FULGENZI, C. F. Maximizing the return from electrode investments. *INFACON 6. Proceedings of the 6th International Ferroalloys Congress, Cape Town*. Volume 1. Johannesburg, SAIMM, 1992. pp. 233–236.

Maximizing the Return from Electrode Investments

C. F. FULGENZI

UCAR Carbon Company, Inc., Parma, USA

Electrodes are an integral part of ferro-alloy furnaces, and usually represent a production cost second only to that of power. The handling and joining of electrodes are often relegated to personnel who do not, or cannot, use the optimum practices. Operating disruptions resulting from poor electrode utilization impose an enormous burden on production costs. However, remedial help is readily available to owners and operators of electric furnaces.

This paper outlines the effective electrode-application techniques that can be used and describes the benefits. A programme of training is described that meets the requirements of those considering furnaces for the first time, as well as the needs of those who have been users for years. It is pointed out that investment to avoid electrode-performance problems yields a high return. High-quality production requires consistent continuous furnace operation, and the electrodes need not be the limiting factor.

Introduction

Electrodes form a significant portion of the cost[1] of products made in electric furnaces. In many cases, the cost of electrodes is second to that of energy. It is imperative to keep this portion of the process costs at or below the budgeted amount, since failure of an electrode column incurs an enormous loss to the user, involving production stoppages and wastage of carbon. The value of the lost carbon pales when compared with a minimum production loss of $25 000 on an old, small silicon furnace or with a loss of $500 000 on a large contemporary furnace.

The real cost burden includes all disruptions and inefficiencies upstream and downstream from the furnace. The furnace may remain upset for a prolonged period following a column failure. This loss of production may result in missed shipments, the use of off-specification material, and further furnace problems as the operators try to make up for lost production. Proper use of electrodes is the greatest insurance against furnace interruptions.

The electrode is the final link in the chain of conductors that deliver energy to the arc zone in an electric furnace. Three types of electrodes are in general use, and the factor common to them all is that they consist of some form of carbon (Table I). Graphite electrodes, which use petroleum coke as the starting material, are available commercially in diameters up to 700 mm, and have a specific resistance of less than 10 μΩm. A major use is in open-arc furnaces for the production of iron or steel; however, in some countries graphite electrodes are the only type available.

Two types of carbon electrodes dominate. Pre-baked electrodes are supplied completely machined as required for joining one to another on the consumable columns extending into the reaction zone of the furnace. The other type of carbon electrode is formed *in situ* and is known as a self-baking or Söderberg electrode[2]. Both types of carbon electrodes are used in submerged-arc furnaces to produce a variety of products including ferro-alloys, silicon metal, refractories, and elemental phosphorus and its byproduct, ferrophosphorus. Pre-baked[3] carbon electrodes up to 1400 mm are available, and self-baking[4] systems up to 1800 mm are in operation. The particle fraction of electrode mixes can include coals, carbons, graphites, and cokes. The binder for all electrodes is some form of pitch. The choice of raw materials determines the specific resistance[5] of the carbon electrode at its baked temperature.

TABLE I
CHARACTERISTICS OF FURNACE ELECTRODES

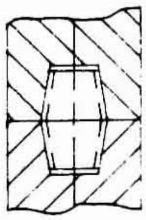
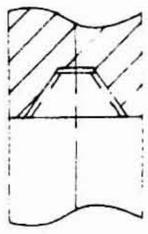
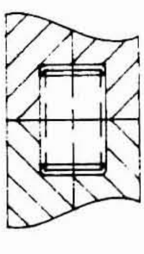
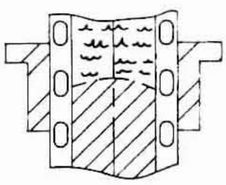
Item	Graphite	Pre-baked carbon	Baked *in situ* carbon
Particles in matrix	Petroleum coke	Cokes, coals, carbons, and graphites	Primarily calcined anthracite coal
Sizes (diameters) in use, mm	≤ 700	≤ 1 400	≤ 1 800
Processing temperature, °C	> 3000	800 to 1 000	500 to 800
Specific resistance at processing temperature, μΩm	< 10	20 to 50	<100

Carbon is a unique element and possesses unusual characteristics that make it ideal for application as an electrode. It is always an electrical conductor, has no softening or melting point, gains physical strength with increasing temperature, and becomes more conductive as it is heated above its final processing temperature.

