THE APPLICATION OF QUALITY ASSURANCE IN THE PRODUCTION OF FERRO BORON USING SPC

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1. INTRODUCTION

The use of boron in steel production has shown a steady increase in recent years and today about 10 million tonnes of boron containing steel is produced worldwide. Boron is mainly used to increase the hardenability of quenched and tempered steels. Other applications include the strengthening of high strength low alloy steels and improving creep resistance and high strength ductility in austenitic stainless steels. Boron is sometimes used in non-heat treated steel where it is added as an intentional nitrogen scavenger in carbon steels for automotive strip stock.

The startling effect of boron on the hardenability of steel has been known since the late 1930's when it was recognised that boron was by far the most potent hardenability intensifier of all the possible alloying elements for steel.

The commercial development of boron steel has been slow because, until recently, steelmaking technology was insufficiently developed to handle a process where the boron addition is in the parts per million range. Only 15 ppm boron is required to give the desired properties, but the boron must be free ie not combined with oxygen or nitrogen. As a consequence addition rates are generally in the 25-50 ppm range and elements such as titanium and aluminium are also added to the steel to protect the boron. Modern steelmaking techniques can now control oxygen levels accurately using processes such as calcium silicide injection and this has led to the growth of boron steel production over the last ten years.

The development of amorphous metals to replace grain oriented silicon steels in distribution transformers is potentially a large application of boron in steel. The development of a steel with 5.5% silicon and 3% boron, rapidly quenched into a strip to give a non-crystalline structure, started in the early 1970's. Allied Signal in the USA have led this work with their range of Metglas alloys.

The change from silicon steels to amorphous steels for transformer cores has not been as rapid as envisaged some ten years ago for a number of reasons. Amorphous metal requires new fabrication techniques for the new design of transformers. The principal advantage of amorphous steels is lower heat losses ie higher efficiency in electrical transmission, and the advantages have been eroded by lower energy costs in recent years and improvements in the properties of the traditional silicon steel.

Most boron additions to steel are made by ferro boron. The boron content is usually around 18% although alloys are supplied in the range 12-20% boron.

2. FERRO BORON PRODUCTION

Until the mid 1970's ferro boron was produced by the aluminothermic reduction of boric oxide. The process was carried out in pots using the most ancient of metallurgical processes - the thermit reaction. Whilst producing a good product the process uses aluminium, which is a very expensive reducing agent, and boric oxide an expensive form of boron. Further, aluminothermic ferro boron contains residual aluminium, which can be well in excess of 1%, making the alloy unsuitable for use in amorphous metal production. For the Metglas range of alloys the aluminium content is required to be below 0.05%.

Today the bulk of ferro boron production is by the carbon reduction of boric acid in small electric arc furnaces. As the use of ferro boron in the Western World is still only at a level of 5000 MT/annum, large scale ferro alloy furnaces are not used.

The quality requirements of ferro boron continue to grow in respect of chemical analysis, sizing and cleanliness. In order to upgrade quality on a regular basis improved procedures are required throughout the whole process. I have deliberately not used the words quality control as this gives the impression (generally correct) that controls are only effected on the basis of the analysis of the final product. What is required is Quality Assurance, which covers control of all aspects of ferro boron from the purchase of the raw materials, through production to a throrough understanding of the customers specification requirements.

3. QUALITY ASSURANCE

Quality assurance is not a new concept, but surprisingly its application outside Japan is still in its infancy. There are many means in which quality can be defined, but for our purpose we define a product as having the required quality when it is fit for its purpose. At the same time we continually strive to make improvements to meet changing demands and lower production costs.

To comply with quality assurance a company has to supply its customers with the correct quality product, delivered on time, cost effectively. If the first aim is adhered to the others should follow automatically. For example, if the product is made correctly first time then there is a greater chance of improved delivery performance. Similarly cost benefits will occur because of reduced reject material and reduced man hours per ton of finished product.

3.1 Quality approval and ISO 9000

In the UK the Ministry of Defence introduced a series of quality standards in ther early 1970's. Many large companies followed this lead by producing their own versions of the requirements to be met by their suppliers. The documents covering the standards were similar in philosophy and essentially were purchasing documents.

For an alloy producer it is crucial to achieve the correct analysis and therefore materials must be properly identified, handled and tested. Thus in the early days of quality assurance the Quality Manager of an alloy supplier had to go through the purchasing documents of all his customers and ensure that his company complied. He also frequently had to admit teams of auditors round the plant to gain approval.

