New Filler materials for Manual Metal Arc Welding of Spheroidal Graphite and Malleable Irons

By M. S. Gopalakrishna*, K. S. Raman,*
B. S. Vaideswaran** and M. R. Seshadri**

ABSTRACT

Feasibility test on calcium oxide-silica-calcium fluoride system with other consumables as the flux on spheroidal graphite (S.G.) core wire for multi-pass manual metal arc welding of S.G. iron base metal and malleable iron (M.I.) base metal has been carried out with a constant pre-heat of 500°C. Under similar conditions of welding, the same flux system on high carbon steel core wire has also been tried on M.I. base metal alone. Structure compatibility between the weldment and the base metal in as-welded condition was aimed at, by welding in a groove design used by Schaeffler and Schumbacker[7]. The metallurgical factors involved in the welding process have been studied. The results obtained are promising and favourable. The structures obtained in the weldment are amenable to post weld heat-treatment and resulted in completely favourable microstructures.

INTRODUCTION

It is generally very difficult to weld cast iron family of engineering materials mainly because of their high carbon equivalent, inability to accommodate welding stresses and the problem of restoring favourable mechanical properties after welding. [1] Hence production welding of these materials is very much restricted as compared to maintenance welding [2,3,4] (or repair welding). These factors apply equally well to two of its most celebrated members, namely spheroidal graphite (S.G.) and malleable irons.(M.I.).

Many welding processes such as fusion welding, bronze welding, manual metal arc (MMA) welding, metal inert gas (MIG) welding and etc., are carried out on S.G. and malleable irons. Of these welding processes, bronze welding using nickel electrodes (ENI-CI by AWS A.S. 15.69) gives the most satisfactory weld as it overcomes the problem of dilution effect with regard to carbon from the base metal to the weld and the carbon separates out in the form of finely divided graphite particles, thus resulting readily in a machinable weld deposit[5]. The weld metal is ductile even when welded without pre-heat (cold welding) because of no transformation taking place such as occuring in the case of ferritic deposit. Rapid cooling rates, therefore, do not have a deleterious effect on the weld metal. However, one disadvantage of nickel weld metal is its susceptability to solidification cracking from pick up of phosphorus or sulphur from a cast iron containing high percentages of these elements([6]). S.G. and malleable irons are normally low with respect to these elements and this problem may not be manifested at any stage of the welding process.

However, all these welding processes suffer from one or more of the following limitations, in addition to some of the above stated ones, using commercially available electrodes for the welding of S.G. and malleable irons. These are :

(a) Microstructural incompatibility between the weldment and the base metal.

* Dept. of Metallurgy, I.I.Sc., Bangalore-560012
** Dept. of Mech. Engg. I.I.Sc., Bangalore-560012

(b) Restriction on the carbon content and section thickness of the base metal.

(c) Colour mis-match between the weldment and the base metal.

(d) Susceptibility of the base metal to corrosion in addition to the weldment on exposure to corrosive medium because of stress build up, and

(e) Electrodes are often expensive.

To over come some of the limitations of the presently available commercial electrodes for manual metal arc welding of S.G. and malleable irons, the present investigation was initiated.

Microstructurally, S.G. and malleable irons do not differ very much, in a broad sense, but for the difference that S.G. iron is an as-cast product while malleable iron is a heat-treated product. S.G. iron welding electrode is possible for S.G. iron base metal. But malleable iron welding electrode on malleable iron base metal is ruled out because of its inherent lack of stability on remelting and would result merely in a white-iron deposition. Hence S.G. iron core wire with CaO-SiO_2-CaF_2 system and other consumables as the flux has been tried for multi-pass manual metal arc welding of both malleable iron base metal and S.G. iron base metal with a constant pre-heat of 500°C. Under similar conditions of welding, the same flux system on high carbon steel core wire has also been tried on malleable iron base metal alone. This is because of less burden on this filler material with regard to carbon equivalent make up, as malleable iron is relatively of low carbon equivalent as compared to S.G. iron. The metallurgical factors involved in the welding process using these new-filler materials have been studied in this investigation.

MATERIALS AND METHODS

(1) *Test Plates :*

S.G. iron base metal test plates (35 cm×16 cm×2 cm) and M.I. base metal test plates (30 cm×23 cm×2 cm) were used for the studies. The chemical composition of these materials is indicated in *Table-I*.

The microstructures of the as-received S.G. and malleable iron plates are shown in *Fig. Ia and Ib and Fig. 2* respectively. The structure consisted of in both the cases, about 50 : 50 pearlite-ferrite matrix with graphite particles embedded.

TABLE I

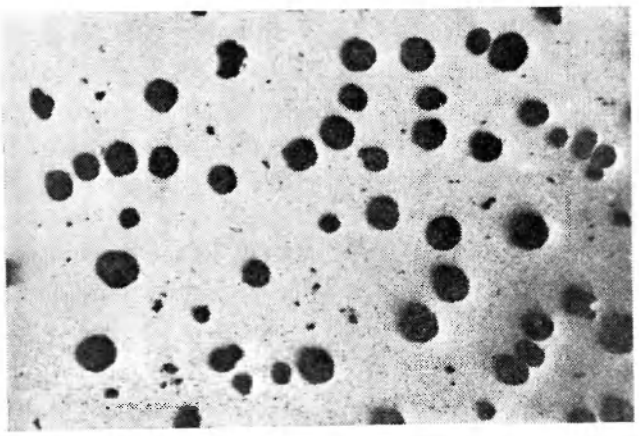
Materials used and their composition

Material	*Composition (wt %)*							
	C	*Si*	*Mn*	*P*	*S*	*Mg*	*Ce*	*Ni*
Malleable iron base metal	2.42	1.4	0.57	0.06	0.06	—	—	—
S.G. iron base metal	3.3	2.2	0.6	0.04	0.01	0.05	—	0.8
S.G. iron Electrode (C.E. : 4.3)	3.4	2.6	0.05	0.1	0.05	0.08	0.01	—
S.G. iron Electrode (C.E. 4.8)	3.4	4.0	0.05	0.1	0.05	0.08	—	—
High carbon steel wire	0.76	0.23	0.7	0.024	0.02	—	—	—

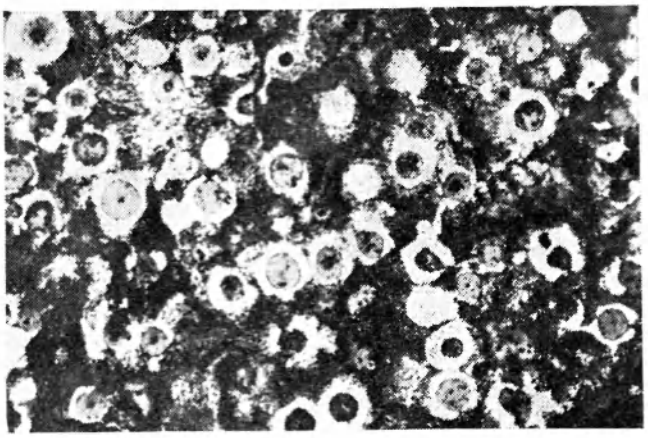
These test plates were planed and machined to the groove profile as shown in *Fig. 3*. This restraint groove design used for standardization of the welding variables has been adopted from the work of Schumbaker and Schaffler [7]. The primary consideration in the design of the test block was that it should be easily preparable, offer considerable amount of restraint to welding, is reproducible and representative of the groove of joint in actual welding practice.

