Metal Powders in Manual Metal Arc Welding Electrode Coatings

By V. R. SUBRAMANIAN*

Introduction

The coatings employed in early years of the development of flux coated Manual Metal Arc Welding electrodes were thin and their main function was stabilisation of the arc. Metallurgical functions for the coatings were not envisaged then. It was Kjellberg who conceived the possibility of developing coated electrodes through the addition of slag forming ingredients, ferro-alloys and arc stabilisers. Since this modest beginning, it has been a saga of rapid development not only in coating formulations but also in electrode manufacturing techniques. In the beginning, the coating was applied by dipping the wire into a flux slurry of appropriate consistency several times, with drying in between, till the necessary thickness of the coating was obtained. This method. no doubt, had its limitations. Modern electrodes are produced continuously in heavy duty presses by extrusion of the coating onto the core wire. In the fascinating history of the development of today's Manual Metal Arc Welding electrodes, addition of iron powder and other metal powders to electrode coverings represents a significant stage in obtaining higher productivity and improved performance.

While metal powders such as nickel, chromium, aluminium, manganese, copper, molybdenum, iron etc. are added to electrode coating formulations to achieve either one or more of the effects, viz. making up loss in the arc, deliberately building up the content of alloying elements in the weld metal, improving the usability characteristics and more importantly in increasing the deposition efficiency without adversely affecting any of the other desirable characteristics in a Manual Metal Arc Welding electrode, by far the most important among these metal powders is iron powder added to different types of coatings for obtaining deposition efficiencies in the Low, Medium and High ranges. When the deposition efficiency is more than 170%, the electrodes are classified as "high efficiency electrodes". In this Keynote Paper, therefore, the discussions will mainly be confined to IRON POWDER in the Manual Metal Arc Welding electrode coating, the effect of its presence, and the characteristics needed in the powder for use in Low and Medium or High Efficiency electrodes. An appreciation of a multitude of factors that deserve careful and close control in iron powder to obtain optimum performance is necessary, not only by the electrode industry but also by the metal powder manufacturers who make available the raw material to the electrode manufacturer. The treatment in this paper will necessarily involve gaining at least minimum knowledge of the method of production of the electrodes and certain terms used by the welding technologists, to evaluate the effects of the presence of metal powders in the electrode coating.

Functions of today's Electrode Coatings

The flux coatings are designed today for performing a variety of functions and their consequences. The following list, perhaps not complete, should serve to

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illustrate the diversity and range of physical and chemical phenomena and processes that must be considered by the electrode designer :

(A) *Metallurgical*

—gaseous protection of molten metal from air
—slag protection and metal-slag interaction
—deoxidation
—alloying
—moisture susceptibility in the case of basic, hydrogen-controlled electrodes.

(B) *Arc Control*

—ignition (open circuit voltage in A.C. welding)
—stabilisation
—penetration (low or high as desired)
—smoothness (spatter)
—re-ignition (re-striking or restarting).

(C) *Manipulation*

—slag melting range
—slag viscosity (fluidity)
—metal/slag interfacial tension
—deslagging (slag detachability after solidification)

(D) *Production*

—paste formation
—paste extrudability
—covering-to-wire adhesion (bond strength)
—resistance of coverings to cracking on drying and baking
—resistance of coverings to damage during handling and transport.

Thus, the simple-looking coated electrode is a product requiring highly specialised designing involving knowledge of chemistry, metallurgy, physics of arc, slag-metal reaction, gas-metal reaction, rheology etc. The chemical and physical characteristics of the constituents making up the flux coating will influence one or more of the above metallurgical (A), usability (C) and production (D) parameters. When metal powders form increasingly greater proportion of the coating, it can profoundly alter the production and welding performance characteristics of the electrodes as well as certain factors governing the economics of Manual Metal Arc Welding. In many aspects these are inter-related. Addition of iron powder, for example, may vary from a modest 10% in hydrogen controlled basic coated electrodes, to as much as 70% of the weight of the coating in high efficiency, basic, Zircon basic or Rutile electrodes.

