

PATENT SPECIFICATION

DRAWINGS ATTACHED

1.183.461

Inventors: PAUL DESMOND BLAKE, ROY DOUGLAS JOHNSTON, BRIAN PHELPS, EDWIN ALBERT CHAPMAN and RONALD LEONARD BARTLETT

Date of filing Complete Specification (under Section 3 (3) of the Patents Act, 1949): 8 Aug., 1967.

Date of Application (No. 48640/66): 31 Oct., 1966.

Date of Application (No. 48972/66): 1 Nov., 1966.

Date of Application (No. 49927/66): 8 Nov., 1966.

Date of Application (No. 12186/67): 15 March, 1967.

Date of Application (No. 13776/67): 23 March, 1967.

Two Applications (Nos. 15578/67 and 15579/67) dated 5 April, 1967.

Date of Application (No. 16380/67): 10 April, 1967.

Complete Specification Published: 4 March, 1970.

Index at acceptance:—B3 R(32G, 32J, 36, 37A1A); C7 A(A249, A279, A28Y, A28X, A329, A339, A349, A369, A37Y, A383, A385, A387, A389, A409, A439, A44Y, A455, A457, A459, A48Y, A497, A499, A50X, A501, A503, A505, A529, A53Y, A541, A543, A545, A547, A549, A579, A58Y, A587, A589, A59X, A591, A593, A595, A609, A61Y, A617, A619, A62X, A621, A623, A625, A67X, A671, A673, A675, A677, A679, A68X, A681, A683, A685, A687, A689, A69X, A693, A695, A696, A697, A698, A699, A70X, 711); C7 M(20X, 202, 205, 207, 208, 21Y, 212, 215, 218, 22Y, 222, 225, 227, 228, 23Y, 232, 235, 237, 238, 24Y, 24X, 242, 245, 247, 248, 25Y, 252, 26Y, 262, 27Y, 272, 275, 278, 28Y, 282, 29Y, 29X, 30Y, 305, 308, 38Y, 40Y, 41Y, 42Y, 43Y, 435, 438, 46Y, 466, 469, 483, 486, 489, 506, 509, 516, 526, 556, 563, 576, 583, 586, 663, 683, 693, 703, 713, 740, 743, 771, 780)

International Classification:—B 23 k 35/30

COMPLETE SPECIFICATION

Improvements in Arc Welding

We, MUREX WELDING PROCESSES LIMITED, of Hertford Road, Waltham Cross, Hertfordshire, England, a British Company, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

It has long been the practice to use for automatic and semi-automatic arc welding continuous electrodes which are devoid of an external flux coating in conjunction with a submerged arc flux or a shielding gas and in recent years widespread use has been made of carbon dioxide as the shielding gas.

An important function of the submerged arc flux and of the shielding gas has been to deny access to the weld metal of atmospheric oxygen and nitrogen. The use of a submerged arc flux, however, prevents observation of the weld metal by the operator, while the use of a shielding gas is costly and requires cumbersome

equipment. It has been proposed to avoid the necessity for external shielding of the weld metal by the use of a tubular electrode, consisting of a mild steel sheath having no external flux coating but having a core containing deoxidizing elements, for example manganese, aluminium and silicon, and also elements, such as aluminium, which are capable of combining with nitrogen to form nitrides. Tubular electrodes of this kind as hitherto proposed have not, however, been capable of producing sound weld metal having the high ductility and good impact strength characteristic of the mild steel weld metal produced by good quality automatic electrodes used with a shielding medium.

The invention, in its broadest aspect, is based upon our discovery that sound weld metal appropriate for welding mild steel workpieces and having such satisfactory physical properties can be produced by the use of a bare mild steel tubular arc welding electrode, containing deoxidizers and nitrogen-fixing elements in its

[Price 5s. 0d.]

core, without shielding of the arc by gas or a submerged arc flux provided that the electrode is so formulated and the arc is drawn under conditions such that the contents of carbon, aluminium, manganese, silicon and titanium in the weld metal are maintained within definite prescribed limits indicated below.

