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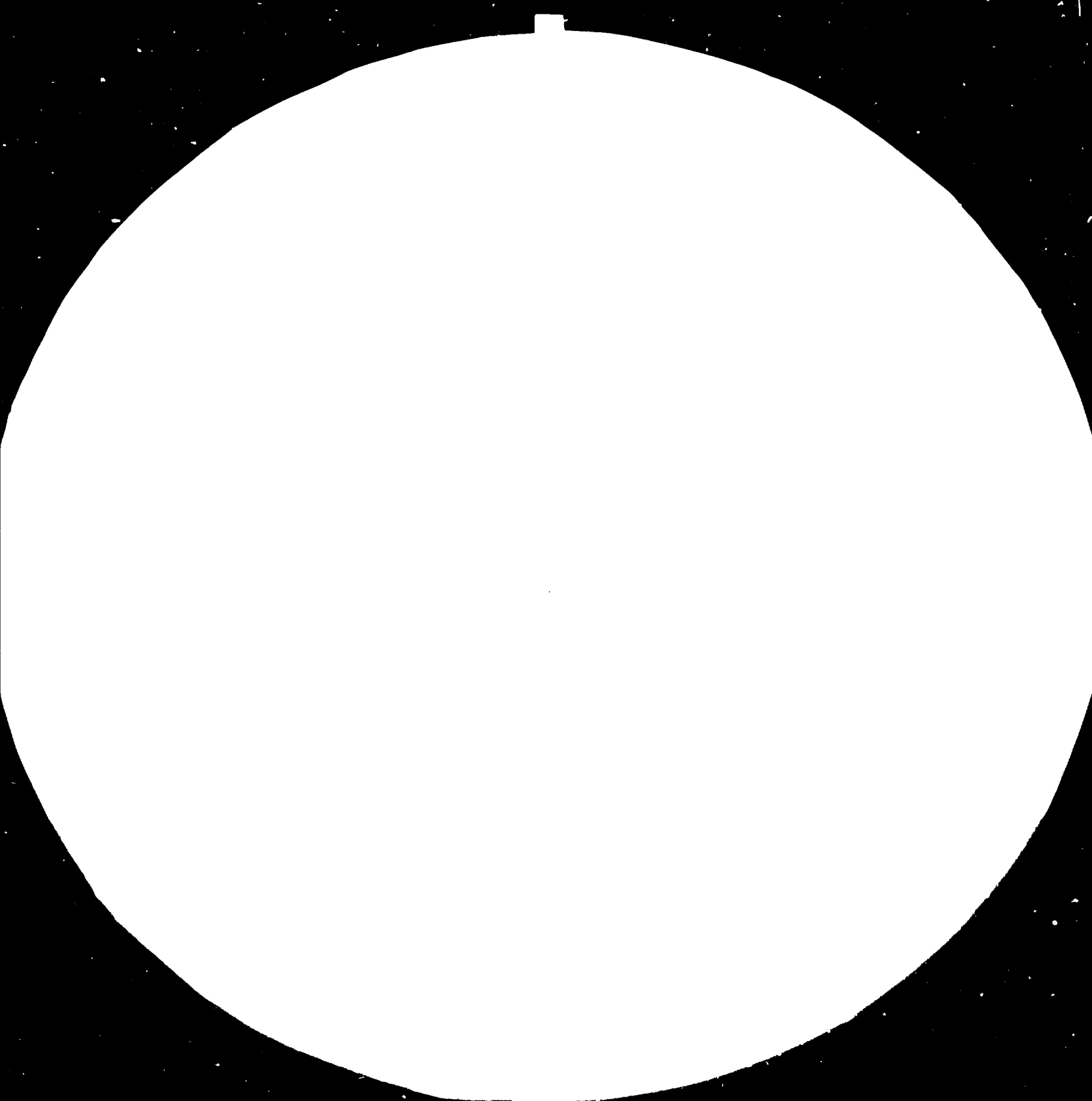
MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS

STANDARD REFERENCE MATERIAL 1010a

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United Nations Industrial Development Organization

Interregional Workshop on the Promotion of
Welding Technology in Developing Countries

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WELDING CONSUMABLES - AN OVERVIEW*

by

K. Narasimhan**

D.V.R. Varma**

A.K. Garg**

A. Raja**

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1.0 INTRODUCTION

Welding plays an important role in the manufacture and erection of power plant equipment, petro-chemical, fertilizer, ship-building and aircraft industries. The amount of welding done is quite high and a number of welding processes are being used to weld a variety of materials under different conditions. A wide range of consumables are available and selection has to be done carefully depending on the material that is being welded. This paper attempts to give a description of the consumables available process-wise, their classi-fications and applications.

2.0 MANUAL METAL ARC WELDING CONSUMABLES

To impart certain properties in the coating, various organic and inorganic materials in correct pro-portion as per the formulation are mixed and extruded on to the core wire.

2.1 Functions of Coating in MMAW Electrodes:

01) To establish and maintain the arc between the electrode and workpiece by providing a continuous stream of ionised gas. It gives stability to the arc;

02) Gas shield that is formed protects the weld metal from atmospheric contamination;

03) Slag that floats on the surface and which can be subsequently removed ensures slow cooling

rate of weld metal. It also gives additional shielding to the weld metal;

04) Deoxidisers and alloying elements are added through the coating;

05) Iron powder is added to increase the deposition efficiency.

2.2   Coating Materials:

2.2.1   Arc Stabilisers and Slag Formers:

Rutile (TiO_2), Ilmenite, Fluorspar (CaF_2), Feldspar, Silica, Iron Powder.

Rutile is an excellent arc stabiliser and slag former. Ilmenite has about 50% TiO_2 but contains more iron oxide. This is a cheaper substitute for Rutile but inferior to it. Fluorspar used in basic coated electrodes decreases the oxidising effect of limestone and increases slag fluidity. Felspar contains SiO_2, Al_2O_3 and K_2O. It is an excellent arc stabiliser because of potassium content. It also acts as a slag former. Silica is a cheaply available slag former and increases the arc voltage slightly. Silicon recovery into weld metal must be watched. Iron powder is added to get increased weight of deposited metal per electrode.

2.2.2   Gas Forming Materials:

Calcium carbonate is used in almost all types of electrodes. It ionises easily and breaks down to

form a carbon dioxide/carbon monoxide shield.

Cellulose is used in cellulose electrodes and also sometimes in mild steel rutile electrodes. Functions are explained elsewhere in this paper.

2.2.3 Deoxidisers:

Deoxidisers like Ferro Manganese, Ferro Silicon and Ferro Titanium are added to get completely deoxidised weld metal. Proportion of deoxidisers is more in the case of basic coated electrodes as higher strength, ductility and toughness at low temperatures are required. Manganese and silicon increase tensile strength while higher amounts of manganese increase the impact strength at sub-zero temperatures. Careful attention must be paid to Titanium level in the weld metal.

2.2.4 Alloying Elements:

Alloying elements like Ferro Chromium, Ferro Molybdenum, Ferro Vanadium, Nickel, Tungsten and Cobalt are added to get properties like increase in tensile strength, high temperature strength, resistance to corrosion and higher hardness with consequent resistance to wear.

2.2.5 Extrusion aids or Slipping Agents:

Gum, Clay, Mica and Bentonite are added to aid the extrusion process and to improve coating strength. They do not contribute anything towards mechanical and chemical properties.

2.2.6   **Binding Agents:**

Sodium and Potassium Silicates are used as the
binding agents and the functions of silicate
solutions are as below -

01) They give good bonding;
02) By proper selection of concentration and
    Alkaline to silicate ratio, good coating
    strength is obtained;
03) They aid the extrusion process;
04) Potassium is an excellent arc stabiliser
    and will reduce arc voltage.