In 1979 a British Standard for Quality Systems was introduced to avoid the problems of multiple assessments. It was given the title of BS 5750. This was superseeded in 1987 by a new version with more stringent requirements and more significantly dual numbered as International Standard 9000. This will mean that in future, companies quality assurance schemes will be recognised across international boundaries. In the more recent version of the standard much greater emphasis has been put on the use and philosophy of statistical techniques eg Statistical Process Control (SPC).

The international standard has three main parts as shown below.

ISO 9001

This covers products which have to be designed from the beginning eg a new type of aircraft and therefore applies to the design of the product through the production process to the finished item.

ISO 9002

This is used for existing products and is the one adopted by most manufacturing companies (including LSM). The standard covers all the stages involved in ensuring that the customer gets what he wants eg document control, purchasing, process control, product identification and traceability, inspection and testing, packaging and delivery, internal quality audits, training and statistical techniques including SPC.

ISO 9003

The third standard is concerned with final inspection only and as a consequence is the weakest of the three.

3.2 Application of ISO 9002

In order to ensure success in the application of quality assurance there are a number of important pre-requisites:-

* The whole company has to be quality minded and this can only be achieved if the top management initiate the concept and back its installation to the hilt. Without the unanimous support of the board it is, in our opinion, not possible.

* All key people have to be educated in quality assurance and are aware that QA is not QC. Initially this can be done by attending courses and when a core of committed people have been trained other members of the workforce can be trained on site.

* Open discussion must take place between management and workforce to ascertain the exact nature of an individual function. By this we mean that management must know exactly what a worker does and not what they think he does.

The essence of ISO 9002 is that a company installs its own quality management system which is then independantly audited by a third party on a regular basis. This is referred to as third party accreditation. A very important aim is to stop multiple audits of a company by many different customers. In the UK there are several assessors approved by the British Government including Lloyds Register Quality Assurance Ltd and the British Standards Institute. Our company selected Lloyds in the belief that as an exporting company Lloyds would be a more internationally known and accepted organisation.

4. APPLICATION OF QUALITY ASSURANCE TO FERRO BORON PRODUCTION

The ISO 9002 standard has been in place for just over 12 months in LSM and covers the following functions:

* Purchase of all raw materials

* Customer specifications and delivery schedules

* The full production process including crushing and packing

* The laboratory procedures for product analysis.

* SPC on key control points in the production process.

* Procedures required to cover trials and developments instituted by the R & D department.

4.1 Raw materials

The main raw materials used to produce carbothermic ferro boron are steel scrap, boric acid and charcoal. The purchasing department, in consultation with production colleagues, has produced a specification for each raw material which is regarded as realistic in terms of chemical analysis and sizing. By realistic we mean that the specification is not unnecessarily tight with respect to the final ferro boron specification and does not restrict the number of suppliers available. The Purchasing Manager may, if the supplier is not covered by ISO 9002, carry out periodic audits or if he has full confidence in the supplier, rely on his assurances that he will supply the correct raw material on time.

Documentation is in place to cover all the purchasing functions and frequent internal audits are implemented to ensure that all procedures are carried out correctly.

The main benefit to be drawn from this part of quality assurance has been a much improved customer/supplier dialogue and a clearer understanding of what we the customer want and what the supplier can actually deliver. There has been an excellent response from our suppliers and desire to improve their performance.

One of the key ingredients in ferro boron production is charcoal. This material has been used in metallurgical processes from earliest times, but is still one of the least understood. For example how can the activity of charcoal be measured? We are now carrying out meaningful development work with our charcoal suppliers and various research bodies to get a better understanding of the desired properties in a good charcoal. This is a direct result of quality assurance and in particular SPC, which is described later.

4.2 Customer specifications

This was the part of ISO 9002 implementation which we believed would give the biggest headache. The main worry was the reaction of the customer to a request to amend a specification, which we have supplying to in a satisfactory way for a number of years.

One of the reasons for requesting a change in specification is a commercial one. A problem, perhaps peculiar to ferro boron, is that it is not sold on a $/lb boron basis, but on a $/lb ferro boron basis. This is a strange concept for a product whose specification can range from 12-20% boron content. One possible explanation for this situation is the difficulty the customer usually has of carrying out accurate boron analysis at high levels. Perhaps the use of quality assurance will remove the need for the customer to do so. Nevertheless we believe that there is a lot of sense in either producing a more standarized product around the 18% boron mark or if this cannot be realised pricing on a $/lb boron basis.

Another reason for the need to discuss ferro boron specifications has arisen from the changeover from a product produced aluminothermically to the current carbothermic grade. This chiefly concerns carbon and aluminium contents. By fully explaining our commitment to quality assurance we have been able to explain to the customer (usually a steel works) that raising the carbon level from 0.1% max to say 0.5% max has no adverse effect on steel quality when boron is added to the steel at the 25-50 ppm level (ie carbon increase in the steel of max 0.7 to 1.4ppm). In short the product is fit for the desired use.