The invention provides a process of automatic or semi-automatic welding which consists in depositing from a cored tubular electrode, having a mild steel sheath devoid of external flux, without external shielding of the arc, weld metal having an elongation of at least 18%, a reduction of area of at least 25%, and a Charpy impact strength of at least 35 ft/lbs at 20° C and at least 20 ft/lbs at -30° C when tested in accordance with the mechanical test procedure given in B.S.S. 639, 1964, the weld metal being of the following composition by weight:—

aluminium	0.12 — 1.3%
manganese	0.3 — 2%
silicon	0.1 — 1%
carbon	0.12% max.
titanium	0.12% max. if the silicon content exceeds 0.35% and 0.25% max. if the silicon content is 0.35% or less
balance	iron apart from incidental impurities.

The incidental impurities include sulphur and phosphorus and may include zirconium in an amount not exceeding 0.05% by weight.

Preferably the weld metal contains 0.12—0.8% aluminium, 0.7—1.75% manganese, 0.4—0.85% silicon and a maximum carbon content of 0.08%.

Proportions throughout the Specification are proportions by weight and the mechanical properties of weld metal are those obtained by tests in accordance with the mechanical test procedure of B.S.S. 639, 1964.

Electrodes for carrying out the process according to the invention have a mild steel sheath, which may be formed from either rimming steel strip containing less than 0.12% carbon, 0.2—0.6% manganese, less than 0.05% silicon, less than 0.04% sulphur and less than 0.04% phosphorus, or from killed or semi-killed strip with up to 0.3% silicon, up to 0.15% carbon, up to 1.8% manganese, less than 0.04% sulphur and less than 0.04% phosphorus.

The aluminium content of the electrode, which is present in the core, may be metallic aluminium or ferro-aluminium and the core will normally contain both manganese and silicon, as such or as ferro-alloys or present as compounds, such as manganese oxide or silica, which will be reduced by aluminium to elementary form when the electrode is used for welding. The electrodes also contain in the core sufficient calcium fluoride, or of a balanced

mixture of other fluorides of alkali or alkaline earth metals to ensure regular burn-off of the tip of the electrode and satisfactory spreading and wetting qualities of the slag and weld metal in order to ensure absence of significant porosity in the weld metal.

In general electrodes according to the invention may be manufactured by bending a mild steel strip, of width 0.6" and thickness 0.025", into a U-shaped channel measuring 0.2" across its mouth, introducing the core material into the channel, closing the channel and drawing it down to a diameter between 3/64" and 1/8". In order to remove moisture and drawing soap the resulting tube should be baked in air at 250—300° C for 30 to 60 minutes and it may then be coiled on spools. An alternative, and if it is desired to reduce the springiness of the coils, the tube may instead be baked at 450° C in an atmosphere of nitrogen.

These electrodes fall into various categories, which will now be described in detail.

CATEGORY 1

Electrodes of this category contain in the core metal powders or wires in amounts such that the electrode as a whole contains 0.8—2.5% aluminium, 0.01—1% titanium, 0.05—1.5% silicon and 0.4—1.5% manganese; 0.4—6% of fluorides of alkali and/or alkaline earth metals and slag forming materials. The aluminium, silicon and manganese act as

deoxidisers and, in addition, both the aluminium and silicon reduce nitrogen absorption by the weld pool and fix free nitrogen as nitride. Although titanium increases the nitrogen solubility in the weld pool, it also acts as a nitrogen fixing element and fixes the nitrogen in the relatively harmless form of titanium carbonitride which does not form a dendritic structure. Concentrations of titanium in excess of that just stated are deleterious to the impact properties and could result in recovery into the weld metal of an amount of titanium greater than that specified above.

While the electrodes of this category must contain at least 0.4% of fluorides of alkali and/or alkaline earth metals, which may be present as borofluorides, silicofluorides or titanofluorides, some of the fluoride content in excess of 0.4% may be replaced by carbonates or titanates of alkali or alkaline earth metals. These ingredients give a stable arc, reducing spatter and loss of alloying elements and improving the general ease of operation of the electrode.