2.3   **Classification of Electrodes as per Coating is**
        given below:

2.3.1   **Cellulose Electrodes:**

The coating is composed of cellulose and silicate
binders and this gives rise to a lot of gas, mainly
carbon monoxide and hydrogen during welding.   The
gas raises the arc voltage and increases the amount
of heat produced.   Very little slag is formed and
shielding is done by gas.   A dragging arc and deep
penetration are obtained.   This electrode is
extremely good for pipe welding.   The weld metal
is of good quality and generally meets stringent
requirements.

2.3.2   **Rutile Electrodes:**

The coating is thicker than the cellulosic type
and is composed mainly of Rutile (Titanium dioxide),

Silicates and a higher proportion of Ferro alloys.
Naturally gas shielding is less but the slag which
covers the weld completely and peels off very easily
on cooling takes care of refining and strengthening
of weld metal.   The electrode is easy to use in
all positions and is widely used for root run
welding of pipes, welding jobs of thickness upto
12mm and structural applications.

2.3.3   Basic Coated low Hydrogen Electrodes:

As the name itself implies, the coating of these
electrodes is low in hydrogen bearing compounds.
Low hydrogen electrodes have been developed for
welding hardenable high tensile and high carbon
and alloy steels in order to avoid the problem of
"underbead cracking".   This effect occurs when
heavy sections of high tensile steel were welded
with conventional cellulose or rutile electrodes.
Underbead cracks occur in the base metal just under
the weld metal and are caused by the absorption of
hydrogen into the weld metal from the arc atmosphere.
The absorbed hydrogen then migrates into the base
metal and collects in the highly strained boundaries
and causes cracking.

Although these cracks do not normally occur in mild
low carbon steels they may occur whenever an ordinary
rutile or cellulose electrode is used on high tensile
steels.   This problem is avoided by usage of low
hydrogen electrodes.   A very short arc has to be
used in order to ensure that the gas shield is fully
effective.   Penetration characteristics are similar
to that of rutile electrodes.   Slag is heavy but

fluid and even though slag release is not as good
as rutile types, it is not difficult to remove.
Current carrying capacity is higher than rutile
or cellulose electrodes of the same diameter.
This enables faster deposition in a variety of
positions especially vertically upwards.

Low hydrogen electrodes are very sensitive to
moisture pick up and must therefore, be thoroughly
baked at 450°C which results in hydrogen levels of
less than 5 mls/100 gms of deposited weld metal.
They are used for the following applications:

01) To prevent cold cracking.   This is the major
    reason for use of low hydrogen electrodes.
    The elimination of hydrogen enables the welding
    of "difficult to weld steels" with less preheat
    than that necessary with other electrodes;

02) To prevent hot cracking on sulphur steels.
    The basic slag and higher manganese deposit
    of low hydrogen electrodes are more capable
    of absorbing sulphur which passes into the slag.

03) To give good toughness.   The weld metal from
    basic electrodes is radiographically clear of
    all defects.   Control of the welding procedure
    results in good toughness at very low temperatures.
    This type of product is therefore, used for high
    technology applications such as pressure vessels
    and offshore structures.

2.3.4   Iron Powder Electrodes:

Iron powder is widely used as a covering ingredient.
It is included in certain coverings to the extent

of one half of the total weight. Large amounts
of iron powder will make the covering an electrical
conductor and allow the electrode to be used as a
"Contact Electrode". Iron powder which melts and
remains unoxidised will join the weld pool and
increase the amount of metal deposited. Torch
welding can be done with this electrode because of
the deep cup that is formed. The advantages of
this electrode are the large deposition rate and
the gain in time that can be achieved as a result.
This electrode can be used wherever heavy welds
are to be made and for large weld lengths in fillet
welds.

2.3.5 Iron Oxide Electrodes:

These electrodes have high percentage of Iron oxide,
Manganese compounds and silica in their coverings.
They are designed to produce flat or slightly concave
horizontal fillet welds and will produce satisfactory
results on fillet and groove welds in the flat
position. When normal welding currents and techni-
ques are employed, penetration is considered to be
medium. However, they are capable of operating
satisfactorily at high currents which results in
deep penetration. Applications include pressure
vessels, heavy machine bases and structural parts
where thickness of section permits.

Iron Powder and Iron Oxide Electrodes:

These electrodes contain high percentages of iron
powder in combination with ingredients similar to

those commonly found in iron oxide electrodes.
They are designed to produce satisfactory fillet
or groove welds in the flat position and will
produce flat or slightly concave horizontal fillet
welds. Weld metal is apt to vary in radiographic
quality and be somewhat inferior to that from iron
oxide electrodes.

2.4 Classification of Electrodes Based on Materials Being Welded:

2.4.1 Mild Steel Electrodes:

They can be cellulose, rutile or basic coated
electrodes. The main elements in the weld metal
are carbon, manganese, silicon, sulphur and
phosphorous.

2.4.2 Low Alloy Steel Electrodes:

Steels commonly welded with low alloy steel electrode.
are normally used for specific purposes. Flux
coating of the electrodes contains small amounts of
alloying elements like chromium, nickel, molybdenum,
vanadium and cobalt to impart necessary mechanical
properties to the weld metal. The field of appli-
cation is found practically in all sectors of
industries using steel such as fabrication of
reactors, pipelines, tanks, ship building, bridge
construction and fabrication of Penstocks.

Flux coating contains small amounts of chromium
and molybdenum to give creep resistance. By addition
of these alloys, the steel becomes air hardenable

and therefore, preheating and stress relieving of
the job after welding are necessary. Electrodes
in this category are known as 1Cr $\frac{1}{2}$Mo, 2$\frac{1}{2}$Cr 1Mo
and 5Cr $\frac{1}{2}$Mo.

For cryogenic applications the addition of nickel
upto 3.5% is necessary. Such steels can be used
upto -60°C with 2.5% Ni and upto -100°C with 3.5% Ni.

2.4.3   Stainless Steel Electrodes:

A variety of austenitic, martensitic and ferritic
types of stainless steel electrodes are available
and these are used to get resistance against corrosion.
Typical all weld metal composition is given in
Table-1. Main alloying elements are chromium,
nickel and molybdenum. Columbium is added in some
varieties to prevent carbide precipitation.

2.4.4   Cost Iron Electrodes:

There are three types of electrodes for welding
cast iron -

i)   Nickel based electrodes
ii)   Copper based electrodes
iii) Nickel iron electrodes

These electrodes can be used for welding of machinable
welds whereas for non-machinable parts of cast iron,
basic coated low hydrogen electrodes can be used
with preheating of the job.

2.4.5 Hardfacing Electrodes:

Hardfacing electrodes are used to repair or reclaim wornout components. Special surface properties like resistance to wear, abrasion, impact, heat and corrosion are obtained by hardfacing. A wide range of electrodes is available and selection is done depending on the hardness of deposit required, type of wear encountered and the service conditions. Both rutile as well as basic coated electrodes that can give hardness in the range 250-650 VPN are available. In the lower range, the deposits are machinable where extreme resistance to wear is required, a more highly alloyed type depositing chromium and carbon or tungsten and carbon are used. Wherever higher resistance to wear is required at elevated temperatures, a cobalt based electrode is used. Typical applications for hardfacing include Rock crushers, Pulverizer Hammers, Pinions, Crane Wheels, Coal conveyors, Cane cutting knives and Hammers, and Sugar Mill Rollers.

3.0 SYSTEMS OF ELECTRODE CLASSIFICATION

The numerous types of electrodes that have been developed have led to a need to be able to classify them according to some coding system. Some systems code entirely on operating characteristics and chemical composition of the coating while others code on the weld mechanical properties and operating characteristics. Two well-known International Classification Systems are described below.

3.1   The American Welding Society Classifications:

This system groups the electrodes according to
four characteristics -   .

