally recognized as being responsible in a large measure for the desirable properties

This photomicrograph of wrought iron, taken at 100 magnifications, shows clearly the glass-like siliceous slag fibres embedded in the high purity iron base metal.

of wrought iron—particularly its resistance to corrosion and to fatigue.

In 1930, the American Society for Testing Materials adopted the following definition of wrought iron that takes into account the facts stated above.

> "Wrought Iron—A ferrous material, aggregated from a solidifying mass of pasty particles of highly refined metallic iron, with which, without subsequent fusion, is incorporated a minutely and uniformly distributed quantity of slag."

The iron silicate or slag content in wrought iron may vary from about 1% to 3% or more, by weight, depending upon the amount of rolling necessary to produce the finished section. It is distributed throughout the iron base metal in the form of threads or fibres which extend in the direction of rolling. In well made wrought iron, there may be 250,000 or more of these glass-like slag fibres to each cross-sectional square inch. The slag content occupies a considerably greater volume than the percentage by weight would indicate, because the specific gravity of the slag is much lower than that of the iron base metal.

The accompanying photomicrograph of wrought iron taken at 100 magnifications shows the manner in which the non-rusting slag fibres are incorporated in the highly refined base metal. The presence of these fibres gives the metal a tough, fibrous structure similar to that of hickory wood. This similarity can be seen easily by comparing pieces of each material that have been nicked and fractured slowly.

A typical chemical analysis of wrought iron showing the distribution of metalloids in the two constituents is listed as follows:

DISTRIBUTION OF CONSTITUENTS

Chemical Composition

Elements	Combined Analysis	Constituents Occurring in Base Metal	Constituents Occurring in Slag
Carbon	.02%	.02%	—
Manganese	.03	.01	.02%
Phosphorus	.12	.10	.02
Sulphur	.02	.02	—
Silicon	.15	.01	.14
Slag, by Weight	3.00	—	—
	Total Metalloids	.16	.18

A clear understanding of the internal structural and chemical differences between wrought iron and other commonly used ferrous metals may be obtained by comparing this photomicrograph and analysis with those in Chapter V.

Chapter II

WROUGHT IRON MANUFACTURE PRIOR TO 1850

WROUGHT iron was known and used long before the beginnings of recorded history and evidences of this are available today. In the Bible, Genesis, IV, 22, mention is made of iron cutting instruments. A wrought iron sickle blade was found beneath the base of a sphinx in Karnak, near Thebes, Egypt, while a blade probably 5000 years old was found in one of the pyramids. Numerous other similar discoveries have been made in Europe, the Mediterranean countries and the Far East.

All of the early methods used for wrought iron manufacture were based on producing the finished product in one operation. These were known as direct methods. It was only after the introduction of the blast furnace during the fourteenth century A.D. that the indirect methods were developed.

PRIMITIVE METHODS

Man's first acquaintance with wrought iron probably was the result of an accident caused by the building of a fire in a locality where the earth was rich in iron ore. Little or nothing is known about the primitive developments, but undoubtedly the use of iron began when it was found that this material could be forged readily into weapons tougher and stronger than wood or stone.

The production of wrought iron became a matter of great importance to our primitive ancestors, and in the course of time they learned to distinguish the iron-bearing ore that would produce the largest yield of metal and to build it into piles around their fires. Very likely they later found that the metal could be

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produced more quickly when the ore was broken up and mixed with the fuel. The first iron furnace on which there is any information consisted merely of a hole in the ground with an opening at the bottom to provide natural draft.

Primitive Method

EARLY EGYPTIAN METHODS

The origin of forced draft in wrought iron making is unknown, but prior to about 1500 B.C. the Egyptians had developed a bellows made of goat skins with a bamboo nozzle and an air inlet valve. The operator of the bellows, probably a slave, stood on the skin bag to expel the air and reinflated it by pulling up on a string attached to the top. The use of forced draft was one of the first major developments in wrought iron manufacture.