Effects of addition of iron powder

Let us now consider the effect of addition of iron powder on the welding performance and economic factors together. For this exercise it is necessary to understand the following four terms, viz :

(i) Burn-off rate
(ii) Deposition rate (Kg/hr)
(iii) Metal recovery or deposition efficiency, and
(iv) Coating thickness (CT)

These are defined, respectively, as :

(i) Time required to melt a unit length of electrode ;

(ii) $\dfrac{\text{Weight of weld deposit in Kg}}{\text{Arc time in hours}}$

(iii) $\dfrac{\text{Weight of weld deposit}}{\text{Weight of core wire melted}} \times 100$ and

(iv) $\dfrac{\text{Diameter of electrode}}{\text{Diameter of core wire}}$

Some of the effects of addition of iron powder to electrode coatings are enumerated in the following paragraphs :

(i) *Arc voltage and Melting*

With the increase in iron powder content in the coating, there is a progressive fall in arc voltage (Fig. 1). At certain level of iron powder content, therefore, this impairs the welding performance of the electrode. The effect on the melting of the coating is illustrated in Fig. 2 for fillet welding.

(ii) *Slag*

Increasing additions of iron powder tend to increase the fluidity of slag because of increased iron oxide. Mere additions of iron powder to the conventional coating formulations, therefore, is not enough to secure optimum benefits. Modification to formulation is necessary to counter the adverse effects of increased iron oxide in the coating.

(iii) *Burn-off rate*

The time to melt a unit length of electrode increases with the increase in iron powder content of coating beyond a certain low level (Fig. 3). This level depends on the type of coating.

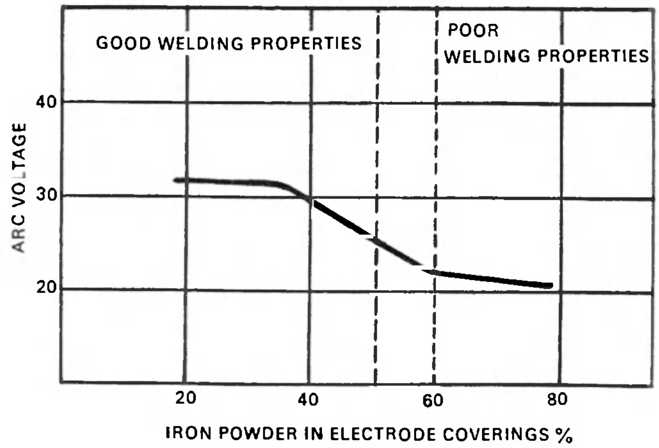

Fig. 1 Effect of iron powder on arc voltage and welding properties during fillet welding