01) Minimum tensile strength of the deposited
    weld metal;

02) Welding position of the electrode;

03) Type of electrode coating;

04) Type of welding current used

For identification each class of electrodes is
designated by the letter 'E' followed by a four
digit number (five digits for the high strength
electrodes), i.e., Exxxx or Exxxxx.   'E' signifies
arc welding electrode.   The meaning of the digits
are shown in Tables-2 and 3.

DIGIT	SIGNIFICANCE	EXAMPLE
1st two or 1st three	Minimum tensile strength(stress relieved)	E60xx = 60,000 psi (Min) E110xx = 110,000 psi (Min)
2nd last	Welding position	Exx1x all positions Exx2x horizontal and flat Exx3x flat See Table-3
Last	Power supply, type of slag, type of arc, amount of penetration, presence of iron in coating.	

TABLE-2

INTERPRETATION OF LAST DIGIT IN AWS ELECTRODE CLASSIFICATION

Last Digit	0	1	2	3	4	5	6	7	8
Power supply	(a)	AC or DC	AC or DC	AC or DC	AC or DC	DC	AC or DC	AC or DC	AC or DC
Type of coating	(b)	Orga-nic	Ru-tile	Ru-tile	Ru-tile	Low Hyd-rogen	Low Hydro-gen	Mine-ral	Low Hydro-gen
Type of Arc	For-ul	For-ceful	Med-ium ful	Soft	Soft	Medium	Medium	Soft	Medium
Penetra-tion	(c)	Deep	Medi-um	Li-ght	Light	Medium	Medium	Medi-um	Medium
Iron Powder coating	Low	Low	Low	Low	Medium	Low	Low	High	Medium

NOTES: (a) E-6010 is DC reverse polarity. E-6020 is AC or DC

(b) E-6010 is organic; E-6020 is mineral

(c) E-6010 is deep penetration; E-6020 is medium penetration

In the case of low alloy steel electrodes (AWS A5.5) the above four or five digit code is followed by a letter indicating type and composition of the alloying elements, e.g. ExxxxAl. Table-4 shows a number of the specifications.

TABLE-3

AWS DESIGNATION OF MAJOR ALLOYING ELEMENTS IN ARC WELDING ELECTRODES

SUFFIX TO AWS ELEC-TRODE NO.	TYPICAL ALLOY ELEMENT, %				
	Mo (Molyb-denum)	Cr (Chro-mium)	Ni (Nickel)	Mn (Manga-nese)	Va (Vanadium)
A_1	0.5	-	-	0.5	-
B_1	0.5	0.5	-	0.9	-
B_2	0.5	1.25	-	0.9	-
B_3	1.0	2.25	-	0.9	-
B_4	0.5	2.0	-	0.9	-
C_1	-	-	2.5	1.2	-
C_2	-	-	3.5	1.2	-
C_3	-	-	1.0	1.0	-
D_1	0.3	-	-	1.5	-
D_2	0.3	-	-	1.75	-
G*	0.2	0.3	0.5	1.0	0.1

* Need have minimum content of one element only.

3.2   British Standard Classifications:

The British system classifies an electrode by using a prefix letter, three digits and a suffix.

i.e., PxxxS

The prefix indicates the methods of manufacture -

F Solid extrusion (general method)
R Extruded with reinforcing
D Dip coated

The first digit indicates type of covering -

1) High cellulose content
2) High content of titanium dioxide (viscous slag)
3) Appreciable amount of titanium dioxide (fluid slag)
4) High content of oxides or silicates, or both,
   of iron and manganese (inflated slag)
5) High content of iron oxides or silicates, or
   both, heavy solid slag
6) Based on calcium carbonate and fluoride
7) Covering of any type not classified above

The second digit refers to the welding position -

0 FHVDO   F - Flat
1 FHVO   H - Horizontal vertical
2 FH   V - Vertical up
3 F   D - Vertical down
4 FH   (fillet weld only)
0 - Overhead
9 Not classified above

The third digit indicates current and voltage
condition -

0 DC + only
1 DC * or AC (Min OCV 90)
2 DC - or AC (Min OCV 70)
3 DC - or AC (Min OCV 50)

4   DC + or AC (Min OCV 70)
5   DC ± or AC (Min OCV 90)
6   DC ± or AC (Min OCV 70)
7   DC ± or AC (Min OCV 50)
9   Not classified above

The suffix refers to any special characteristics

P   Deep penetration electrodes
H   Hydrogen controlled electrodes
J   Iron powder electrodes with metal recovery
    of 110-130%
K   Iron powder electrodes with metal recovery
    of more than 130%

4.0   TESTING OF ELECTRODES

The following tests are done to decide the suita-
bility of the electrodes:

Mechanical Tests:

Mechanical test requirements have been specified
in detail in almost all the electrode specifications
and standards.   The following tests are normally
conducted.

a) Allweld Test
b) Fillet weld tests
c) Chemical analysis

Details of these tests are given in all the codes.
Procedures laid down have to be carefully followed
and results evaluated as per the requirements.
In addition to these tests, usability tests are

also conducted and factors like Arc striking and
restriking, spatter, voltage and current, slag
follow-up, weld metal profile and presence of
defects if any are observed.   Proforma results of
usability tests   are given in Table 4.

5.0   STORAGE OF ELECTRODES

Electrodes not stored properly will pick up moisture
from atmosphere and will give defective welds.
It is recommended that the electrodes should be
stored in warm and dry places where the humidity
can be controlled.

Electrodes must be redried after they are taken out
of the packets, before use.   Low hydrogen electrodes
must be baked at high temperatures before use.
Drying and baking temperatures should be as per the
recommendations of electrode manufacturers.

6.0   MANUFACTURE OF ELECTRODES

6.1   Analysis and Procurement of Raw Materials:

Samples of various raw materials, wires and silicate
solutions are analysed in a chemical laboratory in
order to ensure that materials with exact specifi-
cations are used.   Bulk procurement is then made.
It is always better and preferable to procure
materials from reliable suppliers.   Inconsistency
in batch supplies must be avoided as far as possible.
Frequent sampling inspection is a must.   A well
organised chemical laboratory with facilities for

instrumentation analysis must be available to
provide continuous back-up service.

Raw materials must be stored properly and identified
clearly so as to ensure that there is no mix-up.
A codification system must be evolved to ensure
secrecy.

6.2   Wire Straightening and Cutting:

Rimmed steel wire coils received from steel plants
are redrawn to the required sizes in a drawing
mill.   Diameter must be accurately maintained and
wire drawing lubricants must be completely removed
preferably by acid pickling.   The drawn wires are
straightened and cut to the required length in a
wire straightening and cutting machine.

6.3   Dry Mixing:

Sieving of raw materials is done to ensure that
physical specifications are alright.   The raw
materials for each classification of electrode
are accurately weighed as per the formulation and
are homogeneously mixed in a dry mixer.

6.4   Wet Mixing:

Sodium and Potassium silicate solutions as per
required concentration and specific gravity are
added to the dry mix and wet mixing is done.
Quantity of solution added and mixing time are
important parameters.

Wet paste that is obtained is made into the form
of cakes or pugs in a Briquette Press.

6.5   Extrusion:

Cakes are loaded into the cylinder of the extrusion
press.   Rods are fed from the rod feeder and the
compressed paste is extruded on the rods.   Elec-
trodes are collected in the conveyor and are
air-dried.   Oven drying/baking is done depending
on the classification of the electrodes.

6.6   Quality Control Procedures:

6.6.1   Moisture Pick-up in Electrodes:

It is difficult to avoid moisture pick-up in
electrode coatings for fundamental reasons -

*   Even the most carefully selected and approved
    coating binders are mildly hygroscopic.

*   Electrode stores (unless temperature controlled)
    undergo fluctuations of temperature which lead
    to high humidity and dew condensation.

*   Totally effective packing is prohibitively
    expensive.

*   Stores mishandling and travel vibration damage
    even the highest quality commercial packing.