While the Egyptians' furnaces were crude, consisting merely of pits into which the ore and fuel were placed, the enduring qualities of the wrought iron produced in them is indicated by the excellent condition of implements and other equipment found when exploring ancient tombs.

Early Egyptian Method

ASIATIC IMPROVEMENTS

The development of the original furnace, as such, is generally credited to the Asiatics, who also introduced the idea of adding layers of the ore and fuel mixture at the top of the fire as reduction took place. The early Asiatic

Asiatic Method

furnace had a trough at the top from which the smelter raked the raw materials on the fire.

Bellows of improved design were used to supply the forced draft. In operating them, the heel of the worker's bare foot on the downward stroke closed small holes in the top, thus forcing air into the furnace. On the upward stroke, the top of the bellows being raised by means of a string attached to a springy rod, the holes were uncovered permitting reinflation.

As reduction took place, the refined iron collected at the bottom of the furnace in a spongy mass which, after a sufficient amount had been obtained, was taken out and forged.

DEVELOPMENT OF FURNACES USED IN THE DIRECT PROCESSES

There were many variations in design of the early furnaces used for wrought iron production in different parts of the world. However, many furnaces were of the "shaft" type while others were of the so-called "hearth" type.

About the eighth century A.D. a new furnace known as the Osmund furnace was developed and used extensively. It was square in cross section, somewhat larger at the top than at the bottom, and approximately ten feet high. There were numerous modifications of this furnace. Later designs were circular in

13th Century Improvement—Catalan Forge cross section, with the point of greatest diameter occurring a few feet above the bottom. Forced draft was supplied by means of bellows. As far as it is known, shaft furnaces were used mainly in India and Sweden. The upper portion of the shaft was used both as a stack and as an opening for charging the fuel and iron ore. When the iron was refined and had collected on the bottom in a spongy mass, an opening would be made in one side of the furnace to permit removal of the "ball."

The Catalan Forge, originated about 1293 A.D. by the iron workers of Catalonia in Spain, represented a major advance in the manufacture of wrought iron direct from the ore. This was a hearth type furnace consisting of a hearth or crucible in which the mixture of ore and fuel was placed. The air-blast, produced by means of a trompe or water blower, entered the furnace through tuyeres near the bottom.

The efficiency of the Catalan Forge, which is said to have produced about 140 pounds of wrought iron in five hours, was considerably higher than that of earlier furnaces. This furnace was introduced into the American colonies and used principally in the South.

The American Bloomery, an offspring of the Catalan Forge, represented the highest development of the hearth type of furnace. The hearth was rectangular in shape, with water cooled metal sides, and was surmounted by a chimney for carrying off the waste gases. A forced hot-blast was used, and the bellows supplying the blast were driven by a water wheel or a steam engine. As in all of the other direct processes, charcoal was used as fuel.

The Bloomery was used in this country as late as 1901 and in that connection the following comment appeared in the 1908 Annual Statistical Report of the American Iron & Steel Association, page 78:

> "No forges for the manufacture of blooms and billets direct from iron ore have been in operation in the United States since 1901, in which year the blooms and billets so made amountd to 2310 gross tons, against 4292 tons in 1900 and 3142 tons in 1899. All the

Catalan forges in the South have been abandoned; so have those in the North and West."

Obviously, during the many centuries that the direct processes were used exclusively, it is to be assumed that numerous different types of equipment would have been developed. Space limitations make it impossible to mention all of the furnaces of which there is some record, and, therefore, reference has been made only to the more prominent types.

Although the direct processes for wrought iron production have been abandoned almost completely by the most advanced nations, they are still used in some parts of the world.

DOUBLE-STAGE REFINING

In the fourteenth century the wasteful and tedious method of producing wrought iron direct from the ore began to be replaced by a division of the operation into two stages. Previous to this, the single-stage reduction had been uncertain as to results and tremendously wasteful of time and materials.