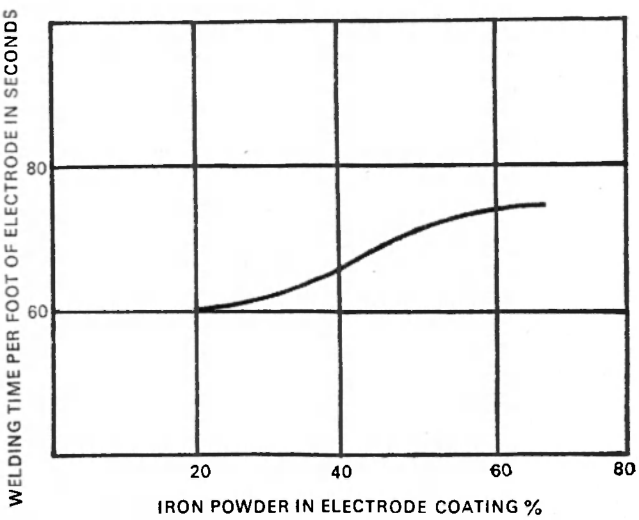

Fig. 3 Effect of iron powder on electrode burn-off rate

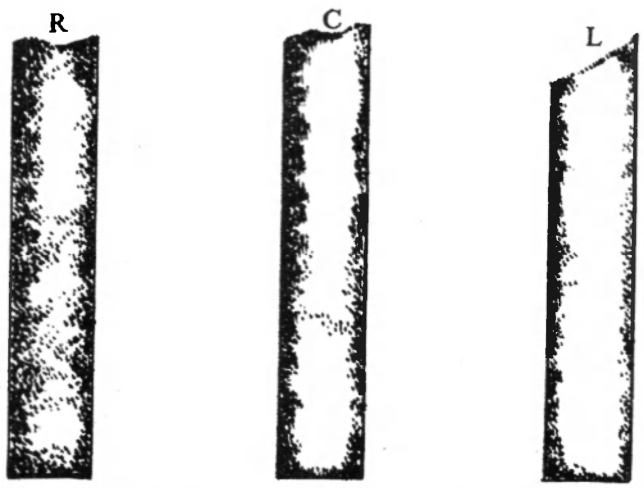

Fig. 2 Effect of iron powder content on electrode melting characteristics during fillet welding (Left: 60% and above ; Centre: 50-60% Right: 50% and below)

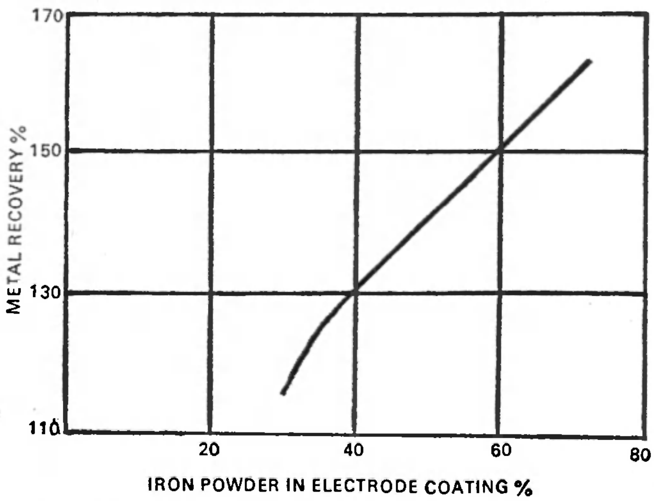

Fig. 4 Effect of iron powder on metal recovery expressed as a percentage of core wire consumed

(iv) *Deposition efficiency*

The deposition efficiency rises progressively as the iron powder content is increased (Fig. 4) Deposition efficiency can also be increased by increasing the coating thickness. Coating thickness, of course, is selected after considerable amount of research work. In practice, an optimum acceptable solution combining both is chosen. The advantage gained in weld metal recovery through increase in iron powder content of coating is to an extent off-set by the decrease in burn-off rate. (Fig. 3,4). Thus, the net gain is less than could have been expected from weld metal recovery alone. But, the burn-off rate can be stepped up by increasing the current. It is therefore necessary that the electrode has capacity for carrying higher current. This is what is precisely achieved by adding iron powder. The presence of iron powder in the coating confers the ability on the coating to share the welding current with the core wire. Iron powder electrodes can, therefore, be used at much higher currents than those employed for normal types of electrodes.

(v) *Arc*

Addition of iron powder reduces the arc force particularly at higher currents due to increased conductivity of the arc stream. This helps reduce the tendency to undercut at higher currents. Presence of iron powder in the coating contributes to arc stability, thus enabling reducing addition of stabilising elements which generally have a tendency to reduce burn-off rates.

(vi) *Spatter*

The formation of a deep cup at the arc end and improved arc help reduce the spatter losses.

It is thus clear that electrode coatings exert significant influence on the welding performance, metal deposition rate, weld quality and appearance. In other words, coating is much more than just a welding flux or an insulation to prevent side arcing of the electrode. Addition of iron powder and consequent modifications improve the performance of Manual Metal-arc Welding electrode. Similar improvements are also obtained by addition of iron powder in other processes of welding, viz. flux cored wire, submerged arc welding etc.