Electrodes are consumable, and new material must be added to the columns to replenish that which has been used (Table II). Graphite and pre-baked electrodes use threaded connections between sections. Tapered pins[6] are the most common for graphite electrodes. Straight pins or male–female joints are used in pre-baked carbon. Self-baking columns do not have physical joints, but the 'joint' is constantly being formed at the liquidus–solidus interface just above the lower edges of the contact plates.

Electrodes are electrical conductors, and joints are electrical connections between conductors. However, joints are never as conductive as the solid body of the electrode. Low electrical resistance is the prime objective of a good connection. The specific current-carrying capacity of the electrode is dictated by its physical properties. The current-carrying capacity of the joint, if it has been machined properly, is totally in the hands of the assembler.

TABLE II
ELECTRODE JOINTS

Electrode type	Description of joint	Pictorial
Graphite	Tapered pins	
Pre-baked carbon	Conical male–female	
	Straight pins	
Self-baking carbon	Continuous	

Time does not permit a comprehensive discussion of all the types of electrodes. The balance of this paper will deal primarily with maximizing the value from pre-baked electrodes. However, it should be noted that all the factors relating to the efficient use of pre-baked electrodes apply also to graphite and self-forming electrodes. There is no greater return on investment than that received from good electrode practices.

Care of Electrodes

There are three general areas in which the user has control over an electrode's performance potential (Table III).

TABLE III
CARE OF ELECTRODES

Before assembly		
Packaging	Handling	Unpacking
Transit	Inventory	Hoisting
During assembly		
Cleaning	Closing	Slipping
Alignment	Torquing	Records
After assembly		
Oxidation	Thermal shock	Mechanical shock
Fluxing	Power level	Operations

Proper Care before Assembly

Packaging must endure the rigours of transit from the supplier. Care in handling electrodes into and out of the inventory is critical if damage is to be avoided. Trained personnel and suitable equipment are needed to ensure that the electrodes delivered to the assembly area at the furnace are undamaged. Any physical damage to an electrode will diminish its ability to perform satisfactorily.

Care during Assembly

Electrode manufacturers are conscientious in providing correctly machined joint features, but the assembly of the joint is the responsibility of the user. The joint is an electrical junction between conductors, and the simple rules of cleanliness and tightness are mandatory. These requirements are not open to compromise: *clean* means no debris in the contact areas of the joined components, and *tight* means the prescribed contact pressure to ensure the efficient transfer of energy from one component to another. These simple rules are often violated, and this is the leading reason for poor electrode performance.

Care after Assembly

Each furnace has a specific and unique set of operating conditions that result in optimum production. Some components of the operation may be utilized to their limit, while others are used at some fraction of their service ability. Once a furnace has been characterized and the specific operating criteria have been established, it is best to keep it operating at that level. Variations of the many process inputs must be minimized to ensure continuous high-quality production.

Starting and stopping of a furnace are events that occur at planned intervals. Practices must be established that minimize disruptions to the process or damage to the components. There will be occasions when unscheduled stoppages occur. These can be due to power interruptions, the failure of key equipment, and even electrode breaks. Proper attention to in-house maintenance and good electrode practices can reduce or eliminate such unscheduled stoppages.

Electrodes are predictable. They will always react to a particular stimulus in the same manner: push and they bend, bend too far and they break, heat them in air and they oxidize, drop them and they chip or crack. Standard operating procedures must allow for these normal reactions that are expected from electrodes.

In all areas relating to good electrode performance, the user is encouraged to give priority concern to those factors favourable to the electrode. To repeat, great benefit is obtained from the little effort needed to ensure proper electrode care before, during, and after assembly.

Responsibilities of Managers

Managers of facilities using electrodes need to know all about those electrodes: their history, their actual value versus their potential value, their performance and whether abnormal costs are being incurred because of poor electrode performance, how to measure the value of the electrodes, who is responsible for proper electrode utilization, and so on. The bottom-line question is whether the return expected from the investment in electrodes is being received.