Following precautions need to be taken by both
electrode maker and user:-

*   The electrodes must be thoroughly and effectively
    dried at the makers works and packed immediately

after drying to prevent to moisture pick-up.
In factories where the steam or water vapour
evolved in the drying process is discharged
directly into the factory atmosphere the rate
of moisture transfer to coating will be high.
Electrodes must not stand unpacked in these
factories.

* The packing must give sufficient protection
against moisture pick-up to permit the rods
to survive a period in the makers' factory
and the journeys concerned and reach the
user's factory in good condition.   Direct
contact with moisture bearing material,
cardboard for example, is not advisable.

* To prevent dew condensation and the occurence
of high humidity the users stores should be
kept at a temperature 5-10°C above the highest
temperature of the day.

* If, in spite of care at all stages, the electrodes
have become wet then redrying or rebaking is
necessary.   The procedures vary widely according
to the electrode type, the components of the
coating, the initial drying and baking process
used by the makers and the extent and duration
of exposure to a wet environment.   Most electrode
makers give thorough and detailed instructions,
on rebaking or redrying, based on experience of
the type, measurements of hydrogen in weld metal
or water expelled at 100°C or 1100°C.   The
instructions should be followed carefully because
requirements depend upon the electrode type,
a cellulosic electrode operating effectively

at 2-3% loss at 100°C while a low hydrogen
type may not accept more than 0.3% loss at
1100°C.   In all cases circulation of the
oven atmosphere is needed to permit steam to
be removed and the electrodes must not be
piled so deeply that the inner layers escape
the drying process.

6.6.2   <u>Electrodes Physically Defective</u>:

The main problems are -

- Coatings and core wire are not concentric
- The strike ends have a covering of coating
  which prevents striking an arc
- The holder end is not sufficiently
  clean to give good electrical contact
- Coatings have been dented by conveyor belts
  or drying racks

The proportion of substandard electrodes is minute
but with mass-production it is, for practical
purposes, impossible to guarantee total freedom
these defects no matter how intensive the inspection.

Eccentric rods cause problems of manipulation and
poor X-rays and hence all four defects are unaccep-
table.

The defects are easily recognisable at the operator/
foreman level.   The essential precaution is to make
certain that when the trouble is found, it is reported
immediately and investigated forthwith.   If the
trouble is confirmed the batch must be withdrawn.

The electrodes may be adequate for non-critical
jobs although most makers replace electrodes
defective in this way.

6.6.3   Electrodes in the packet are not the type shown
on the label:

Complaints of mispacked electrodes have increased
steadily in recent years.   The problems seem to
arise at the user works when electrodes are removed
from their packets and rebaked.   If electrodes
of one type and size only are loaded into an oven
at any one time there is no problem of identification.
When however, a number of them   are being baked
simultaneously there is the chance of a mix up.
Printing electrodes with their brand name and
classification is of assistance but does not
eliminate the need for a further control and identi-
fication system during the drying process because
of the difficulty of finding a printing ink which
will remain legible after heating upto 450°C.
The alkaline nature and in some cases, dark colour
of the coating do not help.   There are very few,
if any paints or inks, that withstand such a heat-
treatment without very drastic deterioration.

It is preferable for the electrodes to be compart-
mented in the baking oven and identified by embossed
metal tags which show name and batch numbers.

A further precaution when time schedules permit is
to make one man alone responsible for the redrying
operation.   If a mix-up occurs there is no doubt
about where the blame rests.

6.6.4   Technical Queries and Complaints:

This heading includes points arising from electrode
design, electrode selection, raw materials and
processing.

Of all the precautions to be taken to ensure quality
there is none more important, more obvious or more
immediately productive of good results, than the
selection of the best or the most suitable electrode.

The quickest way to make an improvement in this
direction is simply to ask experienced welding
engineers for their advice on the application
concerned.   When time permits however, a more
thorough exploration of the   available   resources
may be preferred and there are two approaches.
Either the electrode user may carry out a survey of
existing electrodes already available on the market
or he may ask an electrode maker for a new electrode
designed specifically for the application.   The
market survey is often preferred because of the
belief, not always justified, that an established
type must be more dependable.

7.0   INTERACTION BETWEEN WRI AND INDUSTRIES

Welding Research Institute has done a lot of research
in the field of Manual Metal Arc Welding consumables
and has developed know-how for E6012, E6013, E7024,
E7018, E8018 and E9018, Rutile and basic coated
hardfacing electrodes giving hardness of 250, 350
450 and 650 VPN, 14% Manganese Hadfield Steel
Electrode and a special super hard surfacing

electrode depositing high alloy which can give
high resistance to wear.   WRI would be willing
to give this know-how and assist industries in
developing countries.

TABLE-4

USABILITY TEST RESULT

Electrode Type :	Pipe Size :
Brand Name :	Position :
Size :	WPS No. :
Manufacturer :	Power Source:
Batch No :	Preparation:
Date of Testing :	

STRIKING	VERY EASY	GOOD	POOR	DIFFICULT
Restriking hor arc stability and metal transfer	Very Easy	Good	Poor	Difficult
Spatter	Smooth	Fine	Erratic	Rough
Follow-up	Close	Steady	Clean pool	Semi-clean pool
Control	Easy	Moderate	Diffi-cult	Impossible
Cover	Full	Partial	Incom-plete	--
Cracking	Good	Bad	--	--
Removal	Self-lifting	Easy	Diffi-cult	--
Comments	--	--	--	--
Ripples	Fine	Regular	Coarse	Irregular
Profile	Convex	Concave	Flat	--
Washout	Good	Bad	--	--
Finish	Bright	Dull	Slag sticky	--
Regularity	Good	Bad	--	--
Undercut	Heavy	Inter-mittant	--	--
Cracks	Present	Not present	--	--

GAS METAL ARC WELDING ELECTRODES

1.0   INTRODUCTION

The electrodes used in GMAW is bare, solid wire
and consumable. Almost all electrodes used for
GMAW of steels have deoxidizing or other scaven-
ging elements added to minimize the amount of
porosity and to improve the mechanical properties.
The use of electrode wires with the right amount
of deoxidizers is most important, when using oxygen
or CO_2 bearing shielding gas.

The filler metal specifications covering GMAW are
shown below:

AWS Specification	Metal
A 5.7	Copper and copper alloys
A 5.9	Stainless steel
A 5.10	Aluminium and aluminium alloys
A 5.14	Nickel and nickel alloys
A 5.16	Titanium and titanium alloys
A 5.18	Carbon steel
A 5.19	Magnesium alloys
A 5.24	Zirconium and zirconium alloys
A 5.28	Low alloy steels

The electrodes used for GMAW are generally small
in diameter when compared to other arc welding
processes. Wire diameters ranging from 0.8 mm to
1.6mm are the most widely used. Because of the
small electrode wire sizes and relatively high
welding current levels used, the melting rates of

the electrodes normally range from about 2 mtrs/min
to 16 mts/min.   Because of the relatively small
electrode size, which gives a high surface to
volume ratio, cleanliness of the wire is very
important.   Drawing compounds, rust, oil or other
foreign matters on the surface of the electrode can
cause weld metal defects such as porosity and
cracking.

2.0 CO_2 WELDING ELECTRODE WIRE

CO_2 welding wire must have a special composition to
withstand the oxidising nature of the arc atmosphere.
At the high temperature of the arc, CO_2 gas dissoci-
ates into CO and atomic oxygen.

$$CO_2 = CO + O$$
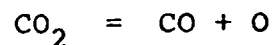
Under these oxidising conditions, the C present in
an unkilled weld pool would react with the oxygen to
form CO and thus form porosity.   To prevent this
happening additions of deoxidants are made to the
welding wire to lock up the oxygen.   Most CO_2 welding
wires are "overkilled" with silicon and manganese
and these remove the oxygen as a slag.   Some wires
also contain small additions of Al, Titanium, or
Zirconium.   Wires containing Al, Ti and Zirconium
produce black, glassy slag islands whereas the
deoxidation product with simple Si, Mn wire is
usually a light khaki colour.

