THIS PAPER WAS FIRST PRESENTED

AT THE

60th ELECTRIC FURNACE CONFERENCE

HELD IN

SAN ANTONIO

NOVEMBER 10-13, 2002

AND IS REPRODUCED HERE BY KIND PERMISSION OF THE

IRON AND STEEL SOCIETY

120 YEARS IN PIG IRON

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Key Words: pig iron, history

INTRODUCTION

Iron is extremely old and yet very modern. It is perhaps more relevant today that it ever was. The modern world without steel is unthinkable as is steel without iron. In fact the per capita consumption of steel is considered a measure of the affluence of a nation. The discovery and development of techniques for the production, refinement and further processing of iron have been responsible for many of the improvements in the world but equally for the increasing toll on human life in war. The early grades of iron are no longer heard of, nor are the earlier grades of pig iron. Yet interestingly although it took 3 millennia to successfully produce pig iron and perhaps 3 centuries to get the production rates up to modern levels, most of the changes in the types of pig iron have taken place in the last sixty years. Alternative sources of iron units have been developed but none has replaced the dominant position of pig iron in the making of steel. In the production of castings the picture is different and scrap has overtaken pig iron in the last half century and is quite clearly the favoured raw material in foundries. Similarly alternatives to the blast furnace for the production of pig iron have been developed but only the EAF route has proven to be a serious challenger. In the next sixty years the changes are likely to be just as profound both in the types of pig iron and the means of making it.

HISTORY OF IRON

Iron was known prior to 3000 BC or before recorded history. The first iron implements date from around 3000 BC. The extraction of iron from ores seems to have started in the Near East (Anatolia & Persia) around 2000 BC and by 1000 BC the Iron Age was under way with the smelting of iron ores; it then spread to Europe by 750 BC and reached Spain by 400 BC. Over the same period iron smelting was probably being developed in China. One theory has it that iron smelting in the West occurred by error whilst trying to smelt copper; iron ore instead of copper ore was placed in the furnace which had a particularly good draft so that the temperature was a little higher than normal.

Although iron is one of the most common elements in the earth's crust (34.6% by mass, 5% by volume) it is not found there in its elemental form. In fact the first source of iron was meteorites, a fact that led to its description as the metal of heaven. Meteoric iron contains 5-26% nickel and this allows it to be distinguished from smelted iron. The first piece of non-nickel iron comes from the great pyramid at Giza and is dated ca. 2900 BC. The first record of a smelting process was found on the wall of an Egyptian tomb dated ca. 1500 BC. The Iron Age opened with the production of bloom which through heating and hammering was made into wrought-iron. The problem was that the temperature could not be raised enough to melt the iron and the conversion of the ores took place chemically. From the tenth century onwards the smelting process developed steadily; hand operated bellows were replaced with waterwheel driven ones so allowing more air at a higher pressure. Heat recovery started with an increase in the stack and the materials being fed down through the gas stream. By the 15th Century the first blast furnaces appeared and pig iron production became possible. The Stuckofen in Germany was the first furnace that resembled modern blast furnaces in its shape and the use of tuyeres. Production rates were a little different to today; the Stuckofen, a great technical leap forward, produced 100 to 150 tpa. With the blast furnace and pig iron came cast iron and a new route to wrought iron called fining. The Stuckofen became the Bauofen which could produce liquid iron or forging iron at will. This then became the Flussofen and ultimately the Hochofen or blast furnace. Over the next centuries efforts concentrated on the production rates of the blast furnaces to such an extent that the fining process could not keep up. The development of the puddling furnace in 1784 enabled malleable or wrought iron production to keep up until the development of the hot-blast stove in 1828. The higher temperatures meant that carbon levels in the iron could be raised with the result that the melting temperature fell so opening the way to liquid pig iron and casting. Fascinating is that at this time the pig iron was considered a problem as it was too brittle to be worked with a hammer. It was often recharged or thrown away. In China the well established porcelain industry meant that blowers were already in existence well before ironmaking started so that pig iron and casting was known and used much earlier than in the West. Whereas the discovery of iron smelting took place in Africa, China and the Middle East the development of the blast furnace was a purely European one; unfortunately it was war and the need to cast cannons that forced this along apace and turned the furnace from a forging iron producer used in the making of swords to a cannon maker. The first blast furnace in North America was at Falling Creek in Virginia in 1622. It never operated because the local Native Americans massacred the operators and destroyed the furnace. Somehow this reminds one of the efforts of some authorities today. The first successful blast furnace was in Sagus, Massachusetts; it started operating in 1645.