(2) Filler Materials :

(a) S.G. iron electrode preparation. Desulphurised pig-iron was melted in an arc-furnace. 2% nickel-magnesium (Ni-Mg) masteralloy (15% Mg) was added to a pre-heated crucible (850°C) just before tapping while ferro-silicon (50% Si-grade) was added to the furnace to obtain a carbon equivalent (C.E.) of 4.3. The molten metal was tapped at 1350°C and poured into inclined sand moulds to obtain S.G. iron rods of 4 mm and 6 mm diameter and 40 cm in length. As cast, the rods were of white iron matrix (because of 1% Ni-Mg excess than the normal amount added and the section thickness is small) with graphite particles embedded.



(a) *Unetched at 100×*



(b) *Etched at 100×*
(Etchant : 2% Nital)
Fig 1. S. G. Iron Base Metal

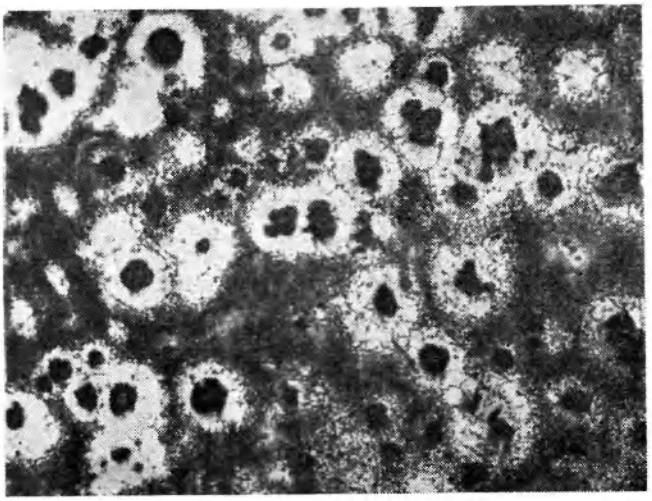


Fig 2. M.I. Base Metal etched at 100×(2% Nital)

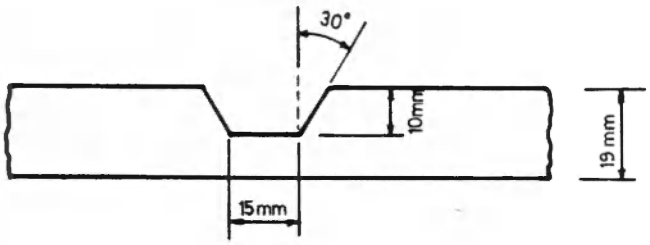


Fig 3. Standard Test Groove

These rods, however, had adequate strength to withstand any normal handling. The composition of this S.G. iron electrode is given in Table-I.

(b) High carbon steel wire : Wrought high carbon steel wire of 4 mm diameter was obtained from M/s. Deccan Wires, Bangalore. The composition of this material is indicated in Table-I.

(c) Flux materials : The criteria for selecting the flux was mainly on the basis of fusion point in the range of 1100-1300°C and a basicity ratio([8]) in between 2 and 3. These basic conditions are satisfied by the following systems :

(i) CaO-SiO_2-CaF_2 (Eutectic at 1100°C)
(ii) CaO-MgO-CaF_2
(iii) MgO-SiO_2-CaF_2

These CaF_2-based fluxes are extensively used in electroslag refining([9]) and mostly serve the purpose of desulphurisation and dephosphorization. Hence it was hoped that these will behave favourably when used as flux coatings on S.G. and high carbon steel filler materials for welding S.G. and malleable irons. Of these systems, CaO-SiO_2-CaF_2 system has been tried exhaustively with other consumables as the flux in the present investigation.

The flux was coated on to the core wires by the dip-coating technique using potassium silicate as the binder. All the ingredients used in the flux were of -100 mesh size and the flux coating thickness of 3-4 mm was achieved by repeated dipping and drying. When once the required thickness was attained; the electrodes were baked at 500°C for one hour and then slow furnace cooling was done. In the absence of an extrusion facility, this method of flux coating was employed in the present study.

The electrodes mode by the above process of flux coating have been designated as A,B,C,D,E,F,G and H and their compositions are indicated in *Table-2*. To start with, the electrode (A) (or flux-A) was designed and

TABLE—2
Fluxes used and their composition

Designation	*Composition (Wt %)*									
	CaO	SiO_2	CaF_2	Fe-Si (75% Si)	Ni-Mg* (15%Mg)	Fe-* Powder	Graphite* Powder	SiC*	Ce* Misch metal	Mill** Scale
Flux-A (or Electrode A)	42	15	43	16	—	10	10	4	—	—
Flux-B	42	15	43	16	2	10	10	4	—	—
Flux-C	42	15	43	16	2	10	10	4	0.02	—
Flux-D	42	15	43	16	1	20	10	4	0.02	—
Flux-E	42	15	43	16	2	30	10	4	0.02	—
Flux-F	42	15	43	30	2	20	10	4	—	10
Flux-G	42	15	43	3	2	20	10	4	0.02	10
Flux-H(.)	42	15	43	12	2	30	10	4	0.02	10

*Electrode weight basis **Flux weight basis (.) High carbon steel core wire

prepared while the subsequent ones resulted with the idea of improving the performance of the earlier electrodes.

(3) Welding technique :

Test blocks to be welded were firmly seated on cast iron blocks and multi-pass manual metal arc welding was carried out with a constant pre-heat of 500°C in all the cases. In between passes, deslagging and cleaning of the weldment was done.

(4) Welding characteristics :

Welding characteristics of electrode (A) to electrode (H) were noted by visual observations during the process of welding the test block with the developed electrodes. The welding characteristics were evaluated subjectively on a three point scale as 'good', 'fair' and 'poor'.

(5) *Tests on welded test block :*

Samples for hardness survey and metallography were cut from the welded test block so as to include the heat affected zone (H.A.Z.) and the base metal. Hardness survey was made using a Rockwell hardness tester across the weld as shown in *Fig. 4*. The readings were taken at every 2 mm distance and these Rockwell B/C values were converted to Brinell hardness values using a conversion chart. Hardness versus Distance plots for electrode(A) to electrode(H) were made and these hardness plots were superimposed for appropriate electrode diameters to get an insight into the performance of one electrode over the other. All metallographic specimens were taken in the transverse direction across the weld and included the H.A.Z. and the base metal.

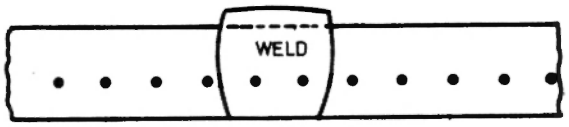


Fig. 4. Hardness Measurement

Rationale behind the flux composition selection :

By looking into *Table 3*, it would be observed that the flux system employed is of multi-component nature. Hence it is very difficult to predict their behaviour in the solution form. However, these have been added to

achieve one or more desired effects at the time of welding based upon their individual properties. Their amount has been decided either on flux weight basis or an electrode weight basis or from the past experiences of the other investigators. The composition of the electrode (A) can be taken as an example to illustrate this aspect.

It consists of 42% calcium oxide (CaO), 43% calcium fluoride (CaF_2) and 15% silica (SiO_2) as the major slag forming components and corresponds to the eutectic composition of this system. Calcium oxide addition was effected in the form of equivalent amount of calcium carbonate ($CaCo_3$) so that on decomposition, calcium oxide and carbondioxide are produced. Carbondioxide so produced may act as a protective shield at the time of welding. Iron powder is added to the flux mainly to achieve arc stability and its barest minimum amount[10] in any basic flux coating is 10% on flux weight basis. Graphite powder is included to make up for the carbon loss at the time of arcing from the core wire. It is assumed that about 20% efficiency of recovery of carbon can be expected on a empirical scale to the weld pool and thus make up for the C.E. in the weld pool and to match with that of the C.E. of the base metal. Calculations revealed that the graphite powder should be maintained at 10% on electrode weight basis. On the other hand, 16% Ferro-Silicon (75% Si-grade) comes from the relationship established by Davila et al[11]. The amount of Fe-Si added in our work was found to be sufficient for the make up of silicon loss from the core wire on remelting. In the latter case also, 50% efficiency of recovery was assumed.