The electrode coating formulation is, therefore, very carefully balanced in terms of chemical compositions and physical properties of coatings for the following reasons :

(1) *Metallurgical and internal quality of weld metal* :

The composition of the weld deposit is controlled by the core wire chemistry as well as coating composition. Ferro alloys of Boron, Manganese, Silicon, Chromium, Columbium, Molybdenum and Vanadium as well as powders of metals, viz. Nickel, Manganese, Chromium, Aluminium, Copper and Iron are used in coatings to obtain weld metals compatible with the base metal. Every weld deposit should be reasonably free of porosity and slag inclusions. Coatings must therefore contain sufficient deoxidizing materials to degas the molten weld metal and float off the oxides and silicates into the slag.

(2) *Production*

For easy and high speed production in extruders, the right combination of particle sizes for the ingredients of the coating is necessary as well as to give a pore structure to the coating in order to permit continuous in-line drying and resistance to breakage in green and dry state handling. When iron powder forms a large proportion of the coatings, its particle size distribution, porous or solid structure, angular or rounded shape etc., become increasingly important. Therefore, the particle size range control is of paramount importance. Liquid sodium and potassium silicates and starches are used as binders and extrusion aids. Sugars and glycerine are used to increase dry and green strength. Talc, mica and clay aid plastic flow under extrusion pressure.

(3) *Slag*

The wetting properties of slag determine the shape or profile and finish of the weld deposit and the extent of slag coverage. A slag with high coefficient of expansion will deslag easily after cooling. Slag viscosity determines the out-of-position welding characteristics of the electrode. High viscosity slag stays put better than low viscosity slag. The freezing point of slag also influences the out-of-position usability characteristics of the electrode. Composition of coating controls all these properties. Common slag modifiers used are calcium carbonate, fluorspar, silica flour, alumina, feldspar, manganese oxides, iron oxides, wallastonite, zirconium bearing minerals etc. When iron powder froms a large proportion of the coating, its chemistry and surface oxide content will have to be closely controlled.

(4) *Arc characteristics*

The coating composition really determines whether the electrode can be used on D.C. or A.C. or A.C. and D.C. Arc voltages and optimum current again depend on the coating composition. Electrode designers use titanium or potassium bearing materials as arc stabilisers, viz. titanium dioxide, rutile, potassium tartarate, potassium oxalate.

To obtain high deposition rates, the iron powder for addition to coating will have to satisfy the following important criteria :

- —The price should be less than or equal to core wire price ;
- —The phosphorous and sulphur contents should be low
- —The chemical and physical properties should be uniform throughout the bulk of the powder.

The iron powders, depending on the method of their manufacture, differ in shape, structure and chemistry. The iron powder used in electrode coating is either sponge iron powder produced by treating iron oxide with a reducing gas or atomised iron powder produced by dispersal of molten metal into fine particles by a moving stream of gas or other fluid. To increase the deposition efficiency, the electrode manufacturers vary the amount of silicate and the apparent density of iron powder in the coating. Apparent density is the weight per unit volume of powder. It varies with the amount of void space in the powder. A porous, irregularly shaped powder will have low apparent density.

In high speed electrode extrusion technology, it has been found that

—the permissible amount of silicate added for a given extrusion pressure depends on apparent density, shape, and size of iron powder particles ;

—yield and melting rate increase with the apparent density of the iron powder and as the silicate is lowered ; and

—narrow specifications on particle shape, size and apparent density are necessary for producing welding electrodes of uniform and consistent quality.

A coarse, high density iron powder for low yield electrodes will reduce arc stability and restrike properties. High density powders, therefore, should be used only for high yield (over 170%) electrodes.

High yield electrodes deposit metal heavily at a given welding amperage because,

(i) the thicker coating develops a deep cup and reduces heat and spatter losses ;

(ii) the electrode coating contains as much as 70% iron powder, putting more of coating into the weld metal and leaving less in the slag ; and

(iii) the electrodes are used with high arc voltages (38-44) and high welding currents.

For high recovery electrodes, atomised powder is used because the particles are uniform in size and chemistry. Atomised particles are low in porosity and are roughly spherical. The apparent density is 3.60 to 3.70 g/cc.

Electrode manufactures continuously seek ways to improve production methods. As coating thickness increases and the amount of iron powder in the coating increases, extrusion becomes more difficult. The coating ingredients are varied to make extrusion easier and produce the best possible product for welding.