2.1 Typical Composition of CO_2 Welding Wire:

Type	% C	Si	Mn	Al	Zr	Ti	S	P	Cu
1	0.12 Max	0.9 to 1.2	0.9 to 1.6	–	–	–	0.03 Max	0.03 Max	0.2 Max
2	0.12 Max	0.3 to 0.9	0.9 to 1.6	0.4 to 0.3	Singly or together upto 0.15 each		0.03 Max	0.03 Max	0.2 Max
3	0.12 Max	0.3 to 0.9	0.9 to 1.6	0.6	–	–	0.03 Max	0.03 Max	0.2 Max

3.0 COPPER COATING

MIG/MAG welding solid wires have copper coating
over the surface, to improve current transfer and
corrosion resistance. Since the specific surface
area to volume ratio of a wire increases with decrease
in wire dia, more copper will be transferred to
the weld with the thinnest wires, if the thickness
of the copper coating remains constant. Ccpper
occupies superior position on the free energy diagram,
so that the total wire copper content is transferred
to the weld pool with virtually no loss. Copper
is regarded as being solu-ble in steel in amounts
upto 0.4% and this quantity is regarded as the safe
maximum. If it exceeds this limit, it can be a
contributor cause of hot cracking.

4.0 FLUX CORED WIRES

Flux cored wires are most widely used for welding
low carbon and low alloyed structural steels.
They are also used for welding alloyed steels,
cast iron, non-ferrous metals and alloys.

The flux cored wires are used with and without
additional shielding gases. The wires used
without additional shielding gas is called self-
shielded wire. In decomposition of the gaseous
materials of the core, the gases are evolved for
protecting the molten metal from air.

The flux cored wires are classified according to
the core type into five types -

01) Rutile-organic
02) Carbonate-fluorite
03) Fluorite
04) Rutile
05) Rutile-fluorite

The wires of rutile-organic, carbonate-fluorite and
fluorite types are used, mainly as self-shielded
ones. The Rutile and Rutile-fluorite wires are
used with the additional CO_2 shielded. The core
of the wire of the rutile organic type consists of
rutile concentrates and aluminium silicates (Fluorspar,
granite, mica, etc). The ferromanganese is used
as a deoxidizer, the starch and cellulose being used
as gas forming materials.

In the wires of the rutile-fluorite type a slag forming part of the core consists of rutile and fluorite concentrates. The oxides of alkali earth metals, aluminosilicates are sometimes introduced into the wire of this type. The ferromanganese and ferrosilicon serve as deoxidizers.

The iron powder is introduced into the cores of all types of wires to increase the efficiency of welding. The amount of non-metallic materials in the wire core does not normally exceed 18%. Wire consumption for obtaining 1 Kg of deposited metal does not exceed 1.3 Kg.

5.0   WIRE QUALITY

Quality problems can create enormous hideen costs involving downtime. Here are some important quality aspects to watch for.

01) Copper Plating: Plating methods and techniques vary considerably among wire manufacturers, poor adhesion is a common problem with some methods resulting in plugged liners and contact tips.

02) Feedability: The wire jamming would probably cause numerous work stoppages in any typical semi-automatic operation. Feedability is also directly related to manufacturing methods.

03) Cleanliness: 'Dirty' wire is a prime source for a number of problems.

04) <u>Temper</u>: Higher wire tensile strength reduces
    'birdnesting' problems.

05) <u>Cast</u>: A cast that is too small can cause
    problem in feeding and weld puddle manipula-
    tion.

06) <u>Helix</u>: A helix of 25.4mm maximum will
    eliminate arc wander.

* * * * *

SUBMERGED ARC WELDING CONSUMABLES

1.0 INTRODUCTION

Among the automatic welding process, Submerged Arc
Welding is quite promising especially for heavy
structural and pressure vessel fabrication and of
late is also being used extensively for surfacing
applications.   This process offers a wide choice
of wires and fluxes to produce all types of weld
metal including mild steel, low alloy steels,
stainless steels and some non-ferrous alloys. An
understanding of types of wires and fluxes and
their classification would facilitate the right
choice of consumables for particular application
and safeguard the quality of welding.

2.0 SAW WIRES

The electrode wires of SAW are classified based on
their chemical composition.   The AWS specification
(A5.17) prescribes the requirements of electrodes
for carbon and low-alloy steels.   The most widely
used electrodes have carbon content in the range of
approximately 0.07 to 0.15 %.   Greater attention
is paid to Manganese as strengthening element.

The classification designation consists of a prefix
'E' followed by letters L, M or H to indicate the
Manganese content as 0.6 % Max; 1.25 % Max and
2.25 % Max.   The carbon content is indicated by
the last digit for example, EL8, EM12, etc.   For
alloy steel application, the classification desig-
nation consists of prefix 'E' followed by composi-
tion identification as A1, A2, B1, B2, etc.   The

tubular or cored composite electrodes are classi-
fied based on their deposited weld metal composi-
tion. The classification designation shall consist
of prefix 'EC' indicating tubular or cored wire
followed by its deposited weld metal composition
identification.

The AWS specification A5.9 covers SAW wires for
corrosion or heat-resisting chrome and chrome Ni
steels. The Nickel and Nickel alloy filler materials
are covered by AWS specification A5.14.

The selection of an electrode for a particular
application may seem a difficult and confusing task,
but only because there are so many avenues of choice.
Some welding engineers prefer to employ neutral
(unalloyed) flux for all their projects and, therefore,
select an electrode which contains all of deoxidising
and alloying elements needed in the filler wire.
This presents a safe, sound practice but procurement
of wire of proper composition often is difficult.
Other's plan all their prospects on the basis of
using the least costly electrode (low carbon rimmed
steel) and they add all the required deoxidisers
and alloying elements through the flux. Obviously,
this practice calls for careful selection of flux
formulation, handling of the flux and close control
of welding conditions.

3.0   SAW FLUXES

Unlike the coatings used on covered electrodes, which
are complex due to production considerations, many

submerged arc welding fluxes can be based on
mineral compounds selected from ternary or
quarternary-oxide systems. The most common
systems in use are based on the manganous-oxide
silica or the lime-silica system, both of which
are combined with various proportions of alumina,
magnesia, zirconia or titania to form complex oxide
fluxes. Phase diagrams for some of the simple
combinations (Fig.1) are useful guides in flux
formation. The viscosities of the welding slags
are in the order of 2 or 7 poises at $1400^{O}C$ $(2552^{O}F)$.
The 200-poise temperature of welding slags is
typically of the order of 1100 to $1200^{O}C$ (2012 to
$2192^{O}F)$. A welding slag must have sufficient
viscosity to give it impermeability to atmospheric
gases and to prevent it from running away from the
molten weld metal, but the viscosity must be low
enough to permit gases to be evolved from the molten
metal.

Fused submerged arc welding fluxes of the type just
described contain few additions aimed at changing
the electrical properties of the composition. In
addition, compounds with low work functions, such
as sodium oxide and potassium oxide, are added to
aid in initiating and sustaining the arc. Other
additions may be made to control penetration, melting
rate and polarity of operation. These properties also
can be incorporated into submerged arc fluxes of the
bonded or agglomerated type.

The raw material requirement for fluxes consist of
a mixture of chemical radicals. The desired mixture

can generally be produced by combining a number
of naturally occuring minerals (Table-1). Given
the further requirement that in the flux finally
used every grain should approximate in composition
to that of the flux as a whole. Therefore, the
problem lies in grinding, mixing and assembling
the different minerals into grains having sufficient
bond strength. The function of the various
ingredients is given in Table-2. The fluxes
available in world market has been given in Table-3.