In the case of other fluxes like flux-B, 2% Ni-Mg (15% Mg) was added to balance for the Mg loss on remelting and the addition was again on electrode weight basis with 50% recovery assumption. SiC was mainly added to reduce the chilling effect and to aid nucleation. Besides, to make up for minor losses of Si and C, it was added as in the case of most of the other additives, on electrode weight basis. However, mill scale was added with the hope that it will improve wettability of the slag onto beads on flux weight basis.

TABLE—3
Welding conditions for Electrodes (A) to (H)
(With a constant Pre-heat of 500°C)

Designation	*Electrode diameter (mm)*	*Electrode material*	*Test block position*	*Current (Amps)*	*Polarity*
Electrode (A)	6	S.G. iron (C.E. 4.3)	Flat	220	D.C. — R.P.
Electrode (B)	6	S.G. iron (C.E. 4.3)	Flat	260	D.C. — S.P.
Electrode (C)	6	S.G. iron (C.E. 4.3)	Flat	269	D.C. — S.P.
Electrode (D)	4	S.G. iron (C.E. 4.3)	Flat	210	D.C. — R.P.
Electrode (E)	4	S.G. iron (C.E. 4.3)	Flat	210	D.C. — R.P.
Electrode (F)	4	S.G. iron (C.E. 4.3)	Flat	240	D.C. — R.P.
Electrode (G)	6	S.G. iron (C.E. 4.3)	Flat	250	D.C. — R.P.
Electrode (H)	4	High Carbon Steel core wire	Flat	190	D.C. — R.P.

RESULTS AND DISCUSSION

Test blocks of S.G. iron base metal and malleable iron base metal were welded using the developed electrodes (A) to (G). The electrode (H) was of high carbon steel core wire and as stated earlier, it was used only on malleable iron base metal alone. The welding conditions and welding characteristics for the electrode (A) to electrode (H) are given in *Table 3* and *Table 4* respectively.

Hardness survey and metallographic observations were made in all the cases. Hardness survey plots on superimposition for appropriate electrode diameter revealed decreasing hardness trend from the electrode (A) to electrode (H), thus indicating better prerformance of one electrode over the other. While photomicrographs of the weld zone (W.Z.) fusion zone (F.Z.) and H.A.Z. were taken in all the cases, data for those electrodes whose performances were found to be satisfactory have been shown in *Fig. 5 to Fig. 14.*

By referring to microstructures in Fig. 5 and 6 for the electrode (A), we observe that in the case of S.G. iron base metal, the W.Z. was partly of white iron and partly pearlitic with graphite nodules in the filler (or top) passes and with quasi-nodules in the root passes. This was also the case with the malleable iron base metal except that the matrix was completely of white iron.

The strength and ductility of the weldment as derived from microstructural and hardness considerations for the electrode (A) was not satisfactory. Hence the electrode (A) had to be modified in reference to graphite size and shape, matrix and hardness. It was realised that if the graphite could be nodularized, much better physical properties of weldmetal can be expected. The modifying elements Mg and Ce have very high affinity for oxygen and it is usually accepted that on remelting S.G. iron, these elements are lost by oxidation and possibly also combination with sulphur.

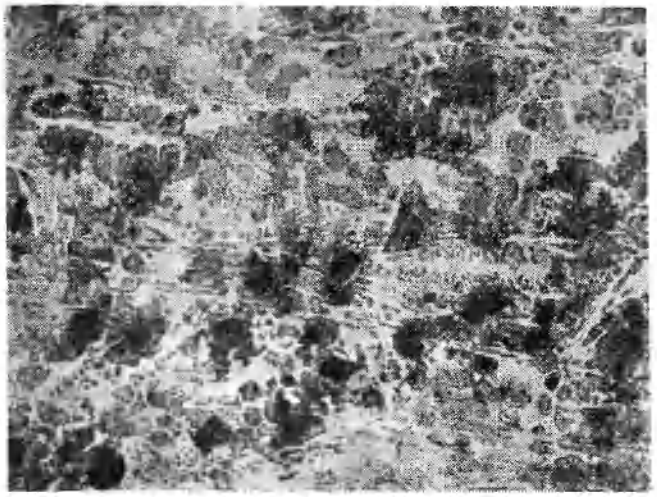
As a first step in improving the performance of the electrode (A), the same S.G. iron electrode was coated with the flux (B) and this contained 2% Ni-Mg on electrode weight basis.

The metallography of the weldment for the electrode (B) revealed that the matrix was still a mixture of white iron and pearlite with graphite nodules embedded. The nodule size and shape had considerably improved and the performance of this electrode was much better than the electrode (A) especially in the case of malleable iron base metal. The dilution effect with regard to magnesium from the weld pool had been made up to a certain extent as compared to the electrode (A) as this electrode contained Ni-Mg master alloy addition through the flux. The fusion was acceptable and microstructural studies showed presence of microporosity.

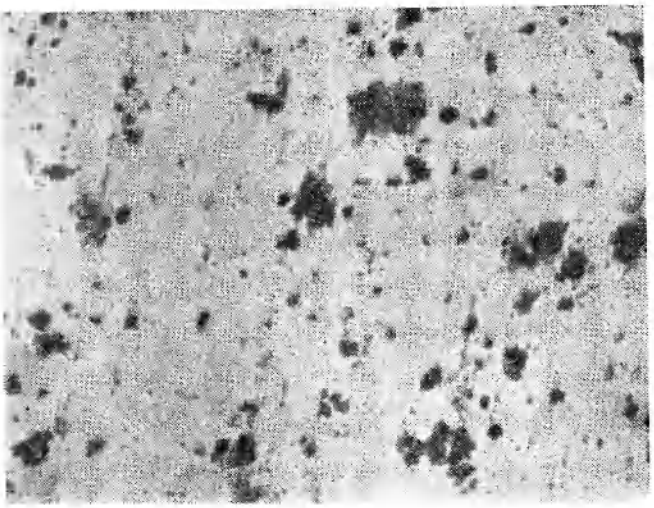
TABLE—4

Welding characteristics rating for Electrodes (A) to (H)

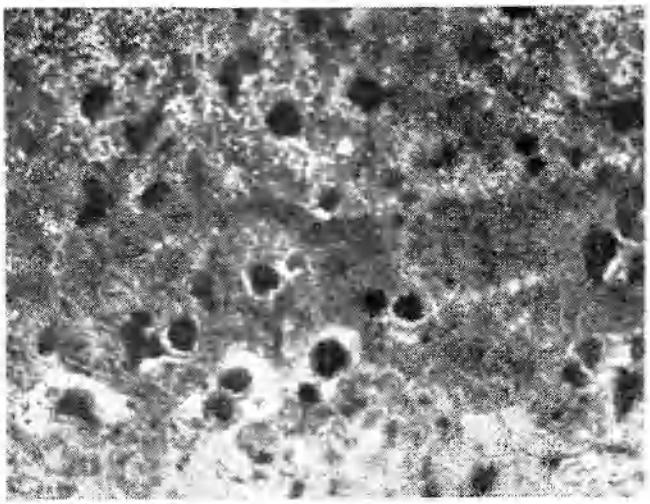
Electrode	*Slag Fluidity*	*Slag Wettability*	*Bead Morphology*	*Arc Stability*	*Slag Detachability*	*Arc gap*	*Fusion*
A	Fair	Poor	Fair	Fair	Good	Long	Poor
B	Good	Fair	Fair	Poor	Good	Long	Fair
C	Fair	Fair	Fair	Poor	Good	Short	Fair
D	Good	Fair	Good	Fair	Good	Long	Good
E	Good	Fair	Fair	Good	Good	Long	Good
F	Poor	Poor	Poor	Poor	Poor	Fair	Good
G	Good	Fair	Good	Good	Good	Short	Good
H	Poor	Poor	Good	Good	Poor	Long	Good