Alumina derived by oxidation from aluminium in the core tends to give an infusible and adherent slag and the slag formers in the core are materials which are capable

of forming with this alumina a slag of low melting point. Fluxes based on sodium oxide, and/or potassium oxide together with silica are capable of taking up alumina up to about 50% of their weight while retaining a melting range of 1300—1500° C. Limited additions of lime and iron oxide help to retain a low melting point. The fluxes may consist of potash felspar, which contains approximately 14% K₂O, 62% SiO₂, 1% Na₂O and 18% Al₂O₃ or of synthetic fused potassium silicate. Alternatively, soda felspar containing approximately 11% Na₂O, 68% SiO₂ and 19% Al₂O₃ or lime felspar or fused sodium silicate are suitable. They may be used alone or as a mixture. The amounts of these materials, based on the weight of the electrode, are:—

1) 4—8% potash felspar and/or soda felspar and/or lime felspar, or 4—8% of fused potassium silicate and/or sodium silicate.

2) 0—2% of calcium carbonate.

3) 0—5% of calcium meta-silicate as natural or synthetic wollastonite.

4) 0—5% magnetic iron oxide or other iron oxide. The total amount of slag forming elements added is, in general, less than 10%.

Electrodes of this category yield weld metal of the following percentage composition:—

	Overall Range	Preferred Range
Aluminium	0.2 — 0.85	0.3 — 0.5
Silicon	0.1 — 0.5	0.25 — 0.35
Manganese	0.3 — 1.5	0.8 — 1.0
Titanium	0.02 — 0.25	0.05 — 0.1
Carbon	0.12 max.	0.08 max.
Sulphur	0.035 max.	0.01 — 0.02
Phosphorous	0.035 max.	0.01 — 0.02
Iron (apart from incidental impurities)	balance	balance

The weld metal obtained has an ultimate tensile strength of 28—36 tons per square inch, an elongation of 21%—35%, a reduction of area of 35—75% and a Charpy impact strength as specified above.

The following are examples of two typical electrodes of this category, the proportions being by weight of the electrode:—

	1	2
Aluminium	1.75	1.9
Manganese	1.30	1.35
Silicon	0.40	0.3
Titanium	0.25	0.15
Sulphur	0.03	0.025
Phosphorus	0.02	0.02
K ₂ CO ₃	0.1	—
Na F	0.1	0.1
Li F	0.25	0.2
Li ₂ CO ₃	0.1	0.1
Cs F	0.1	0.1
K ₂ TiF ₆	0.25	0.35
Potash Felspar	3.0	4.0
Soda Felspar	3.0	2.0
Magnetic iron oxide	0.6	0.3
Ca CO ₃	1.0	—
CaSi O ₃	—	1.5
Iron	balance	balance

CATEGORY 2

Electrodes of this category deposit weld metal of the following percentage composition by weight:—

	Overall Range	Preferred Range
Aluminium	0.2 — 0.9	0.5 — 0.75
Silicon	0.35 max.	0.2 max.
Manganese	0.3 — 1.25	0.7 — 1.0
Titanium	0.25 max.	0.15 max.
Sulphur	0.04 max.	0.025 max.
Phosphorous	0.04 max.	0.025 max.
Carbon	0.04 — 0.12	0.08 — 0.11
Iron (apart from incidental impurities)	balance	balance

The electrodes contain aluminium in the core, of which about half is recovered in the weld metal the remainder being oxidised to aluminium oxide which forms a slag.

- 5 The aluminium oxide presents a problem in that it interferes seriously with the deposition of the weld metal, tending to form irregular slag globules of high melting point which spoil the appearance of the weld and cause excessive undercut or sharp notches at the toes of the weld, which may seriously reduce the effective strength of a welded fabrication. The surface tension of the molten metal is affected and weld appearance deteriorates. A high spatter loss is associated with this condition.