In most cases especially where the customer is already into quality assurance, the reaction has been one of understanding when the matter was fully and frankly discussed and has led to the customer agreeing to the suggested changes. This is turn has made the life of the production manager easier and more importantly enabled longer runs of a particular ferro boron grade giving a more consistent product.

If we find ourselves in a position where we have material available for prompt shipment, but it does not meet the customer specification on every count, the material cannot be shipped. Under ISO 9002 we can, however, apply to the customer for a concession in such a situation and if he agrees the material can go. We do, however, strive to keep concessions to a miniumum - the aim is zero - by upgrading our controls. Too many concession requests would throw the quality assurance system into disrepute and could lead to Lloyds refusing to continue giving their accreditaiton to ferro boron production.

4.3 Production

Ferro boron is produced at LSM in a number of electric arc furnaces, which operate round the clock. The operation begins with the input and assessment of raw materials. The operators have set procedures for weighing out and mixing the raw materials prior to charging into the furnaces. The arc furnaces are operated under optimised conditions of voltage and current and tapping into a mould is carried out on a regular basis.

All the procedures used from receiving the raw materials to packing the product are written down and are strictly adhered to. During the writing of the manuals we received full co-operation from both the furnace operators and the management. It was at this time that management realised that operators on different shifts had different working methods and that the procedures at that time were not necessarily the best way to do the job.

Thus the thorough discussions and debate, which accompanied the writing of procedures to meet ISO 9002 requirements was of enormous benefit to all parties and resulted in a production routine which can produce to the customers specification day in day out. The equipment used for the weighing of raw materials and product has to be checked on a regular basis against known national/international standards. This has already proved itself to be a very useful discipline as weighing errors are a frequent problem in ferro alloy production.

4.4 Laboratory

At LSM the routine analytical laboratory works on a three shift system to keep pace with production. All laboratory methods have definite procedures covering sampling and standarisation of solutions and equipment.

Ferro Boron is routinely anslysed for B,C,Al, Si, P, and S. An inductively coupled plasma spectrometer (ICP) is used for all analysis except C and S which is carried out on a Leybold analyser.

Although ISO 9002 accreditation covers ferroboron analysis we are also seeking NAMAS approval for the laboratory as a whole. NAMAS is a British Institution and stands for National Measurement Accreditation Service.

4.5 SPC

A major difference between the original BS 5750 and the current ISO 9002 is the much greater emphasis the latter places on statistical techniques such as SPC. SPC is a technique that has been known for many years and practiced in a number of countries especially Japan, who were strongly influenced by an American called Deming. In simple terms it is the monitoring of a process using basic statistical techniques in a graphical form ie control charts. The result is that the process is monitored objectively rather than subjectively.

In the production of ferro boron prior to the use of SPC the Departmental Manager used to obtain the boron and carbon analysis of the previous day's production first thing in the morning. He would then use the results to decide whether any adjustments needed to be made to the mix. This approach could lead to, and an occasion did lead to, the situation of a whole 24 hours production being out of specification.

SPC has now been introduced where Shewhart Control Charts are used to control the process. One of the key points here is that the charts are filled in by the senior melter and not by supervisory staff. The laboratory analyses and reports the boron and carbon results heat by heat throughout every 24 hours to the melter. He plots the results on an appropriate chart and then, if the process has gone out of control, follows a set of rules to decide upon and take the appropriate action.

Figures 1 and 2 show charts for the carbon and boron results from three furnaces producing ferro boron. It can be clearly seen that the charts show that the process has gone completely out of control on all three furnaces simultaneously.

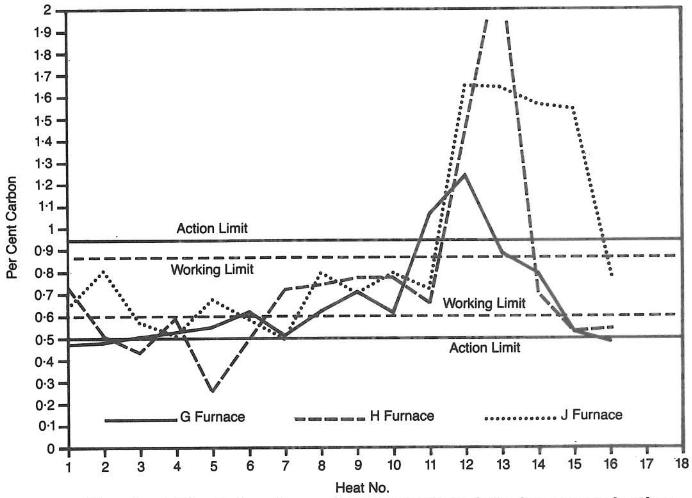

Fig. 1. Shewhart Chart showing carbon analysis in ferro boron production.