The extrusion pressure depends on the physical properties of iron powder and the amount of silicate in the coating. Higher slicate content allows higher extrusion pressure and therefore faster production.

A small reduction in the silicate content or a small increase in the apparent density of iron powder can push the extrusion pressure out of the optimum range—with nasty consequences. Excessively high pressures cause longitudinal cracks after extrusion and transverse cracks after baking. Excessively low pressures lead to soft coating.

For a constant silicate content, addition of iron powder with smoother surface will require lower extrusion pressure. Irregularly shaped iron powder grains increase friction within the coating constituents. A smooth, heavy iron powder enables the electrode manufacturer to produce higher than usual yield electrode by keeping the silicate content low.

Fig. 5 indicates at 400 kg/cm² extrusion pressure, electrodes with 2.4 g/cm³ apparent density iron powder give 15% lower yield than electrodes with 3.5 g/cm³ apparent density iron powder.

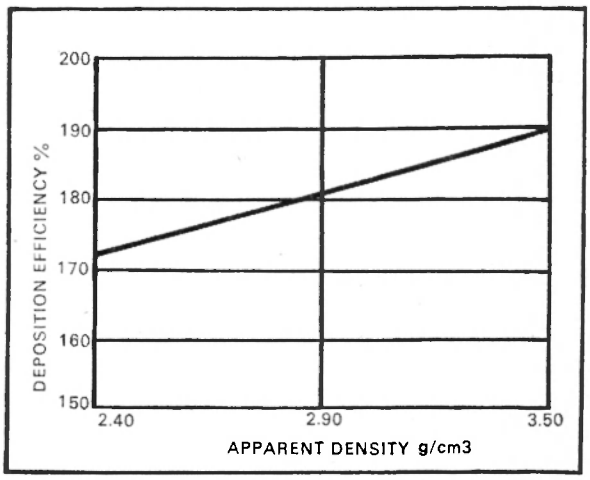

Fig. 5

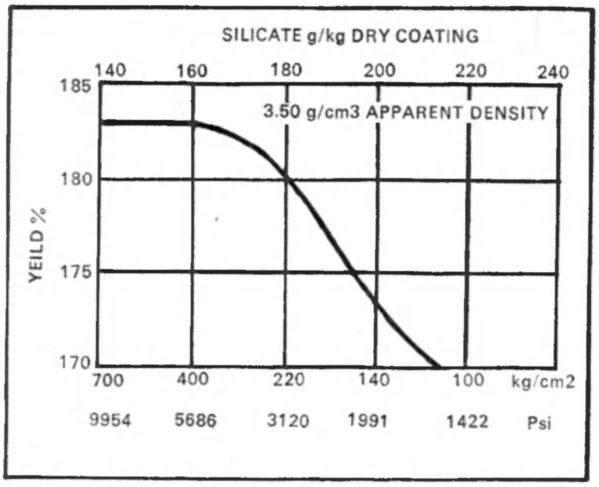

Fig. 6

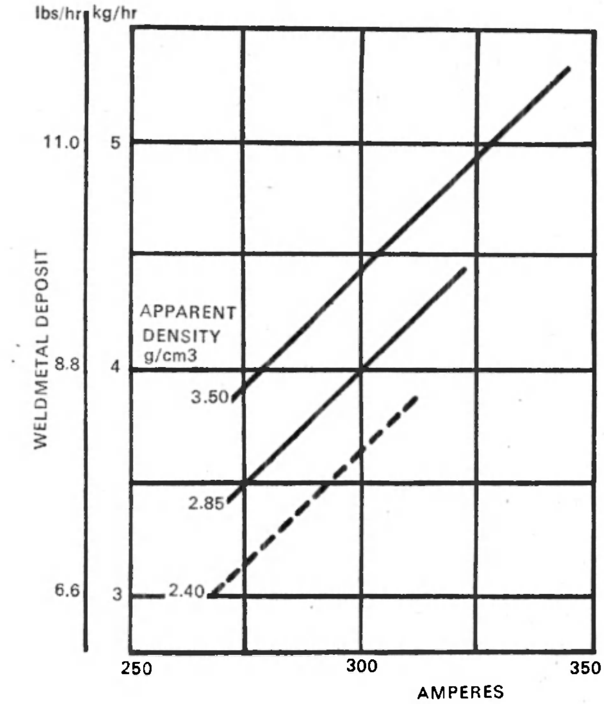

Fig. 7

Fig. 6 shows that the electrode yield steeply falls with the addition of silicate. For this electrode, 160 g. of silicate per Kg. of dry coating gives the best combination of yield : 183% and extrusion pressure 400 kg/cm².