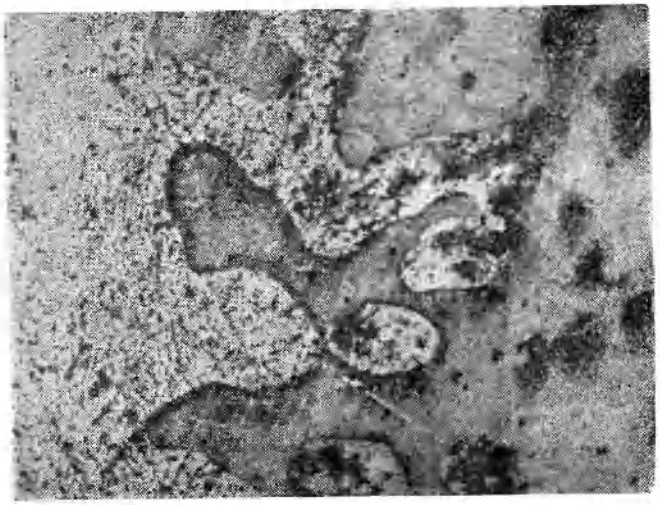
(*a*) *W. Z. at 100×*



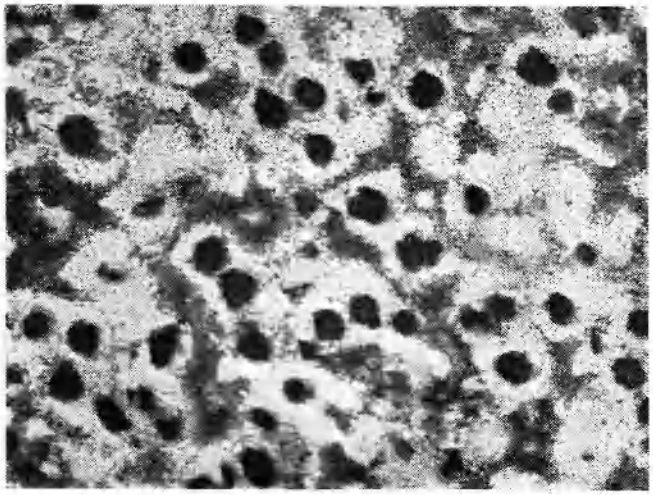
(*a*) *W. Z. at 100*



(*b*) *F. Z. at 100×*

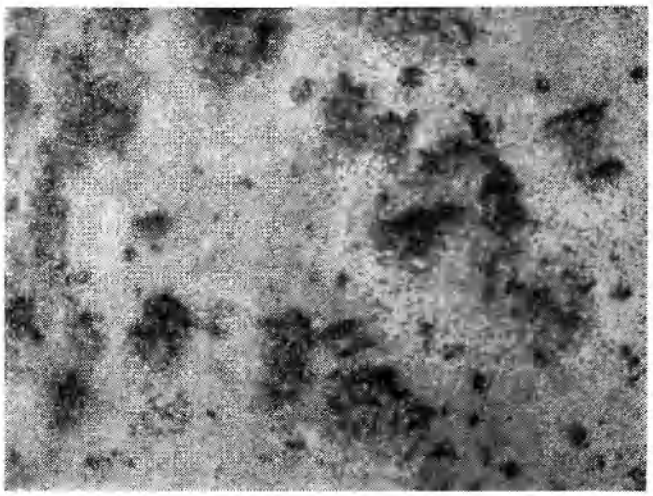


(*b*) *F. Z. at 100*



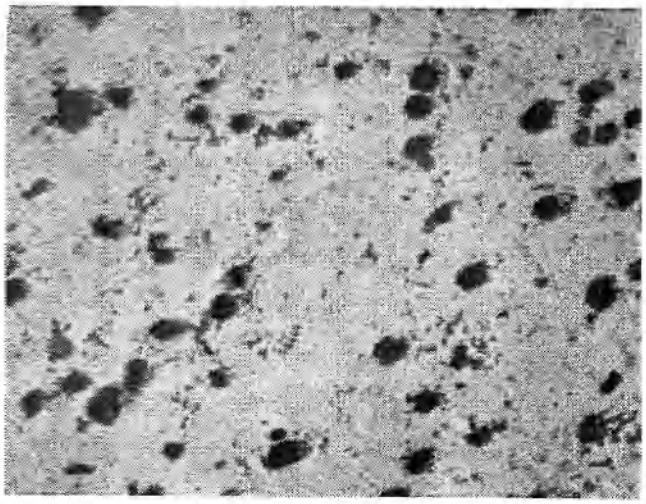
(*c*) *H.A.Z. at 100* (*Etchant : 2% Nital*)

Fig 5. S. G. Welded with Electrode—A

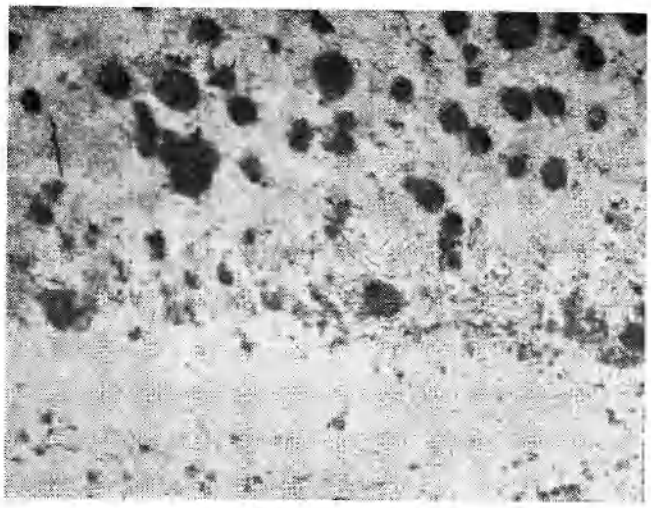


(*c*) *H.A.Z. at 100* × (*Etchant : 2% Nital*)