Managers should have the freedom to evaluate various brands and systems to determine which is best for their particular operations. They must be isolated from pressures to buy the cheapest, and must remember that value is the watchword. They must be sure that the 'three T's' are supplied to those who handle, assemble, or use electrodes: *tools, training, and time*.

Without these, one cannot expect good electrode performance. The utilization of electrodes is often relegated to personnel who do not, or cannot, incorporate optimum practices owing to lack of involvement or support from their managers. Those who actually add electrodes may be in entry-level positions and may therefore lack adequate understanding or training. Assemblers need to have the few basic *tools* needed for proper joining. They need to be *trained* in what they are doing. A knowledge of the function of the joint will help them do the job correctly, and prompt them to correct any errors before problems arise. *Time* to do the job correctly is a necessity. There can be no time limits on proper assembly. If it is correct, it is acceptable. Anything less is unacceptable, and additional time must be provided to make it correct.

Tools

The tools are simple yet rugged devices for lifting, transporting, cleaning, assembling, and torquing electrodes. Considerable physical effort is required. The addition of labour-saving devices such as mechanical equipment for the quick connection and release of threaded devices on handling equipment is a good investment. A crane should be used to move heavy assembly equipment, to reduce manual labour, and to save time. The electrode-joining area must be maintained in a manner that encourages good work performance. Proper lighting, ventilation, and safety are mandatory.

Training

Most electrode producers provide training[7] in the form of courses given at a client's plant at no cost to the client, the various programmes being geared to suit the specific assignments of the trainees. All courses emphasize why certain requirements of good electrode handling and joining must be met.

The *how* of good electrode handling is given only on new facilities. Those doing the jobs can find the best way of achieving the required results. Effective electrode-handling practices are unique to each facility, and those who do the work must develop these practices. This gives them ownership of the techniques and pride in their performance. Safety is always stressed to ensure accident-free operations.

Training sessions should be scheduled as needed to include all new personnel. Periodic follow-up sessions reinforce the good practices implemented by the user. Practices not conducive to good electrode performance are discussed to explain why they are unsatisfactory. Remedial action is quickly achieved in-house.

In such training sessions, the user is informed about the manufacture of electrodes, their function, and their characteristics. This knowledge enables him to make the best decision on any action that can influence electrode performance.

Time

The time required for the proper performance of an assigned task can often be defined precisely. However, electrode joining must not be a time-regulated event. Any error made while assembling a joint must be corrected. To leave a known error uncorrected is not acceptable for any reason. Under normal conditions, well-trained crews have a predictable assembly time. Those few occasions when extra time is needed must be treated as part of the proper procedure and not a reason for censure.

Many furnaces continue to operate during electrode additions, which means that no production time is lost.

Facilities

Many electric-furnace plants do not have, as original equipment, those features which contribute to efficient electrode utilization. However, information[8] regarding features favourable to electrodes is available to those considering new facilities. These features are most effectively included in the original construction because many cannot be fitted later, or may be cost-prohibitive when installed later. The time to consider efficient electrode utilization is in the earliest design stages. It should be borne in mind that the cost of the electrodes used in a silicon furnace will exceed the price of the whole furnace in only a few years' time.

On the contrary, there are features that can be fitted later into a facility and that will result in a short-term return on the investment. Those that cannot be so fitted will highlight the reasons for even greater diligence regarding good electrode practices; namely, the need to remain competitive with those who have the 'better' facilities.

Maximizing the return on the investment in electrodes is a top-down management-driven project. There are no excuses for poor performance, and managers who have accepted excuses should implement remedial action. The alternatives are high costs and the loss of competitive position.

Efficient Production

This presentation has concentrated on electrodes; however, these constitute only one of the many areas of concern to all levels of management. The simplified diagram of an electric-furnace complex in Figure 1 shows some of the many inputs needed for an operating facility. Each is essential, and they are therefore all of equal importance. The same attention should be given to electrodes as is paid to all the other departments of an operation: modern production practices must be used, and records must be kept so that causes and effects can be determined.

Quality has become the battle-cry of all, and 'partners in quality programmes' are common. Electrode manufacturers should be considered in the role of partners in progress. In addition to the training already mentioned, they can assist in the identification and resolution of problems. Perhaps they can suggest changes to the electrodes that will improve the process. As more customers demand certification of the products they purchase, modern production and quality-control techniques are necessary in the use of electrodes. Consistent product quality requires continuous operation, and investment in the three T's of good electrode performance will eliminate a serious cause of process interruption.