Fig. 7 shows that the deposition rate at a given welding amperage increases with density of iron powder. Normal, maximum allowable welding current is higher for electrodes made with higher density iron powder.

Properties & Application of iron powder of different Grades for Coated Welding Electrodes

(i) Sponge iron fine powder usually-100 mesh with an apparent density of 2.5 g/cm³ is specially suited for small diameter hydrogen controlled (basic) electrodes. Due to micro-porous particles and irregular grain shape, this powder will have large specific surface. This contributes to higher electrical conductivity of the coating, stable arc, good re-striking properties and smooth arc.

(ii) Sponge iron powder, with grain size between 40 and 200 mesh and grain shape irregular with apparent density 2.5 g/cm³ is the most commonly used grade in the production of hydrogen controlled basic coated electrodes. It is also used in rutile and acid coated electrodes with low and medium deposition efficiency.

(iii) Sponge iron powder with grain size between 40 and 200 mesh with denser particles with irregular shape with apparent density of 2.9 g/cm³ is usually used in electrode coatings with medium deposition efficiency : 120-160 percent.

(iv) Atomised high density iron powder with apparent density 3.70 g/cm³ ± 0.10 with the screen analysis carefully adjusted to provide good coating strength, arc stability, restriking properties and current carrying capacity : the chemistry and particle size are in narrow range to ensure a good reproduction of the plasticity of flux during and after extrusion. Close control in chemical and physical characteristics is a necessary prerequisite for high production rates, low rejections and consistent and stable electrode properties. This type of powder can be with higher carbon or surface oxide, enabling the electrode manufacturer to use the iron powder as a means to modify and control chemical composition of weld metal and viscosity of the slag. These are used only in the production of high efficiency electrodes (deposition efficiency more than 170%).

In high yield basic and zircon basic electrodes, atomised high density iron powder with very low carbon and iron oxide content provides a smoother arc and high rate freezing of slag, thus attributing easy slag detachability.

(v) Atomised high density iron powder with low carbon, but with controlled oxide coating, when used in high yield basic electrode coatings provides not only a more fluid slag and fine droplet transfer, but also helps keep silicon and carbon in deposit metal low which favours good impact and ductility properties.

(vi) Atomised high density iron powder with high carbon (0.08-0.12%), when used in rutile high yield electrode and high strength and low alloy basic high yield electrode coatings, enables attaining higher yield and tensile strengths in weld metal and obtaining a pore-free deposit.

(vii) Atomised high density iron powder with high carbon (0.08-0.12%) and surface oxidised when used in high yield rutile electrode coatings contributes high productivity (kg hr) and long bead length, giving pore-free weld deposit at high amperages, because of the reaction between carbon and iron oxide.

The above insight into the characterisation of iron powder for electrode coatings, I am sure, will serve well not only the powder manufacturing industries but also the electrode manufacturers. In our country, iron powder is manufactured by electrolytic deposition and grinding and grading. There has been continuous dialogue between the metal powder producers and electrode manufacturers in respect of quality and suitability of indigenously produced iron powder for electrode coatings. It will be in the interest of the metal powder producer to understand the requirements of his customer and gear himself up to meet the specific and specialised requirements dictated by the influence of iron powder quality on the customers' electrode production and performance criteria.

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MEMBERS TO NOTE

From the number of circulars and communications that are being returned to the institute's office, it appears that many members omit to keep the institute posted whenever there is a change of address.

All members are requested to remember to intimate the Superintendent, The Indian Institute of Welding, 48/1 Diamond Harbour Road, Calcutta 700 027 promptly of any change of address so that communications intended for them do reach them in time.