3.1 Production Method of Different Types of Flux:

3.1.1 Fused Fluxes:

The appropriate minerals are collected and crushed to
a convenient grain size and mixed dry. The solidi-
fication following the melting gives the desired
bond. The bonds in the solid material are ionic.

In practice the ingredients are weighed out, premixed
dry at room temperature and fed gradually into a
heated vessel of graphite or, more commonly, of an
industrial refractory such as magnesia and fireclay.
If of graphite, the vessel is usually heated by
high frequency induction or if of a refractory is
surrounded by conventionally fired furnace. When
the batch of flux is all molten it is poured out
into water or onto steel chills, where the flux
first solidifies and then breaks up under thermal
shock. The fragments are gathered and crushed to
convenient size. Typical melting and pouring
temperatures range from $1500^{\circ}C$ to $170C^{\circ}C$. The

fluxes are also melted by the heat generated by
passing large currents through the molten bath,
instead of using open arcs on the surface of the
melt.   The current may be regulated simply by
changing the depth of immersion of the electrode
in the molten bath.   The flux powder produced
consist of individual solid, angular, glassy
particles, a range of sizes, which stand up well
to the various handling operation associated with
welding.   The product is crushed and passed over
a series of screens for sizing.   The sized
particles have lower and upper limit (minus 12
mesh to plus 200 mesh).

The fusion process is simple in principle but the
use of high melting temperature ($1400^{o}C$ to $1700^{o}C$)
and subsequent quenching makes the practice very
difficult.   The melting point is based on the
composition and some times the ingredients are
added in stages.   This is rather a cooking process
so, vast experience is needed.

The minerals used as starting materials are
frequently metallic oxides, or carbonates and from
elementary chemistry it will be seen that carbonates
will probably break down to oxides, before or during
the melting stage, while molten there is possibility
for mixing of oxides with atmospheric oxygen.   So
protective atmosphere is sometimes necessary.   The
oxygen from the atmosphere either diffuses into or
away from the liquid oxides depending on the initial
state of valency, and the state of valency which is
most stable at the temperature of the melt.   On

quenching, the high temperature form of the oxide, may or may not transfer to a form which is stable at room temperature. Even if no valency change is known to occur at high temperature the oxide formed may react during or after the quenching stage, which again represents a loss of control over the process.

Carbonate Decomposition

$$Ca\ Co_3 + Heat\ \ -----\ \ Ca\ O + CO_2$$
$$2CO_2 + Heat\ \ -----\ \ 2CO + O_2$$
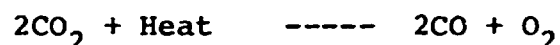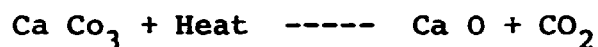
(CO_2 dissociation occurs in arc atmosphere).
The advantages of fused fluxes are:

1) Extremely good chemical homogeneity

   (a) Quiescent slag pool with no gas evolution

2) Fines may be removed without changing the composition of the flux;

3) Most prefused fluxes are a non-hygroscopic product that is unaffected by moisture, thus simplifying storage problems;

4) The unused portion may be collected and used again without significant change in particle sizing or flux composition;

5) Suitable for highest speed of travel.

The primary disadvantage of prefused compositions is the inability to add deoxidizers and ferroalloys without segregation or prohibitive losses during processing due to the high temperatures involved.

3.1.2   Bonded Fluxes:

With bonded fluxes, the raw materials are ground
to approximately 100 x D, dry mixed, and then
bonded together with an addition of potassium or
sodium silicate.   The resulting mixture is then
pelletized, dried at a relatively low temperature
and broken up by mechanical means and screened,
the exact method depending on the manufacturer.
The atmosphere in the drying kiln can be controlled
and is generally kept in a reducing condition.

The primary advantages of bonding fluxes are that:-

1)   The low temperatures involved in the bonding
     process permit the extensive use of metallic
     deoxidizers and ferroalloys;

2)   The lower bulk density permits the use of a
     thicker layer of flux in the weld zone;

3)   Generally, excellent detachability of fused
     slag;

4)   Flux can be colour identified by incorporating
     pigment minerals.

However, there are disadvantages:

1)   In many cases, fines cannot be removed for
     fear of altering the flux composition;

2)   Bonded fluxes may have a tendency to absorb
     moisture, and

3)   The molten flux pool may evolve gases.

3.1.3 Agglomerated Fluxes:

The agglomerated fluxes are similar to the bonded
fluxes except that a ceramic binder which is cured
at temperatures in excess of $760^{\circ}C$ ($1400^{\circ}F$) is
used.   The high temperature required limits the
use of deoxidizers and ferro-alloys as with
prefused fluxes.

3.1.4 Agglomeration:

The agglomeration process depends upon making
bonds between the constituent minerals by a
cementing action.   The minerals are ground and
then mixed with a small proportion of water glass
(Sodium potassium silicate).   Sodium silicate
has a melting point of $1089^{\circ}C$ and potassium
silicate has a melting point of $976^{\circ}C$.   But
waterglass melts at $543^{\circ}C$.   Alternatively it is
necessary to postulate the precipitation of complex
carbonates due to absorption of CO_2 from the air
into the sodium and potassium silicate.   The
important feature of the agglomeration process is
that the powder may be bonded together by the action
of aqueous solution at room temperature, and that
even if individual bonds may switch over at high
temperature.   The overall binding effect persists
virtually upto melting point of the flux.   Possi-
bilities of use of boric oxide has yet to be
exploited, but sodium potassium silicate as a
binder still predominates.

In agglomeration the production of flux as discrete
particles of the desired sizes is achieved by an

elegant method involving surface tension effects.
When a powder is wetted with water (or waterglass
solution) applied as a find spray it is observed
that there is a tendency for the powder to form
into moist balls.   This effect is enhanced by
flinging the mixture at, and allowing it to fall
down, a vertical surface.   By repeating the
tumbling process the whole of the moistened mixture
is formed into balls, and the finer balls begin to
coalesce one with another to form larger ones.
The art of the flux maker is to grind the material
to a very fine particle size (0.05 mm or finer),
to mix, spray and tumble as above, and finally to
stop the process when all of the mixture has
balled-up, but before too many overlarge balls
have formed.   Difficult as this may appear, the
technique can in fact be mastered remarkably
quickly, as has been shown by the successful work
of several researchers who made their own fluxes
by agglomeration.

4.0   METALLURGICAL, ELECTRICAL, AND TECHNOLOGICAL
        PROPERTIES OF FLUX

4.1   Metallurgical Aspects:

If we look into the metallurgical aspect of flux
formulation two components become more significant
that is, the Si and Mn reaction.   The patent
formulations have been chiefly manganese, calcium
and magnesium alumina silicates.   A manganese
silicate composition with typical analysis is
shown in Table-4.   This can be carefully balanced
by phase diagram shown in (Fig.1) as a guide to

slag composition. The bonded fluxes have
sometimes addition of ferroalloys. The fusing
process is finally accomplished during the welding
operation. The ferrosilicon in a bonded compo-
sition reacts stoichemically with the manganese
dioxide in the weld zone to generate additional
manganous oxide and silica. Further modifications
of the metallic silicates aim at the production of
more economical fluxes using less manganese.