In summary, electrodes are an essential part of arc furnaces, and rarely is the electrode the limiting factor in an operation. Although every electrode problem results in a major loss, these problems can be minimized and even eliminated. Proper practices requiring little or no extra effort can ensure trouble-free performance.

Professional help offered by electrode producers should be used to provide the training portion of the three T's: training, tools, and time.

References

1. Fulgenzi, C.F. (1983, 1988). Typical electrode consumption rate. Union Carbide Corporation, Carbon Products Division, *Technical Information Bulletins* #0978L, 1983, and #2570c, 1988.
2. Söderberg, C. W. (1923). Electrode for electric furnaces and process for manufacturing the same. *U.S. pat* 1,440,724. Appl. 8 Sep. 1921. Acc. 2 Jan. 1923.
3. Electrocarbonium S.p.A. (1987). *Amorphous Carbon Products Bulletin,* Apr.
4. Cavigli, M.D. (1978). Trends in technology of self-baking electrodes. *Electric Furnace Proceedings,* Toronto, vol. 36, pp. 205-208.
5. Kirk-Othmer (1978). *Encyclopedia of chemical technology. Carbon and artificial graphite,* vol. 4, 3rd ed., New York, John Wiley & Sons, Inc., pp. 607–612.
6. Union Carbide Corporation, Carbon Products Division. (1964). *Carbon products handbook.*
7. Union Carbide Corporation. (1978). Electric arc furnace electrode handling service program. *Technical Information Bulletin* cp 5806.
8. Fulgenzi, C. F. (1986). Efficient electrode utilization. Union Carbide Corporation, Carbon Products Division, *Technical Information Bulletin,* 2085y.

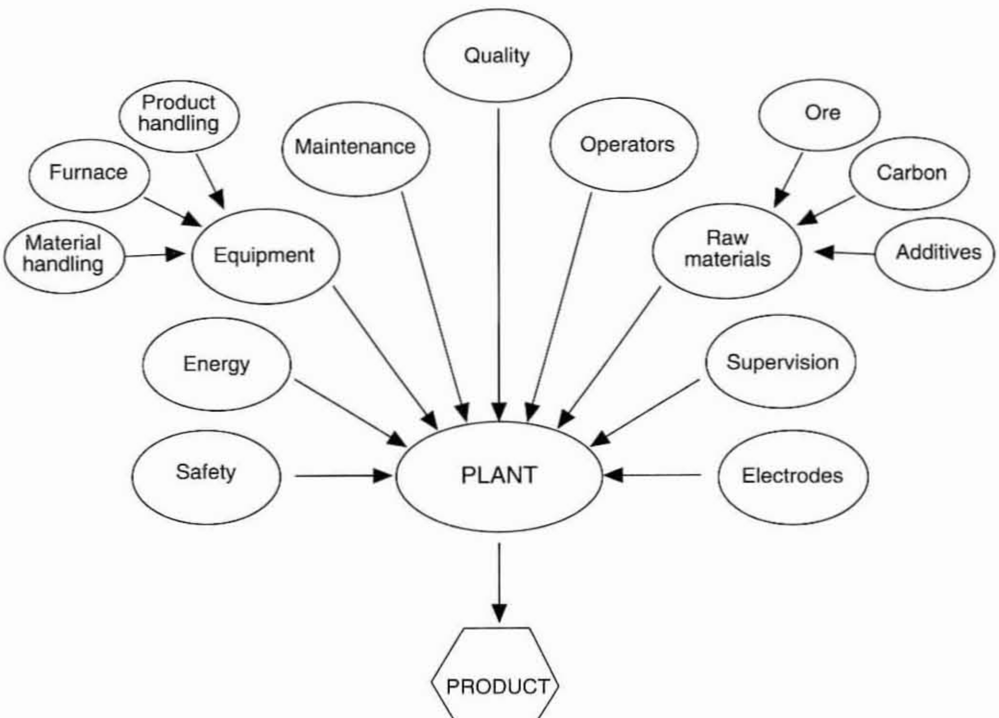


FIGURE 1. Inputs to a typical electric-furnace complex