In the early days all iron making relied on charcoal; the depletion of the forests that were being used for firewood and charcoal forced the iron makers to look for another fuel and this led to the use of coal. The development of coke seems to have been a natural follow-on to the manufacture of charcoal with the charcoal furnaces being "misused" for coke production. The first coke was produced in England because deforestation was most advanced there. It was not published as a great discovery and its use seems to have spread slowly outwards from the English midlands where it had been discovered. It allowed higher furnaces and larger volumes of air and so increased production. There were many other discoveries that helped ironmaking progress, especially in chemistry which was often closely related; the discovery of manganese in 1774 and the element oxygen in 1773 being just some examples.

Iron has a natural affinity to unite with other elements and so can take on many forms; however to simplify things one can define three broad categories, wrought iron, cast iron and steel. Wrought iron has lost its significance and is today only found in some decorative work, cast iron is still of great relevance and is made in large tonnages but these pale next to the quantity of steel produced.

IRON AND LANGUAGE

The name pig iron is one that fascinates the non-English speaker. According to tradition at the International Pig Iron Secretariat the name comes from the combination of using agricultural labours in the first iron plants that then "saw" pigs suckling in the shapes of the launder, runners and pools where the lumps of iron or "piglets" were formed.

Long before these thoughts gave a colourful view to a fairly dirty business the name for iron had derived from its first source in meteorites. The Babylonians called it "parzillu" and the Sumerians "barzel" and the Egyptians "ba-en-et" all meaning "metal from heaven". The Europeans had a similar "legend" with the Roman god Jupiter Dolichenus being the witness to its birth somewhere in Anatolia so that in references to where he came from one is forever finding the phrase "ubi ferrum nascitur" or where iron was born. The Latin word Ferrum has given us the chemical symbol for iron of Fe. This root can be found in many European languages today, "fer" in French, "ferro" in Italian and Portuguese, "hierro" in Spanish, "fier" in Rumanian, "fièr" in Walloon, "fierro" in the Neapolitan dialect and ferrous in English. The Latin word for steel "acies" meaning sharp is also very widely found; "acier" in French, "acero" in Spanish, "aço" in Portuguese, "accaio" in Italian, "acîr" in Walloon, "accirio" in Neapolitan and "acîr" in Rumanian. The German word for iron "Eisen" seems to have come from the Slavonic root. Strangely the word for pig iron in Russian and Ukrainian appears to be have been adapted from the Chinese; it probably came with the Mongols. The original words from which they made the adoption "chu" is no longer in use in China but is probably the origin of the word "gun". The same word also moved to Japan to give the word "chutetsu" a mixture between a Chinese word and an original Japanese word. The word in Italian "ghisa" and Portuguese "gusa" are derivatives of the French word "guese" which in turn comes from the German word "Göse" for goose. The idea of a goose came from the appearance of the surface of the pig iron. The word "iron" itself is Anglo-Saxon. Interesting is that the Romans took over very few words related to iron from the Greeks. This is probably because they didn't learn of iron from the Greeks but rather from the Phoenicians via Anatolia. Words of Greek origin that appeared in Latin appeared in the last century BC, examples are "metalla" and "kaminos".

Regrettably like the reasons for the development of ironmaking even our quotes involving iron are either warlike or unflattering. Sidney Whiman describing Lord Salisbury said he was "a lath of wood painted to look like iron". Bismarck said "this policy can not succeed through speeches, and shooting matches, and songs; it can only be carried out through blood and iron". Churchill speaking in 1946 "from Stetin in the Baltic to Trieste in the Adriatic an iron curtain has descended across the Continent". A Psalm reads "To bind their kings in chains: and their nobles with links of iron". Richard Lovelace wrote "Stone walls do not a prison make, Nor iron bars a cage".

Perhaps Samuel Smiles speaking in 1884 best summed up *OUR* relationship with iron when he said "This extraordinary metal, the soul of every manufacture, and the mainspring perhaps of civilised society".

IRON ACT

Before I move on to the advertised subject of this paper one totally useless piece of information I came across which somehow seems appropriate for a person born in England speaking to a largely American audience, “the Iron Act”. This act which was one of the British Trade and Navigation Acts was intended to stop the development of colonial manufacturing in competition with home industry by restricting the growth of the American iron industry to the supply of raw metals. To meet British needs pig iron and iron bars made in the colonies were permitted to enter England duty free. In the colonies the establishment of furnaces that produced steel was prohibited. The policy was successful in that in suppressed the manufacture of finished iron goods in the colonies whilst colonial production of basic iron and pig iron, which were then shipped to England, flourished. (Encyclopaedia Britannica, Inc. 1994-2000).