The basicity of the flux has been a criteria for
selection of flux. Though there are 31 types of
formulae for basicity calculations, but one given
by Tuliani, Boniszewskii and Eaton seems to be
more practical from calculation point of view.

$$B = \frac{CaO+MgO+BaO+SrO+Na_2O+K_2O+Li_2O+CaF_2+\frac{1}{2}(MnO+FeO)}{SiO_2 + \frac{1}{2}(Al_2O_3 + TiO_2 + ZrO)}$$

Referring Figs.2a, 2b, 2c and 2d we can conclude
the following:

(a) Fluxes having basicity Index less than 1 are
    incapable of controlling the sulphur content
    of the weldmetal effectively. BI is less than
    1 is equal to Acid;

(b) Fluxes having basicity Index between 1 and 1.5
    are capable of controlling the sulphur effect-
    ively but not oxygen. Basicity Index is greater
    than 1 and less than 1.5 = Neutral;

(c) Fluxes having basicity Index between 1.5 and 2.5

are capable of controlling the sulphur and
oxygen content effectively and lower the
transition temperature by controlling silicon
content.   Basicity Index is greater than
1.5 but less than 2.5 = Basic;

(d) Fluxes having basicity Index above 2.5 are
capable of lowering the charpy-V notch transi-
tion temperature down to $-40^{\circ}C$ or even below
by controlling the composition and microstructure
of the weldmetal.

Basicity Index is greater than 2.5 = High basic.

But these criterions do not give sufficient reasons
for the flux formulations.   This was only a guidline
to the user of flux.   So, in the following paragraph
we have taken the analysis from Ionic Theory.

The several oxides present in the flux may vary
from more or less strongly basic via chemically
neutral to less or more strongly acid in character.
Basic oxides are characterised by their tendency
for splitting into O^{2-} ions for example,

$$CaO \rightleftharpoons Ca^2 + O^{2-}$$
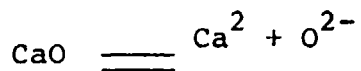
Acid oxides on the contrary bind with available free
O^{2-} ions for example,

$$SiO_2 + 2O^{2-} \rightleftharpoons SiO_4^{4-}$$
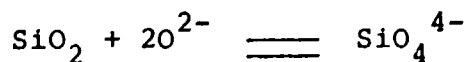
The chemically neutral (amphoter) oxides can do
both, depending on the composition of the slag as

a whole.   But, this is less significant.

Here, it is worthwhile to quote Dr. Julius Zeke's
interpretation of basicity based upon ionic theory.
This proves to be more scientific and according
to this formulation of flux can be developed.

The number of free gram-ions nO^{2-} will be calculated
according to the general equation:

$$nO^{2-} = mMeO + mMe_2O - (mTiO_2 + mAl_2O_3 + 2mSiO_2)$$

$$\text{No.of mols. 'm'} = \frac{\text{\% of Metal Oxide}}{\text{Mol. Wt.}}$$

The nO^{2-} will be known as main metallurgical
characteristic.   If this value is positive the
slag is characterised by the existence of free O^{2-}
anions.   According to ionic theory this slag is
said to be Basic nature.   Then we can say whether
the flux has oxidation potential or reduction
according to the value:

$KIRsi$ and KIR_{Mn}

$\% \quad Mn \quad = K'_{Mn} \cdot KIR_{Mn}$

$\% \quad Si \quad = K'_{Si} \cdot KIR_{Si}$

Finally $\% Si_{Me} = 42.5 \ KIR_{Si}$

$\% Mn_{Me} = 5.66 \ KIR_{Mn}$

Thus by calculating nO^{2-}, KIR_{Si} and KIR_{Mn} we can say the metallurgical characteristic is of what nature.

4.2 Electrical Characteristic:

Arc Stability:

Arc stability may be described as the easy initiation and further maintenance of an arc. While the elastic impact occurs between electrons of low energy, and atoms, there should not be exchange of energy. But if the energy of electron is increased it gives some amount energy to the atom and changes the direction. It is known as excitation energy. If the energy of the electron is further increased it pulls out or knocks out one or more electron from the outer shell of the atom. This is known as ionisation energy. The maximum probability of ionization is found between 70 and 100 ev (Energy of the electron) for most gases, except for potassium and sodium vapours that show a maximum arc stabilising agents.

As early as 1924 Ogden suggested that substances with high thermionic emissivity such as oxides of the alkaline earth promote arc stability. Smith and Rinehart suggest that arc stabilizing material such as titanium and potassium compounds are generally found in the modern arc heavily coated electrodes and that arc stabilizers produce a better energy balance between cathode and anode. Hazlett used an arc-stability index to compare different coating ingrediant (Table-5, 6). So, we can say Na, K, TiO_2 and in some composition silica and fluride compounds generally assure satisfactory arc stability.

Electrical Conductivity:

The Fig.2 shows the conductivity (mhos) Vs.
temperature (^{O}C). The composition of these
fluxes are also studied by Noor M.A.B. It was
found that the content of alkali oxides (Na_2O and
K_2O) differs from one flux to the other. Bockris
has pointed out the increasing content of sodium
and pottasium oxides in binary silicate melts
increase the electrical conductivity and it is
apparent that no such correlation exists. But
it is clear from (Figs.2 & 3) with an increase in
temperature the electrical resistance of the flux
decreases and becomes highly conductive at the
temperatures in the welding zone.

4.3 Technological Characteristic:

Viscosity:

The weld bead shape is governed by slag viscosity,
amount, density and freezing point. A fluid slag
is necessary to for rapid solution of oxide
inclusions from the molten steel. The viscosities
of the welding slags are in order of 2 to 7 poises
at 1400°C (Figs.2,3 & 7). Some compounds increase
the viscosity whereas some decrease viscosity.
Calcium fluoride decreases viscosity. Titania
is also effective in reducing viscosity, especially
when replacing alumina or silica. Ferrous oxide
has greater effect on reducing viscosity than Titania.
When manganous oxide replaces ferrous oxide, a
slight increase in viscosity results. Lime also
causes a considerable decrease in viscosity but

increases melting point.

The structure of slag determines the viscosity.
Slags form molecules of silica or alumina tetra-
hedrons.   The metallic oxide breaks this confi-
guration and as the network breaks down viscosity
decreases.   Aluminium is much like silicon.   So
substituticn of alumina into silica network does
not result in marked changes.   But larger alumina
gives rise to sharing of six atoms.   So after
certain level it does not replace for silica
tetrahedron.   But increase and decrease of
viscosity with temperature is well marked.

Surface Tension:

The surface tension of a liquid arises from the
fact that atoms on the surface are not completely
surrounded by neighbours of the same type as are
those in the interior.   The unsatisfied chemical
or binding forces result in a net inward force
normal to the surface.

The surface tension affects covering by molten
slag, bead geometry and slag detachability.   When
the string effect is going on the surface tension
allows the slag to float from the molten metal.
Typical surface tension for manganese oxide silica
or lime-silica slag at $1600^{\circ}C$ is 400 dynes/cm where
iron has surface tension of 1500 dynes/cm in helium
atmosphere.

In general the slag constituents decrease the
surface tension of pure iron.   Hazlett indicated
that light surface coatings of magnesia, alumina
titania or manganous oxide in carbon monoxide
decreased the surface tension of molten iron by
3% (944 dynes/cm).   Addition of silica, calcium
carbonate or fluor-spar increased the surface
tension by 5 to 7 percent.   Ferrous oxide reduces
very strongly the surface tension (about 15%).
Submerged-arc fluxes with controlled excess oxygen
can reduce undercut by reducing surface tension
of the weld metal.

Fluidity:

The fluidity of slag is desirable for rapid solution
of oxide inclusions from the molten.   However, a
very fluid slag would flow to the side and front
of the arc, leading to possible overlapping with
the molten metal and subsiquent difficult slag
removal.   On the other hand it is difficult for
the metal to remove sluggish slag and finally slag
entrapment results.   A slag that is not fluid
enough to allow the gases to escape and may result
in pitting or depression on the bead.   Fluidity
of the slag is governed by CaF_2.   So it has to be
controlled carefully for SAW flux.   There has been
example of ESW flux containing as high as 55% of CaF_2.