The harmful effect of the aluminium oxide is counteracted by the inclusion of fluorides in the core of the electrode. When fluorides are present in the amount indicated below, the aluminium oxide dissolves in the liquid fluoride to form an acceptable slag. It is also highly desirable that the electrode should include a small amount of ferrotitanium with a view to eliminating, entirely or almost entirely, porosity in the weld deposit. The fluoride content includes calcium fluoride or cryolite but may also contain potassium titanofluoride or sodium fluoride.

The following is the overall composition of the electrode in percentages by weight:—

Titanium as ferrotitanium	0.1% max.
Manganese	0.8 — 1.5%
Sodium or potassium silicate	0 — 0.3%
Fluorides, at least 1.7% being calcium fluoride or cryolite	1.7 — 5.5%
Titanium oxide as titanates or minerals	0.25% max.
Aluminium	1.2 — 2.6%
Silicon in sheath	0.03% max.
Iron as sheath	60 — 85%
Iron as powder or ferro-alloys	balance

- 35 The ferrotitanium preferably contains 25% Ti. The manganese includes manganese in the sheath (e.g. 0.4%) plus ferromanganese in the core, which preferably contains 80—90% Mn and may contain up to 7% C. The iron powder may contain up to 0.25% C.

Examples of typical electrodes of this category will now be given, these being followed by particulars of the mechanical properties and composition of the resulting weld deposits.

20

25

30

40

Experimental No.	Examples of Core Composition in Percent by Weight of Electrode					411
	403A	403	406	408	404	
Ferrotitanium (25% Ti)	0.25%	0.30%	0.30%	0.25%	0.30%	0.2%
Ferromanganese	0.73%	0.73%	0.73%	0.60%	0.70%	0.60%
K ₂ CO ₃	0.07%	0.07%	0.14%	0.14%	0.07%	0.17%
Fused sodium silicate	0.2%	0.2%	0.2%	0.2%	0.2%	0.26%
Rutile sand	0.2%	0.2%	—	0.2%	0.2%	0.2%
CaF ₂	2.2%	—	3.5%	3.3%	2.7%	3.3%
Na ₃ AlF ₆	—	2.5%	—	—	—	—
K ₂ TiF ₆	—	—	0.07%	0.07%	—	0.1%
Na F	—	—	—	—	—	0.1%
Aluminium (wire)	1.75%	1.75%	1.75%	1.75%	1.75%	1.75%
Iron powder (low C)	15.14%	14.9%	13.3%	13.5%	14.0%	13.3%

The above noted constituents were contained in the core of the electrode, of which the iron sheath represented 80% by weight and was

of the following composition 0.06% C, 0.4% Mn, trace Si, 0.03% S, 0.02% P, balance Fe.

5

Mechanical Test Results						
Experimental No.	403A	403	406	408	404	411
YP t.s.i.(tons square inch)	25.12	25.44	20.80	27.04	20 20	27.2
UTS t.s.i.	31.52	31.36	29.36	32.80	28.64 28	32.6
Elongation %	24	24.3	27	23	26 26	25
Reduction of Area	51	48	49	45	60 55	45
Charpy ft. lbs. — average of 3 specimens.						
at 20°C	54	43	74	76	52	50
at 0°C	38	34	69	61	39	35
at -10°C	29	26	58	43	28	34
at -30°C.	24	20	46	37	22	29

Weld Metal Composition in Percentages by Weight						
Experimental No.	403A	403	406	408	404	411
Manganese	1.0	1.05	1.14	0.81	1.06	0.73
Silicon	0.25	0.27	0.21	0.22	0.22	0.23
Titanium	0.20	0.21	0.13	0.20	0.23	0.17
Aluminium	0.73	0.77	0.805	0.83	0.77	0.82
Iron (apart from incidental impurities)	balance	balance	balance	balance	balance	balance

CATEGORY 3

Electrodes of this category are based on the discovery that the good impact properties of the weld metal are retained, and indeed improved, and improved arc stabilization and easier slag removal are achieved when the core of electrodes of category 2 also contains a chloride of one or more of the metals caesium, potassium and sodium in an amount of 0.1—1% by weight of the electrode. Similar beneficial results are obtained by the inclusion in the core of up to 1% by weight of the electrode of a carbonate of an alkaline earth metal or of an alkali metal.