60 YEARS AGO

All the above relates to the last three or four millennia. As promised in the abstract to this speech I took it upon myself to say something of the development of pig iron over the last sixty years and then to look ahead to developments in the next sixty years.

Sixty years ago in 1942 the world was at war. Iron and steel were essential commodities. Due to shortages all these and all kinds of raw materials and production processes were tried that one would not consider in more normal times. In 1946 Europe and much of the Far East lay in ruins and had to be rebuilt. In Europe, this and the desire to make war impossible, led to the establishment of the European Coal and Steel Community. The formal contract was signed in Paris on the 18 April 1951 by Belgium, France, Germany, Italy, Luxembourg and the Netherlands. It attempted, successfully as it turned out, to link the Steel and Coal industries within the various countries so closely that war between them would not be possible whilst allowing economic and industrial recovery to go ahead.

It certainly worked. Steel production in the ECSC countries rose from 40 million tonnes in 1953 to 159 million tonnes in 2001; world steel production rose from 200 million tonnes to 847 million tonnes over the same period. At the time steel production was based almost exclusively on the blast furnace and hence the pig iron route. Perhaps even more impressive and certainly more importantly, for the first time in many centuries there has been peace in Western Europe for more than fifty years; iron and steel had reversed their historic role and had become promoters of peace rather than war. It established a free market for coal and steel products and was the forerunner of the European Union.

In 1967 the International Pig Iron Secretariat, IPIS for short, and the association that I represent was founded. There were 12 members, eight from Europe, Australia, South Africa and my homeland Zimbabwe. The purpose was then, as it is now, to promote the use of pig iron.

World trade in pig iron in 1967 was estimated by IPIS at 8.9 million tonnes against the background of world pig iron production of 340 million tonnes. At the time the foundry industry was a significant user of pig iron with far higher percentages of pig iron in the charge than is common today; yet even the amount of pig iron used in the foundries then was minute in comparison with the amount used for steelmaking. It is very difficult is to establish a breakdown of the pig iron production between pig iron for steelmaking and for foundry use.

Many countries statistics did not distinguish between grades. A rough guess based on the ratios for Europe and the USA gives figures of 92 to 94% of the pig iron made being consumed in steelmaking. This gives consumptions of 315 million tonnes in the steel industry and 25 million in the foundry industry.

At the time one was dealing with products that have, at least for us today, exotic sounding names:

Thomas pig iron – for steel production
Siegerländer pig iron – higher levels of Mn (1.0-6.0%)
Blast furnace ferrosilicon – higher Si (9-15%)
DKC or Silver or MIGRA pig irons – low C (2.4-2.8%)
Hochgekoltes or high carbon pig iron – contained Ti (0.1-0.9%) with C (4-6%)
Temper or Malleable pig iron – normally lower Si and C.
Gießerei or foundry pig iron – higher P (0.5-2.0%)
Mottled pig iron - low Si (0.7-0.8%) & low Mn (ca. 0.3%)
White pig iron – v. low Si (0.4-0.6%), low Mn (0.2-0.3%) & high S (0.10-0.15%)
Nickel-Chrome pig iron – Ni (1-15%), Cr (0.3%-10%)
Charcoal based pig iron –
Titanium pig iron – Ti (0.8-1.1%)
Spiegeleisen – a type of ferromaganese, Mn (6-30%),
Kügelgraphiteisen – a forerunner of spharodial pig iron for SG castings.
And Haematite pig iron.

And these were just those grades on offer from the German producers.

Pig iron from blast furnaces remains the main route to steel in 2002. It has however lost its overwhelming dominance with the emergence of electric arc furnace production based largely on scrap. Today this route accounts for 33% of the steel made. Today world steel production is approximately 850 million tonnes and world pig iron production 580 million tonnes. Of this pig iron some 12 to 15 million are being traded as merchant pig iron. By far the largest portion of the traded merchant pig iron is basic pig iron for the use in electric arc steel production. The usage of pig iron in the foundries is very hard to estimate because a number of large consumers make and consume their own pig iron but a rough guess puts the figure at 5 to 10 million tonnes per annum; sharply down on the situation sixty years ago.