Little difficulty was encountered in ridding the manganese, sulphur, phosphorus and other impurities from the iron, but the elimination of the carbon in the iron was a doubtful process, because the charcoal used as fuel was an energetic carburizing agent, and it was only by the most painstaking care that the wrought iron, when brought into contact with this fuel, was prevented from recarburizing to the point where it was no longer malleable and ductile.

It was discovered that a second heating would serve to further refine the metal which had been so over-carburized, and the wrought iron produced by this additional working was more uniform and otherwise superior to the product of the single reduction. In this second operation, which ordinarily was carried out in a Catalan type of furnace, the iron was further refined and, in addition, a portion of the slag was removed. This double-refined ball of wrought iron was called the "blume," or flower, from which the present use of the word "bloom" is derived.

THE DEVELOPMENT OF CAST IRON

Until the iron makers of Central Europe developed a new type of furnace around 1350, wrought iron had been the only product made from iron ore. This development was the result of efforts to reduce the fuel consumption and the cost of manufacture by increasing the size, and especially the height, of the furnaces used in the production of wrought iron. However, the product of this new furnace was not wrought iron since it was taken from the furnace in the molten state, as contrasted to the slag-impregnated sponge-like mass of iron secured from the furnaces or forges in which wrought iron was made. Also, upon cooling, this new metal possessed properties unlike those of wrought iron in that it was hard and brittle, and, when fractured exhibited a crystalline or granular structure as contrasted to the tough, fibrous structure of wrought iron.

This new furnace, known as a "stuckofen," was the progenitor of the modern blast furnace, and, like all furnaces of that time, it required the use of charcoal as fuel. The raw materials—iron ore, flux and charcoal—were charged in at the top of this furnace, while air, under very low pressure was blown in at the bottom.

Coke was first considered as a fuel in 1619, but it did not come into extensive use until about 1730 when Darby successfully applied it to blast furnace operation. This development was followed by the introduction of the hot blast in the early 1800's. The greatest improvements in blast furnace design and operation have been made since 1880.

While the product of the stuckofen, or blast furnace, was not malleable and ductile, and could not be hammered or forged and welded like wrought iron, it was soon discovered that the new metal could be cast into various useful shapes. Thus, cast iron was introduced. Subsequently, the principal product of the blast furnace became known as "pig iron" because it was cast in small moulds or "pigs." In this form it is remelted and used for the manufacture of other products.

THE DEVELOPMENT OF CHARCOAL IRON

Shortly after the commercial production of pig iron was commenced, the need for a more highly refined material than cast iron led to the introduction of so-called charcoal iron. Originally, charcoal iron—also called knobbled iron—was made by charging alternate layers of pig metal and charcoal upon the hearth of a small rectangular furnace provided with a stack and a number of tuyeres for the introduction of cold air blast. The temperature in this furnace became sufficiently high to melt and partially purify the pig iron. Most of the silicon and some of the phosphorus was eliminated. This partially purified metal, when tapped out, was allowed to solidify and was then broken up and charged into a second furnace with alternate layers of charcoal. As the metal was melted in this second furnace, it was further purified and practically all the carbon removed. Since it was impossible to obtain high temperatures in this furnace, the molten metal, as it trickled down through the mass of iron and charcoal, became partially solidified by the time it reached the furnace bottom and in this stage entrained a small amount of the refining slag. The spongy mass of iron and the entrained slag in the bottom of the furnace was collected from time to time and pressed into a bloom.

Charcoal iron, as made by this process, differs from wrought iron in that it has a higher carbon content and a considerably lower slag content. Furthermore, the slag consists almost entirely of iron oxide in charcoal iron, while the slag entrained in wrought iron is of a glass-like siliceous type which is considered much more resistant to corrosion than the iron oxide type slag.

Charcoal iron, because of its small slag content, around one per cent, possesses somewhat more ductility than does genuine wrought iron. This higher degree of ductility is most pronounced opposite to the fibre direction. Accordingly it has found some use for applications where severe fabrication must be withstood. At present this material is used very little except for boiler

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