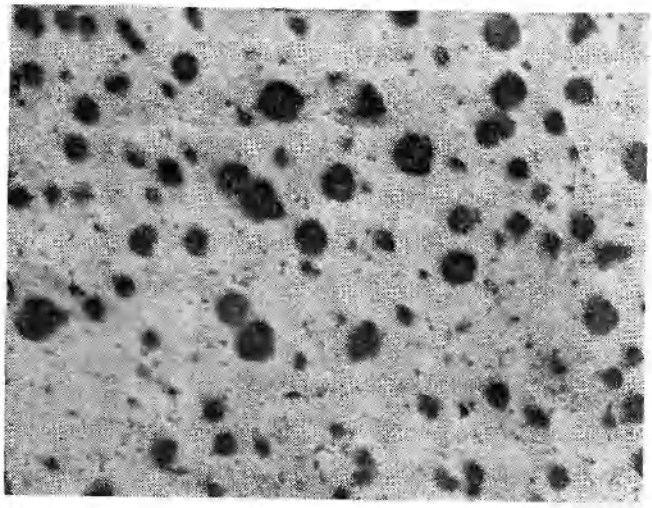
Fig 5. M.I. Welded with Electrode—A



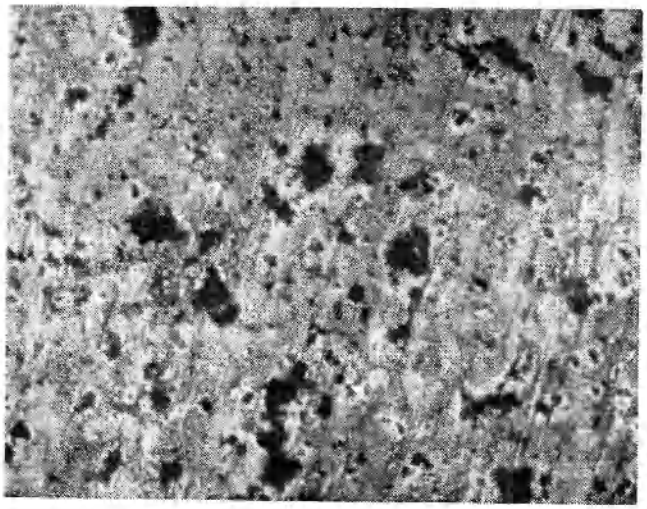
(a) W. Z. at 100×



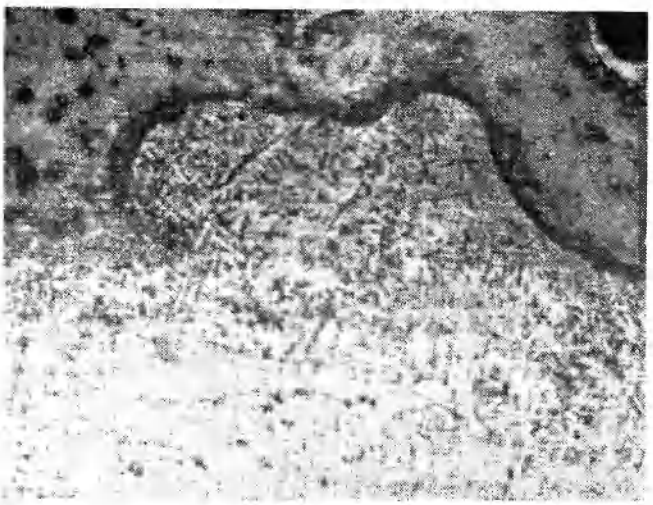
(b) F. Z. at 100×



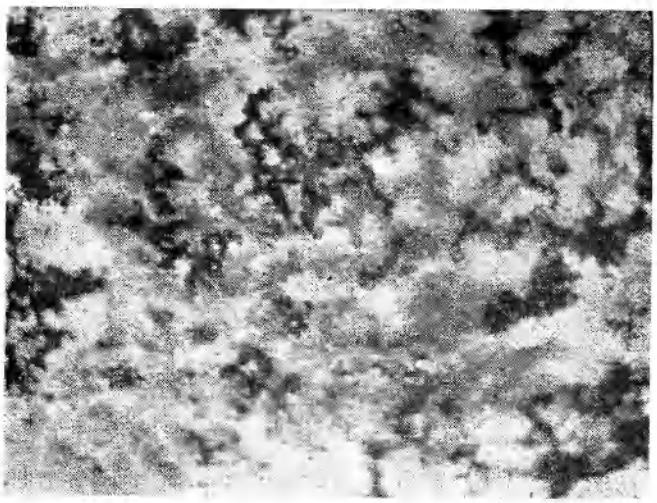
(c) H.A.Z. at 100×(Etchant : 2% Nital)
Fig 7. S. G Welded with Electrode—D



(a) W. Z. at 100×



(b) F. Z. at 100×



(c) H.A.Z. at 100×(Etchant : 2% Nital)
Fig 8. M.I. Welded with Electrode—D

In an attempt to temper quasinodules and to avoid the presence of porosity, the flux (B) was modified to obtain flux (C) to yield the new electrode (C). The photo-micrographs of the weldment for this electrode are shown in *Fig. 7 & 8*.

The metallography of the weldment indicated that along with white iron, there were localized pearlitic colonies to a much greater extent than the earlier case and the graphite appeared to be tempered to a much greater degree. The nodule count of the weld was much higher than that of the base metal. The fusion was sound and there was no evidence of microporosity. Hence from the above observations, it is clear that the addition of Ce had helped in the tempering of graphite. Besides, it had been noted that the addition of Ni into the matrix in presence of Ce had taken care of dispersed and shrinkage porosities as reported by some earlier investigators[12].

However, the matrix continued to be a mixture of white iron with localized pearlitic colonies. In order to increase the fluidity and wettability of the slag and to improve the arc stability, the flux (D) was prepared.

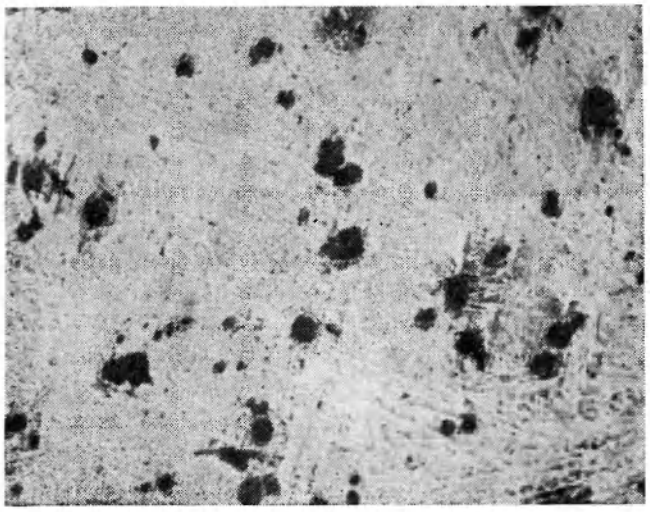
The metallography of the weldment (Fig. 7 & 8) indicated that the nodule count was high and the distribution of the nodules was uniform all over the weld eventhough, at root passes, there was a tendency for the nodules to degenerate. The matrix was predominantly of white iron with localized regions of pearlite.

The increase of Fe-powder content in the flux (D) had improved slag fluidity and wettability marginally. However, arc stability had improved markedly. To further enhance the welding characteristics, the flux (E) was designed.

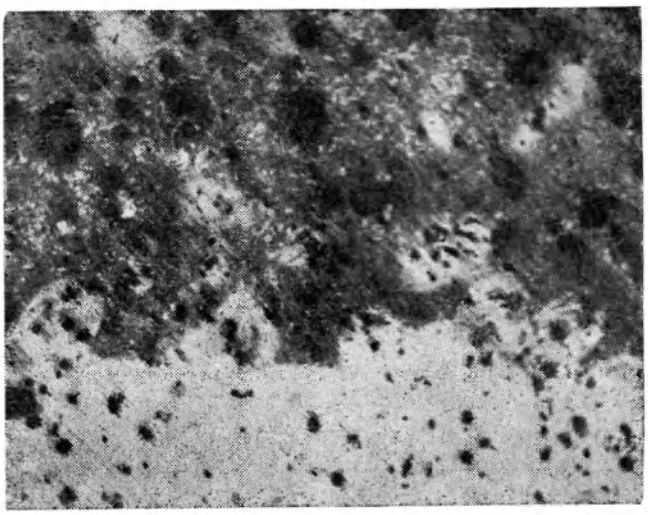
The microstructural observations (*Fig. 9 & 10*) showed that the matrix was a mixture of pearlite and white iron. The nodule count remained rather uniform all over the weld.

From the welding characteristics in Table 4 for the electrode (E), it can be seen that there was a marked improvement in the arc stability even though wettability of the slag onto the bead had not shown any signs of improvement.