The above-stated modifications tend to reduce the content of the incidental impurities sulphur and phosphorus in the weld metal to a value which is normally below 0.016% in the case of each of these elements, so improving the impact resistance of the weld metal.

The following are the compositions of some typical electrodes of this category. In each case the sheath of the electrode was of the mild steel specified in category 2, and the core constituted 22% by weight of the electrode. The core constituents specified below are in percentages by weight of the electrode.

	Electrode 1	Electrode 2	Electrode 3	Electrode 4	Electrode 5	Electrode 6
Aluminium	1.75	1.80	1.75	1.75	1.75	2.2
Titanium	0.05	0.07	0.06	0.06	0.05	0.08
Manganese	1.0	0.9	0.85	0.85	0.85	0.93
Silicon	0.03	0.03	0.03	0.03	0.03	0.03
Na F	0.15	0.15	0.13	0.07	—	0.13
Ca F ₂	3.3	3.2	3.3	3.7	3.7	2.7
Na ₂ Al F ₆	0.16	0.15	0.17	0.17	0.17	0.17
K ₂ Ti F ₆	0.10	0.10	0.10	0.10	0.10	0.10
Ca CO ₃	0.20	—	—	—	—	0.53
K ₂ CO ₃	0.10	0.10	0.07	0.07	0.10	0.06
K ₂ Ti O ₃	0.07	—	—	0.10	0.10	—
Cs Cl	0.10	—	—	—	—	—
K Cl	0.20	0.35	—	—	—	0.27
Na Cl	0.05	—	—	—	—	—
Fused sodium Silicate (33% NaO)	0.30	0.36	0.27	0.27	0.27	—
Iron powder	balance	balance	balance	balance	balance	balance

The following are the compositions of weld deposits produced by these electrodes:—

	Electrode 1	Electrode 2	Electrode 3	Electrode 4	Electrode 5	Electrode 6
Carbon	0.07%	0.075%	0.109%	0.119%	0.102%	0.06%
Manganese	0.87%	0.93%	0.90%	0.90%	0.90%	1.04%
Silicon (from silicate)	0.21%	0.24%	0.19%	0.23%	0.18%	0.14%
Titanium	0.13%	0.09%	0.06%	0.11%	0.11%	0.08%
Aluminium	0.74%	0.61%	0.62%	0.79%	0.84%	1.10%
Sulphur	0.013%	0.011%	0.018%	0.018%	0.015%	0.02%
Phosphorous	0.014%	0.12%	0.015%	0.015%	0.015%	0.012%
Iron	balance	balance	balance	balance	balance	balance

The following are the mechanical properties of weld metal deposited by electrodes 3 — 6:—

	Electrode 3	Electrode 4	Electrode 5	Electrode 6
Yield Point t.s.i.	25.48	24.83	23.76	26.4
U.T.S. t.s.i.	31.4	33.64	31.92	31.04
% Elongation	26.2	23.7	22.5	25
% Reduction of Area	45	44	40	62
Charpy V at 20°C	—	—	—	93
Charpy V at 0°C	61.5	55	57.3	—
Charpy V at -20°C	46	59	53	57

CATEGORY 4

The electrodes of this category are of the following composition in parts by weight of the electrode:—

	Overall range	Preferred range
Carbon	0.3% max.	0.2% max.
Aluminium	1.5 to 3.5%	2 to 2.8%
Manganese	0.3 to 1.6%	0.5 to 1.0%
Silicon	0 to 0.6%	0.2 to 0.3%
Fluorides	8 to 16%	10 to 15%
Carbonates	1 to 6%	2.5 to 3.5%
Slag balancers	0 to 4%	0.2 to 1.0%
Iron (apart from incidental impurities)	Balance	Balance

The ratio by weight of fluorides to carbonates is 3.2—6 and preferably 4.2—4.7. The aluminium may be present in the core as metallic powder, ferro-alloy or as wire.