Other processes and products have emerged in the last sixty years to challenge the leading position of pig iron as the primary raw material for steelmaking. DRI and HBI have risen from nothing sixty years ago to a production of 45 million tonnes per annum today. Iron carbide has not been the success that many hoped and is still a bit player today. Both of these processes rely for their economic success on the availability of cheap natural gas and low priced iron ores and therefore expansion is restricted to particular localities.

If one accepts the blast furnace and the electric arc furnace as the commercially viable and proven major league players in the production of steel then there are a number of others challenging for promotion. Three types of process have emerged over the last few decades which have a chance. Direct reduction technology followed by an electric furnace. This is the most advanced and proven technology at a commercial level but has yet to break into the big time. Rotary hearth technology has been around for some time but is still playing a minor role with the main thrust in the direction of waste material processing where it has major advantages in the separation of zinc, a real problem for the blast furnace guys. The latest challengers are the single unit smelting reduction processes Corex, Hismelt, Finex, Rosmelt and Ausmelt. All have high energy consumptions and with the exception of Corex are not proven at full commercial production levels. There are others like Technored and Cupola reduction but these are all very much in their infancy at least as regards becoming big time producers of pig iron for the steel industry. One sees from this that new means of producing pig iron have emerged but aside from the electric arc furnaces none have come near to challenging the blast furnace. Perhaps the most remarkable development in the last sixty years has been the increased efficiency and productivity achieved in blast furnaces, a so-called mature technology.

What has emerged in the pig iron world in the last decade is renaissance of the trade in basic pig iron. Whereas in the fifties and sixties this was aimed at supplementary iron units for the blast furnace producers it has now become a clean iron unit source for the electric arc operators looking to produce ever higher quality steels. I look into this in some detail in my paper "Is pig iron vital to electric furnaces users?" to be presented later at this conference. Also the pharmaceutical approach to making many hundreds of grades of pig iron for the foundry industry has rationalised into two main categories and less than twenty grades. This development was unavoidable as the many small furnaces and producers, often serving a very local market, have closed down. Today's big players are Russia, Brazil, Canada and South Africa all of whom ship pig iron all around the world; it is thus impossible to offer more than a very limited number of grades. Today a producer offers three to four grades in each category of pig iron, normally defined according to the silicon content.

THE NEXT 60 YEARS

The changes in the pig iron market in the last 60 years were profound and there is little reason to believe that the next 60 years will be any less exciting. When one asks the question in which direction the pig iron world will go, then one is really asking a number of questions.

- Question 1
  Will the blast furnace remain the dominant process route for the production of pig iron?

- Question 2
  Will other production routes move to the fore?

- Question 3
  Will pig iron remain the major raw material for the production of steel?

- Question 4
  Will scrap quality deteriorate as many have predicted?

- Question 5
  Will the production of pig iron as a by- or couple-product continue to grow at current rates?

- Question 6
  Will the foundry industry continue to use pig iron as a feed?

- Question 7
  Will new grades of pig iron be discovered?

- Question 8
  Will old grades of pig iron fade away?

- Question 9
  Will the location of the major production facilities, both steel and foundry, move?

I will try to answer these questions but they are huge topics and detailed answers are quite beyond the scope of a twenty minute presentation. My answers are of course speculations and nothing more; sixty years is a very long time in technological terms. Probably most of the predictions will prove to be wrong; however it is certain that, assuming some of them do turn out to be correct, many will happen well before 2062.

Question 1. Will the blast furnace remain the dominant process route for the production of pig iron?

The answer is probably no. The blast furnace will remain a major route for the production of pig iron but its dominant position will be further eroded. The electric furnace route will probably be the main winner but the other technologies will find their place in the market, if in some cases only as niche producers. The reason for this conclusion is that the environmental protection requirements converted into capital costs will make the blast furnace progressively more difficult to finance because of the sheer size of the initial layout. Here I am thinking not only of the blast furnace itself but of the coke and sinter plants associated with them. Building a coke plant today is a massive undertaking compared with securing the electric supply for an arc furnace. Sinter plants, already a dying breed in North America, are also massive undertakings when one looks at the environmental requirements. Hence there are likely to be far more closures of coke and sinter plants than start-ups, at least in the developed world. The loss of these plants will also result in the closure of some blast furnaces. Companies wanting to replace this lost capacity will find it easier and cheaper to do so other means. There is also a strategic argument. Will the companies want to rely on distant countries of unknown supportiveness for the bulk of their critical raw materials when there is an alternative where the raw material, namely scrap, is available domestically? The quality argument will also fade with arc furnaces increasingly able to make the better grades of steel. In one sentence; still important yes but not as important as it was.