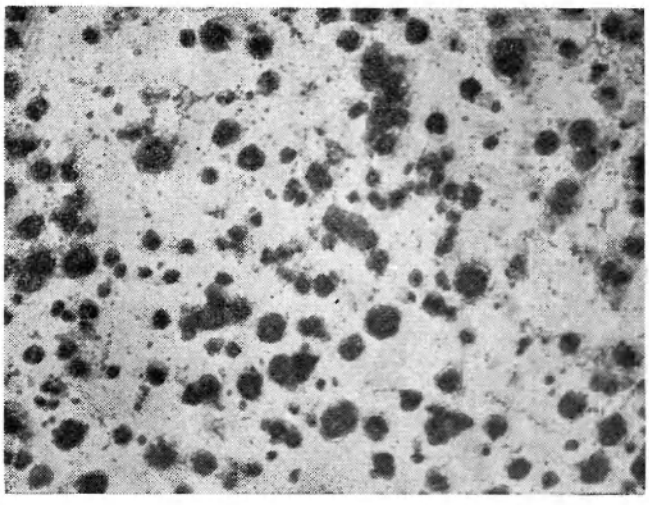
After having achieved some acceptable level of welding characteristics, it was envisaged to modify the flux further to change the matrix completely to that of pearlite.



(*a*) *W. Z. at 100×*



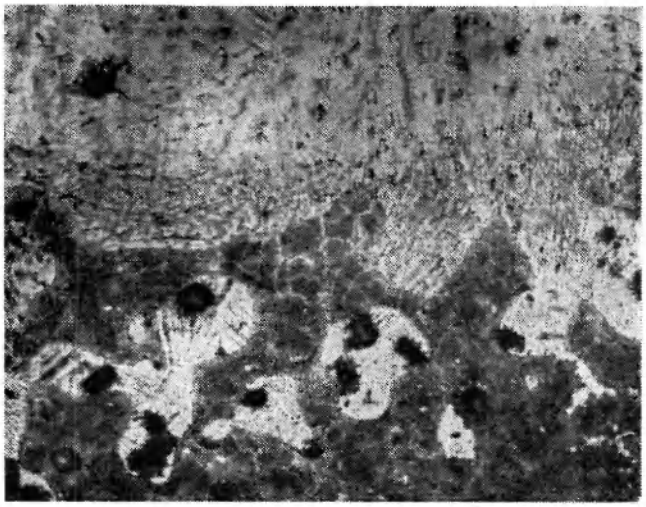
(*b*) *F. Z. at 100×*



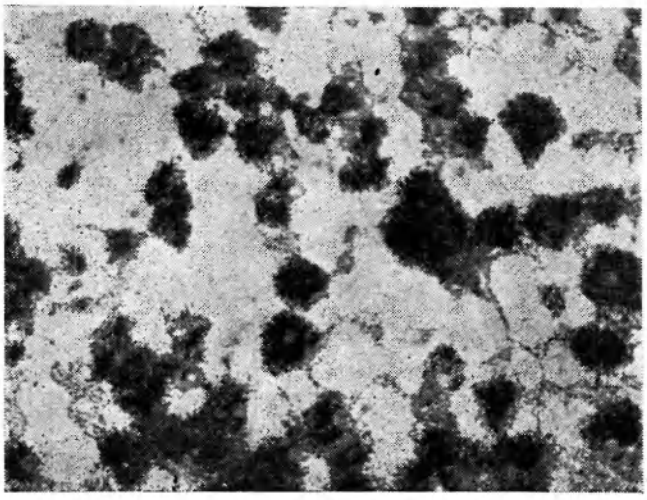
(*c*) *H.A.Z. at 100×*

Fig 9. S. G. Welded with Electrode—E

(*a*) *W.Z. at 100×*



(*b*) *F. Z. at 100×*



(*c*) *H.A.Z. at 100 ×(Etchant 2% Nital)*
Fig 10. M.I. Welded with Electrode—E

In an attempt to achieve this, the welding process was conceived as analogous to a permanent mold casting wherein cooling rates are comparable with the arc welding. Since a hypereutectic cast iron composition is an excellent graphitizer, the C.E. was changed from 4.3 to 4.8.

On these lines, the flux (F) was developed. This flux was expected to maintain a C.E. of 4.8. in the system though the bulk of the silicon was introduced from the flux.

Even though this electrode showed significant improvement in the structure compatibility than the earlier electrodes, it was totally rejected because of its extremely poor welding characteristics and hence commercial unacceptability.

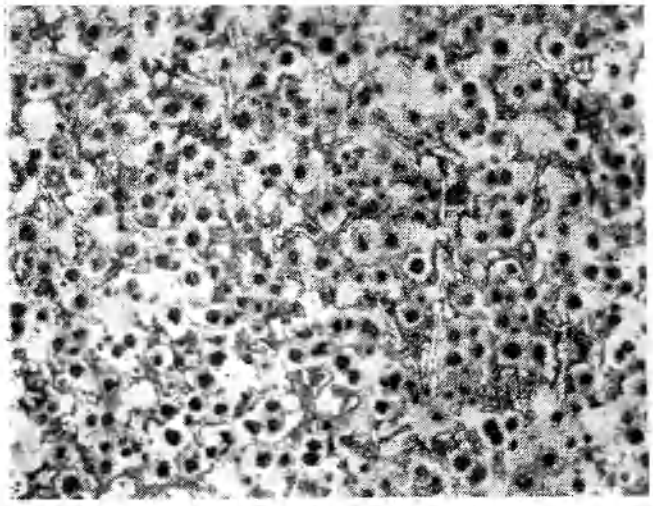
In the next flux (G), changes were incorporated so that the electrodes were hypereutectic composition with a C.E. of 4.8.

Hence silicon was introduced in solid solution form and thus the recovery of silicon was expected to be very high as compared to the introduction of silicon from the flux (as in flux-F) on remelting. The remaining additions were maintained at the levels as indicated in table 2.

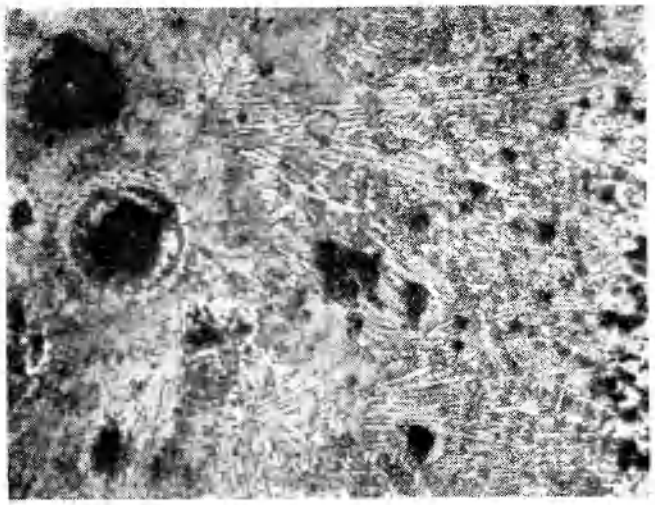
The metallography of the weldment with regard to S.G. iron base metal (*Fig. 11 & 12*) depicted that the matrix was of pearlite with a little white iron in the filler passes. The spheroids were distributed uniformly and the nodule count in the weld was much higher than the base metal. There was total absence of shrinkage and cracks. The colour match between the weld and the base metal was as desired.

However, the same electrode on M.I. base metal behaved relatively less satisfactorily as compared to S.G. iron base metal. The microstructural features of the middle passes and the matrix was of pearlite and white iron. The root passes showed degenerated type of nodules. The dilution effect with regard to Mg, Si and C from the weld to the base metal was predominant and may be the cause for the less satisfactory performance of the electrode.