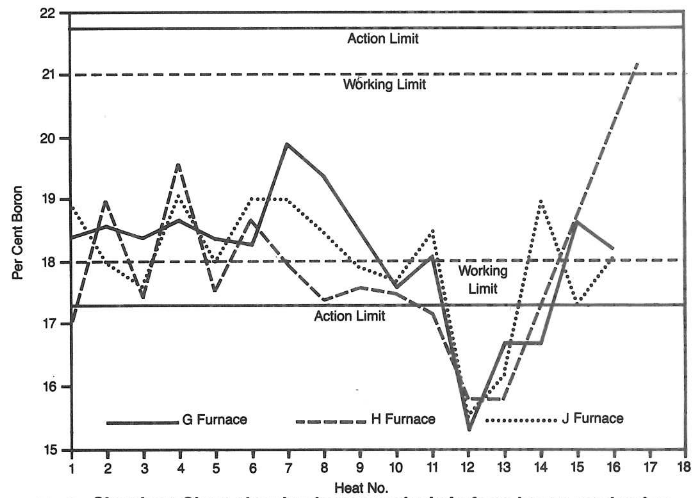

Fig. 2. Shewhart Chart showing boron analysis in ferro boron production.

This extreme case resulted in the furnaces being shut down until the cause of the problem had been determined. It was quickly established that the problem was caused by a defective batch of charcoal. If SPC had not been in use production would have carried on for a much longer time producing out of specification ferro boron. The problem would have been eventually solved, but there would have been a large amount of virtually unsaleable product, which would have remained in stock for some time.

Following the incident illustrated in the charts discussions took place with the charcoal supplier and he is now controlling his production process more closely.

Note that on the Shewhart Charts there are warning and action limits, which are determined statistically based on previously accumulated data. A feature of using SPC for a period of time is that as more control is exercised the fluctuations in boron and carbon analyses reduce and the action limits become closer together. This means that the furnaces are producing a more consistent ferro boron quality.

SPC need not only be applied to analysis of the final product but can be applied to key parts of the production process. In the next stage of SPC application in ferro boron production SPC will be applied to the weighing of the raw materials. This, we anticipate, will reduce the variability in the weight of each raw material used to make up the individual batches of mix thus ensuring a more consistent raw material supply to the furnaces.

One aspect of SPC, which had not been anticipated was the response of the workforce. The melters producing ferro boron have welcomed the opportunity to have more control over the production process and take a great pride in their success in reducing the variability in the ferro boron analysis. The result is the need for less supervision of the workforce because they are now monitoring their own quality, and this aspect may point to the most significant long term cost benefit of quality assurance.

4.6 Development

The use of quality assurance procedures and SPC charts does not restrict development work. On the contrary it provides a much sounder environment in which to carry out trials. If the researcher knows that the ferro boron production is strictly controlled he has more confidence in results coming from a trial where one or more variables are changed. We are now seeing a situation where development work in carbothermic ferro boron production is proceeding at a much faster rate than ever before.

From a quality assurance angle there is no problem in introducing process improvements into the system as long as the correct laid down procedures are followed and everyone from the purchasing, production and sales functions are fully informed of the changes, which are taking place.

5. SUMMARY AND CONCLUSIONS

We have described how quality assurance has been successfully applied to the production of ferro boron in an electric arc furnace.

There is no doubt that the introduction of ISO 9002 is a culture shock and everyone in the organisation is affected. Quality assurance can only be effected if there is total commitment from the top to the bottom of the company.

The installation of the procedures in all aspects of ferro boron production ie raw materials purchasing, manufacture and sales took nine months to put into place. Accredition with Lloyds was achieved first time and Lloyds continue to assess the systems on a six monthly basis. The only new position created has been that of Quality Assurance Manager, which covers the quality management systems in all LSM's manufacturing activities.

ISO 9002 provides a sound basis for the use of SPC which leads to individual accountability continually improving quality, greater customer satisfaction and most importantly reduced costs.

The reduced costs come from several areas including:

* Less scrap with subsequently lower costs:-

If the ferro boron is produced to the customer's specification first time off-grade material does not require to be recyled.

* Less complaints on sizing, analysis and delivery times:- A complaint on one order can often mean that the customer goes to the competition when next in the market.

* Less staff in the production area:- Because melters carry out their own SPC and take the necessary actions to keep the process in control supervision can be reduced.

One other benefit, which is more difficult to quantify, is that of greater job satisfaction for the furnace operators.