Question 2. Will other production routes move to the fore?

The closure of sinter plants combined with the requirement to process wastes and find an alternative outlet for fine iron ore will ensure that some of those processes currently in their infancy will grow to be major players. Hence alongside the electric arc route others will move into the major league.

Question 3. Will pig iron remain the major raw material for the production of steel?

Here the answer is an emphatic yes. The erosion of the blast furnace will be primarily to the benefit of the electric arc route and it is also a pig iron producer. Also some of the new technologies will also go to pig iron rather than stopping at DRI.

Question 4. Will scrap quality deteriorate as many have predicted?

The answer to this question is also yes. The implication behind this question is that it will mean the automatic renaissance of the blast furnace and other routes to clean pig iron. The thinking being that the electric arc route, relying on scrap, will not be able to cope with the dirtier scrap. This I do not believe. Scrap will surely get dirtier since it is nothing other than the recycling of the steels from earlier, and they are getting dirtier in the sense that they contain more zinc in the form of galvanising and more alloying agents. However the sorting and classifying of scrap will also get better and the users of scrap will get learn how to cope and counteract the problems associated with the increasing level of contaminants. It will however mean that use of pig iron in this area will probably increase.

Question 5. Will the production of pig iron as a by- or couple-product continue to grow at current rates?

Here the answer is also an emphatic yes, at least for so long as titanium dioxide remains the major whitening agent. The production of titanium slag with its by-product production of SG pig iron has been increasing steadily over recent years and seems set to grow even faster in the future. On top of this the restrictions on the beaching of pig iron will ensure that those blast furnaces that continue will build pig casters to allow them to run flat out at all times independent of the steel shop off-take. A further source will arise from those processes that today dump iron in various forms because it is too expensive to recover it; they will no longer be allowed to dump.

Question 6. Will the foundry industry continue to use pig iron as a feed?

My answer here is a cautious yes. I believe that the foundry industry will continue to reduce the percentage of pig iron in the charge. The basis for this belief is the same as that for the electric arc furnace users; they will continue to learn how to cope without it and with the problem elements in the scrap. That they can live without pig iron is evident today in many foundries. Another trend will tend to encourage this and that is the steady and continuing move in the foundry industry from grey iron castings to SG. The internal returns from the SG production make an ideal feedstock for the grey iron foundries. Pig iron as a feed to the foundry industry will move into certain niche markets and as a type of alloying agent.

Question 7. Will new grades of pig iron be discovered?

My answer here is a definite yes. Casting remains the optimal process for certain types of job. Where one is confronted with making a complex object which should or can be a single piece then casting is often the best solution. Two examples are the hub for wind driven generators and units to hold the very powerful magnets used in experiments for synchrotron radiation. In the first a structure made from steel would require welds at exactly the points where there are the highest dynamic loads. In the second the strong magnetic fields set up large forces yet positional accuracy is very important even after frequent assembling and disassembling and here a welded structure can not satisfy these requirements economically since the ribs of the structure could not have been adapted to handle the stress in the same way as a casting. The difficulty is that steel for these uses would require expensive alloying elements and elaborate process to achieve the necessary mechanical properties. Casting has so many advantages that it will continue to be used in many traditional areas and will find new uses. Thus the casting industry has a secure future.

The pig iron and casting industries will continue to develop and create new products. As this happens new grades of casting will be discovered and they will require new types of pig iron. The pig iron industry itself will produce new types of pig iron, either due to economic necessity or due to new recycling production processes coming on-stream.

Question 8. Will old grades of pig iron fade away?

My answer here is an emphatic yes. Life moves on and grades known today will no longer be available and/or demanded. I believe that SG pig iron will blur with time into a type of basic pig iron. I believe that haematite will shrink down into the level of the exotics. The dominant pig iron in the future will be basic pig iron both for steelmaking and for the foundry industry.

Question 9. Will the location of the major production facilities, both steel and foundry, move?

My answer here is yes. We are seeing this already and the trend will continue. The real question for this discussion is however whether this will affect the types and amount of pig iron processed. The answer here must also be yes; it will probably delay some of the changes I am predicting here as the countries to which the production moves will have to reach the same level of industrial development as the current centres of production before the processes discussed here can begin.

SUMMARY

Pig iron has been a defining factor in the history of the development of man. It has changed more in the last sixty years than in all the millennia before. It will surely change equally significantly in the next sixty years. How is very difficult to predict; the only certainty is that it will still be here and significant in sixty years time.

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