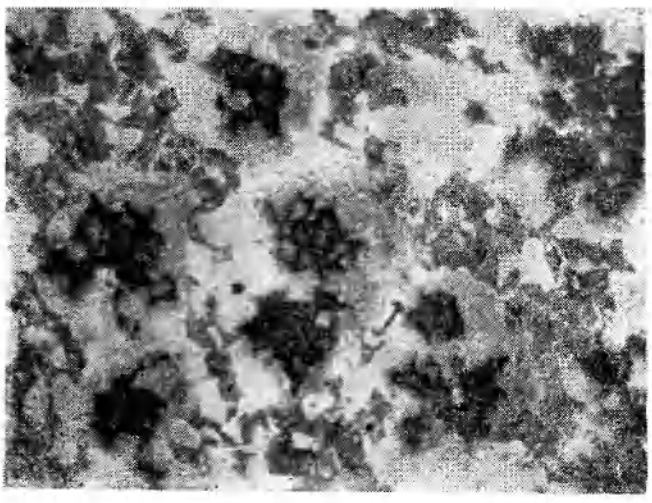
At this stage, having made several changes in the flux composition either to enhance welding characteristics and/or to improve metallographic features in the weldment, adequate knowledge was gained about the calcium fluoride based flux system.



(*a*) *W. Z. at 100×*

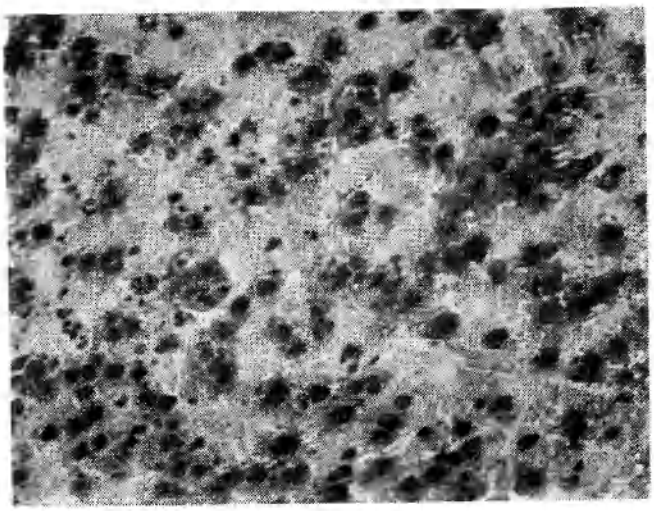


(*b*) *F. Z. at 100×*

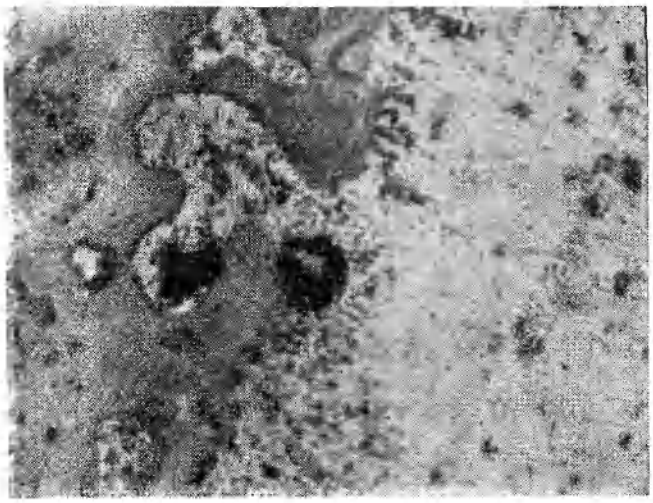


(*c*) *H.A.Z. at 100× (Etchant : 2% Nital)*

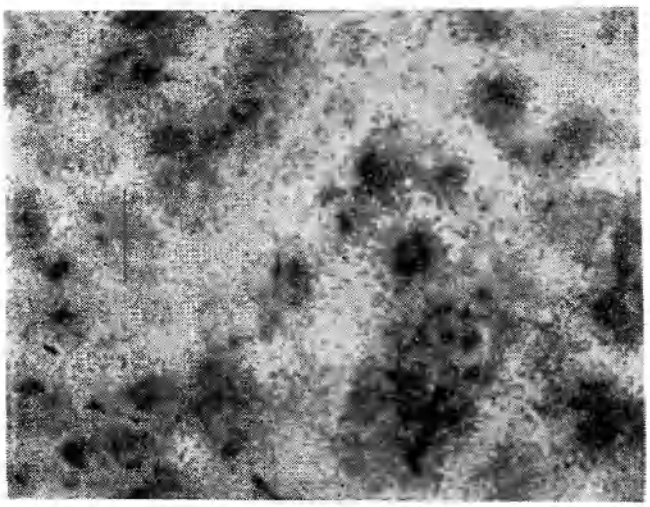
Fig 11. S. G. Welded with Electrode—G



(*a*) *W. Z. at 100×*

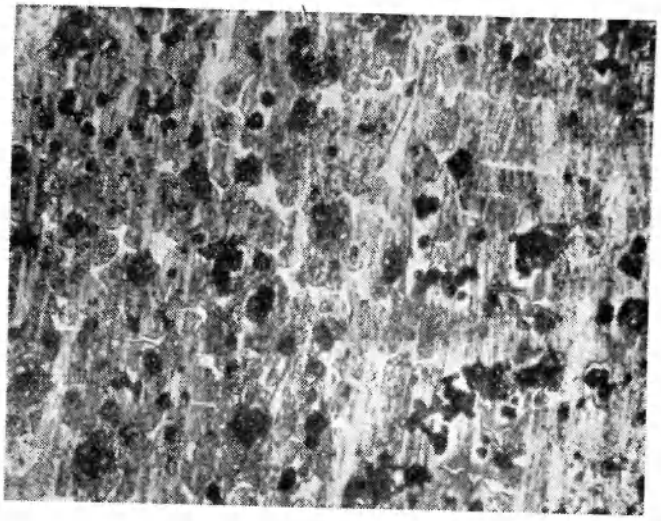


(*b*) *F. Z. at 100×*

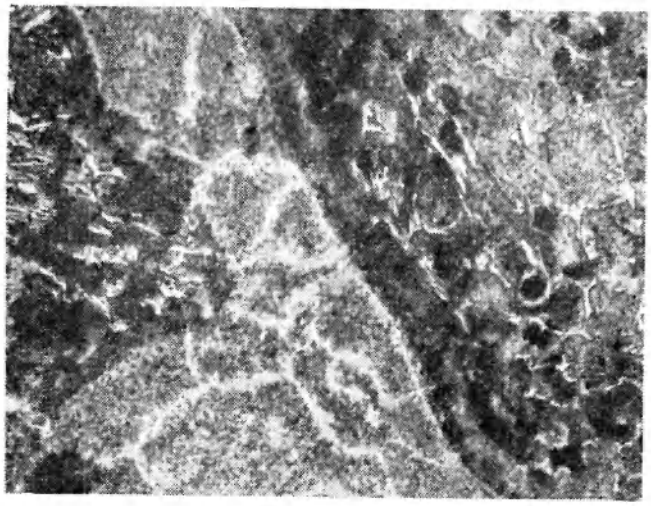


(*c*) *H.A.Z. at 100× (Etchant : 2% Nital)*

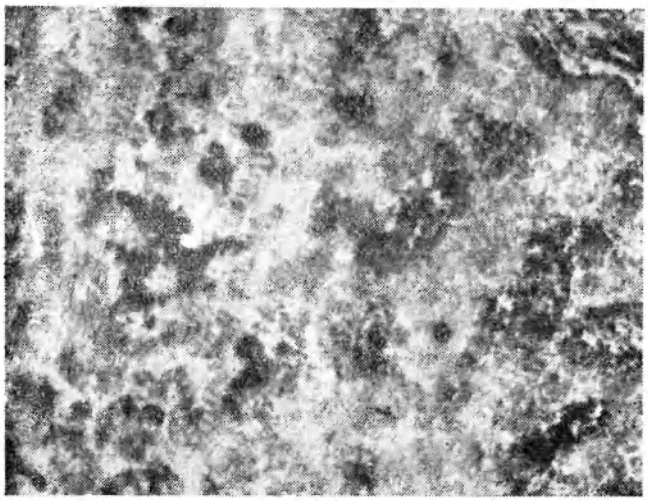
Fig 12. M.I. Welded with Electrode—G



(*a*) *W. Z. at 100×*



(*b*) *F. Z. at 100×*



(*c*) *H. A. Z. at 100×(Etchant : 2% Nital)*

Fig 13. M.I. Welded with Electrode—H

Hence the same flux system was tried on the high carbon steel core wire and after repeated trials, we arrived at the electrode (H) flux composition as indicated in Table 2.