Slag Detachability:

It is desirable to have the temperature co-efficient
of expansion of the slag slightly different from
that of the steel.   Only enough difference is

required to give good slag removal as too-rapid
slag lifting will lead to undesirable tempered
colours.   So to the flux constituent with
different co-efficient of thermal expansion are
added.   But it is seen sometimes the oxide formed
at the top layer binds with slag and metal make
slag removal difficult.   There is also an opinion
that if the atomic lattice of slag is similar to
the steel it is difficult to detach the slag.

The desired quality of submerged arc welds is
obtained by a judicious choice of wire/flux
combination.   The weld metal properties are to
be evaluated for a particular combination of wire
and flux and not with wire and flux in isolation.
For instance teaming a high manganese steel
electrode with a flux that contains substantial
alloy addition of manganese, unless, ofcourse a
very high manganese content is desired in weld
metal, may seriously effect the toughness proper-
ties of weld metal.   Similarly a combination of
high silicon-killed steel electrode and high-silicon
flux might prove to be a crack susceptible combination.

TABLE-1

CHEMICAL COMPOSITIONS OF COMMON MINERALS USED IN FLUX PRODUCTION

Chemical Name	Typical Chemical Composition
Ilmenite	$FeO \; TiO_2$
Magnesite	$MgO-FeO$
Magnesium Oxide	MgO
Manganese Ore	$MnO-SiO_2-Al_2O_3$
Silica, quartz	SiO_2
Alumina (Cal or Hyd)	Al_2O_3
Corundum	$Al_2O_3-SiO_2$
Bauxite	$Al_2O_3-SiO_2-TiO_2$
Rutile, titania	TiO_2
Dolomite	$MgO.CaO.(CO_2)_2$
Fluorspar, fluorite	CaF_2
Lime	CaO
Limestone,Calcite,Marble	$CaCO_3$
Zirconia	ZrO_2
Feldspar	$K_2O.Al_2O_3.6SiO_2$
Sodium silicate	SiO_2/Na_2O ratio 3:22
Potassium silicate	SiO_2/K_2O ratio 2:11
FERROALLOYS	
Ferro-silicon	50 % Si
Ferro-manganese high carbon	80 % Mn
Manganese-silicon	60 % Mn, 30 % Si
Chrome oxide	Cr_2O_3

TABLE -2

FUNCTIONS OF VARIOUS FLUX INGREDIENTS

Ingrediants	Deoxidizers and fluxes	Slag former	Control of slag viscosity	Arc stabilization	Binders	Alloying agents
Calcium carbonate	X	X	X	X		
Calcium oxide	X		X	X		
Calcium fluoride	C		X			
Titania, rutile	X	X	X	X		
Zirconium oxide				X		
Alumina			X	X		
Silica	X	X	X	X		
Ferro silicon	X	X				X
Ferro manganese	X	X				X
Sodium silicate		X	X	X	X	
Potassium silicate		X		X	X	
Manganese dioxide		X		X		
Feldspar		X	X	X		

TABLE-3

ANALYSES OF TYPICAL MnO-SiO$_2$ COMPOSITIONS ON WORLD MARKET

	USA	Russia	Czechoslovakia	Germany	India	Holland
MnO	41.5	36.0	42.5	37.8	32.9	38.0
SiO$_2$	38.0	42.2	45.2	44.7	4C.4	40.7
MgO	0.8	6.5	--	0.4	2.1	2.5
CaO & BaO	5.5	5.5	2.7	6.61	7.7	6.6
MnO$_2$	1.0	0.20	--	3.1	--	0.4
Al$_2$O$_2$	4.0	4.5	1.5	2.1	1.4	4.8
P	0.03	0.10	0.10	0.02	--	--
S	0.02	0.10	0.04	0.02	0.01	--
C	0.02	--	--	0.01	--	0.01
FeO	--	--	0.9	--	3.7	--
Fe$_2$O$_3$	2.0	--	--	0.8	--	2.8
CaF$_2$	5.0	4.0	3.4	4.7	3.4	4.1

TABLE-4

TYPICAL MANGANESE-SILICATE SUBMERGED-ARC FLUXES

	Prefused, %	Bonded, %
MnO	42.0	36.5
MnO_2	--	5.2[a]
SiO_2	45.0	38.0
CaF_2	6.9	3.9
CaO	1.2	0.8
MgO	0.3	2.8
BaO	0.1	0.3
Al_2O_3	2.0	1.1
FeO	1.5	--
Fe_2O_3	--	2.8
TiO_2	0.1	0.1
K_2O	0.4	--
Na_2O	0.4	1.6
PbO	0.1	0.1
FeSi(50%)	--	7.1[b]

[a] $0.815\ MnO_2\ ---\ MnO$

$0.815 \times 5.2\quad 4.2\%$

[b] $2.14\ Si\ ---\quad SiO_2$

$2.14\ (7.1 \times 0.5)\quad 7.6\%$

Ratio $\dfrac{MnO}{SiO_2} : \dfrac{42.0}{45.0} = 0.93$ $\quad\dfrac{36.5 + 4.2}{38.0 + 7.6} = \dfrac{40.7}{45.6} = 0.89$

CONSUMABLES FOR TIG WELDING

In TIG welding, the filler wire addition is optional.
Filler wires have been developed for almost all the
metals and alloys. If no filler wire is available,
then the parent metal itself may be added as the fillers,
in most of cases. But it is preferable to use filler
wire because additional constituents are added in them
for improved metallurgical properties and for better
quality. AWS and BS have given codes for consumables
for filler wire various metals and alloys. The list of
specifications is given in the Annexure. Filler wires
are available in Ø 0.8, 1.2, 1.6, 2.0, 2.4, 3.2, 4.0mm.
Filler wires are available in the form of wire spools
less than 2.4mm diameter, and rods 0.5m or 1m long for
other diameters.

Tungsten electrodes are available from TIG welding
equipment manufacturers and are classified for welding
different materials as per AWS 5.12. Normally 1% or
2% Thoriated Tungsten is preferred over pure Tungsten
for welding of most of metals other than Al, Mg and
alloys. Addition of Thoria increases the current
carrying capacity and arc stability for electrode. For
welding of Al, Mg and alloys 0.3% - 0.6% Zirconiated
Tungsten electrode is preferred over pure Tungsten
electrode.

In TIG welding normally Inert Gases are used for
shielding the molten weld pool and the hot Tungsten
electrode against oxidation. Normally Argon, Helium
are used. Argon and Hydrogen (upto 10%) mixture, and

Argon and Helium mixture are also used to increase
heat input to the job to meet specific requirements
to compensate for the heat loss in highly heat
conductive materials like Copper, Aluminium and to
avoid undercuts at the sides during relatively higher
welding speeds in some materials like Stainless Steels.
AWS Welding Handbook Vol.II 7th Edition suggests the
recommendations for the selection of shielding gases
and their composition limits for various applications.

The most commonly used shield gas-industrially pure
Argon has the following composition:-

Argon   - 99.96 % Min
Oxygen   - 10 PPM   Max
Nitrogen   - 300 PPM   Max
Hydrogen, CO_2, others - 5 PPM   Max
Water vapour 0.0056 MG/Lit Max

TIG WELDING CONSUMABLES SPECIFICATIONS - AWS SPECIFICATIONS FOR VARIOUS METALS AND ALLOYS

A 5.7   Copper and copper alloys welding rods

A 5.9   Corrosion resistant Chrome, Chrome Nickel steels bare electrodes and welding rods

A 5.10   Aluminium and Aluminium alloy welding rods and bare electrodes

A 5.14   Nickel and Nickel alloys welding rods and electrodes

A 5.15   Titanium and Titanium alloys welding rods and electrodes

A 5.28   Carbon steel welding rods and electrodes

A 5.19   Magnesium and Magnesium alloys welding rods and electrodes

A 5.24   Zirconium and Zirconium alloys welding rods and electrodes

BS specification is given in the following specification:

BS 2901-1970 Parts 1-5.

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