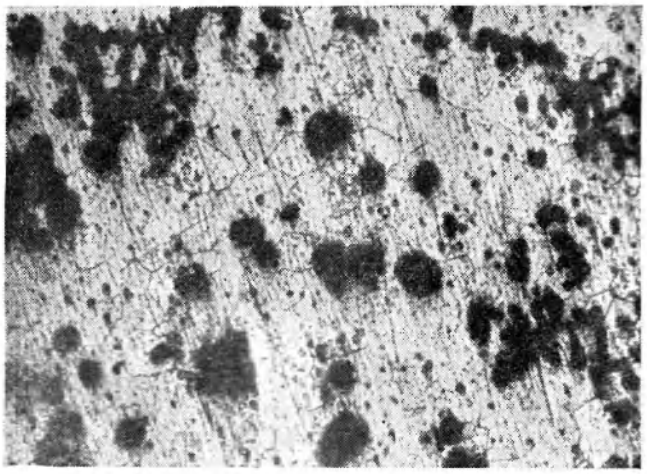
The metallographic details (*Fig. 13*) for this electrode (H) on M.I. base metal revealed that the matrix of the weld was of white iron and pearlitic with graphite nodules embedded in them. The size of the nodules was appreciable and the nodule count increased from the root passes to the filler passes. No porosity or cracks were observed. The bonding between F.Z. and W.Z. was excellent and the colour match was as desired. The dilution effect with regard to silicon and carbon from base to weld was appreciable with this electrode.

Hence, it can be seen that the electrode (G) gave the best performance w.r.t. hardness and microstructural compatibility in the as-welded condition though the welding characteristics especially slag wettability needs to be improved for commercial viability. We found in our work that interfacial tension between the weld bead and the molten slag was not matching in spite of mill scale addition in some of the fluxes (F to H). The molten slag used to flow to the edges of the bead and resulted in the exposure of the bare metal surface to the atmosphere. Thus suitable additive(s) has to be put in to the flux system in order to achieve satisfactory performance. The same flux compositions if coated by the extrusion technique would yield better results in welding.

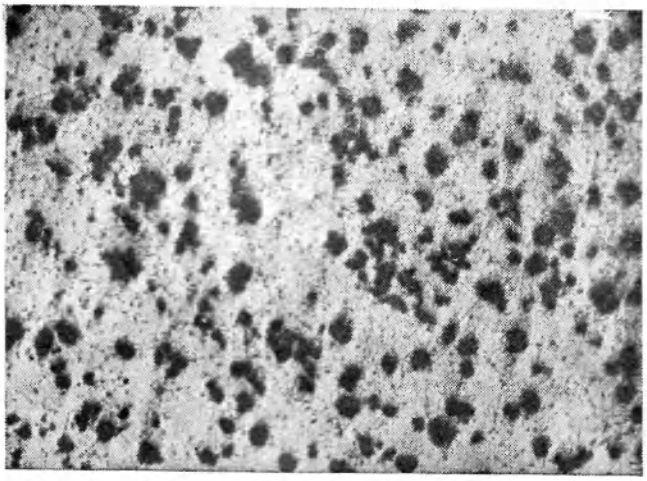
The performance of all the electrodes (A to G), in general, was much better on S.G. iron base metal as compared to M.I. base metal both w.r.t. welding characteristics and structure-compatibility wise. This can be attributed to the initial residual Mg content in S.G. base metal and may be due to matching of C.E. between the weld pool and the base metal.

The dilution effect with regard to Mg, Si and C from the weld pool to the base metal with S.G. iron filler material was markedly pronounced in the case of M.I. base metal and was one of the reasons for less satisfactory results. With high carbon steel core wire as the filler material on M.I. base metal, the dilution effect was observed from the base metal to the weld and thus indicated that C.E. of the weld was less than that of the base metal.

With regard to the soundness of the weld, in both cases (S.G. & M.I.), F.Z. and W.Z. cracks and porosity (micro & macro) were hardly observed as we passed on from the electrode (A) to the electrode (H). H.A.Z. in



(*a*) *For electrode G at 250×*



(*b*) *For electrode H at 250×*
(*Etchant : 5% Nital*)
Fig 14. M.I. Weld heat treated at 950°c for 2 hrs and furnace cooled

all the electrodes in both S.G. and M.I. was only coarsening of grains and no transformations were observed. The latter can be attributed to the level of pre-heat of 500°C that was employed in our work.

Even though post weld heat treatment was not desirable, in order to show that the structures obtained in the weldment are amenable to heat-treatment, the electrode (G) and (H) welded samples of M.I. base metal were heat treated. The photomicrograph is shown in *Fig. 14* which consisted of ferrite matrix with graphite particles.

CONCLUSIONS

The conclusions of the experiments carried out to develop a suitable filler material for welding of S.G. iron base metal and M.I. base metal indicate that with W.G. iron as well as High carbon steel (used only on M.I. base metal) as the core wires and CaO-SiO_2-CaF_2 system as the flux for arc welding

(1) It is possible to obtain crack-free welding with minimum heat build up and H.A.Z. with (CaO-SiO_2-CaF_2) system with both the core wires.

(2) With each of these filler materials, 30% Fe-powder in the flux gives good arc stability.

(3) The matrix of the weld is a mixture of white iron and pearlite (quality grade B welding) with graphite nodules embedded in them. This possibly can be restored completely to pearlitic structure with extruded flux and by addition(s) to the CaO-SiO_2-CaF_2 system which will improve its wettability on the beads.

(4) Dilution effects are markedly pronounced especially with regard to Mg, Si and C from the weld to the base metal in the case of S.G. iron electrode and Si and C depletion from base metal to the weld in case of high carbon steel electrode.

(5) Bonding and colour matching are excellent with both the filler materials for both base metals.

(6) The structures obtained in the weldment are amenable to heat treatment (post weld) which will yield satisfactory microstructural constituents viz., ferrite and pearlite with graphite nodules embedded and hence other properties.

ACKNOWLEDGEMENT

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Beware of Robots

A top technical executive of General Electric Co., USA, has made the following observations after working extensively with robots on the shop floor :

1. Don't expect a few token robots in your factory to guard the door of your business against the Japanese. If your other equipment lacks numerical controls, if your factory processes are manually rather than computer controlled, you may be kidding yourself. Robots poorly integrated or misapplied can be a bottleneck.

2. If you buy a robot, don't waste it on jobs that can be accomplished more efficiently by simpler, cheaper equipment. No robot is an island : the cost of associated machinery to feed and serve a robot runs 1 to 3 times the cost of the robot itself.

3. Americans see the robot as a tool for productivity ; the Japanese see it as a tool for quality. The Japanese are right. Robots produce quality products ; they reduce rework, scrap, and warranty costs. A robot is a maddeningly demanding and consistent machine. Provide it complete, uniform, and reasonably flawless parts and it will give you better quality as well as speed and efficiency of operation.