5 Manganese is derived partly from the sheath and partly from ferro-manganese or silico-manganese in the core. Ferro-manganese typically contains 80% manganese and 0.5% carbon with balance substantially iron but a carbon level of 6% is acceptable. Silico-manganese typically contains 60% silicon and 40% manganese.

10 Silicon is derived chiefly from the core being present, for example, as a ferro-alloy or as silico-manganese but a small amount, for example 0.02%, of silicon may be present in the sheath.

15 The fluoride content of the electrode is such that the electrode contains at least 8% of calcium fluoride. When, however, the amount of calcium fluoride substantially exceeds this figure part can be replaced by cryolite. The carbonates are selected from barium, calcium, strontium or magnesium carbonate, but potassium carbonate may be used in the amount of up to 2% by weight of the total content of carbonates.

20 The slag balancers, which control the fluidity of the slag by stiffening it, are selected from alumina, silica, titania and zirconia and may be present as these oxides or as compounds of these oxides such as potassium titanate, sodium silicate or feldspar. A small quantity of slag balancer may be helpful in giving exactly the degree of slag follow-up necessary. We prefer to use alumina but the other slag balancers are adequate but must not be used in sufficient quantity to give a significant alloying recovery into the weld metal due to reduction by aluminium. To ensure that the titanium content of the weld metal does not exceed the

above-stated amount and that zirconium is not present in the weld metal otherwise than as an incidental impurity, the total amount of titania and zirconia must not exceed 0.5% by weight of the electrode. 45

Iron is derived from the sheath, ferro-alloys and iron powder in the core. There is no objection to the use of iron powder containing significant amounts of carbon providing the amount of carbon does not exceed the above stated maximum. This is to ensure that carbon recovery into the weld metal does not exceed the limit stated below. 50

The electrodes of this category are intended primarily for welding in the horizontal and flat positions and give weld deposits of good shape with fine ripple marking, a good wash-out at the toes of the weld and weld metal of high ductility and good impact strength. The electrodes are easy to use, require no special degree of concentration on the part of the operator and hence reduce operating fatigue. The deposition rate of weld metal from the electrodes is high and hence the electrode assists in rapid welding and fabrication. The slag follow-up is good and the weld pool is easily observable. 55

The electrodes may contain iron powder in an amount of up to 35% by weight of the electrode. When iron powder is present in the core, the core should constitute at least 20% by weight of the electrode in order to ensure a fast deposition rate and the core may amount to as much as 48% by weight of the electrode. The range 24—35% by weight of core to electrode is preferred. When the core contains no iron powder it is, of course, lighter and in this case the ratio by weight of core to electrode may be 14—20% and is preferably 16—18%. 60

The weld metal deposited by electrodes of this category is as follows:—

	Overall range	Preferred range
Carbon	0.12% max.	0.11% max.
Aluminium	0.25 — 1.0%	0.45 — 0.8%
Manganese	0.4 — 1.8%	0.6 — 1.2%
Silicon	0.5% max.	0.2 — 0.4%
Titanium	0.12% max.	0.1% max.
Sulphur	0.03% max.	0.02% max.
Phosphorous	0.03% max.	0.02% max.
Iron	balance	balance

The following are examples of electrodes of this category. In each case the sheath of the electrode was of rimming quality steel of the following composition:—Extra deep drawing quality rimming steel of composition:—Carbon 0.04%; manganese 0.37%, silicon 0.01%;

sulphur 0.021%; phosphorus 0.019%; balance iron.

The core compositions of these electrodes are as follows, the compositions being expressed in percentages by weight of the core:—

	1	2	3	4	5	6	7	8	9
Aluminium Powder	8	9	8	8	9	10	9	6	16
Ferromanganese	3	2	3	3	3	3	3	2	5
Ferrosilicon	2	1	2	2	1.5	1.5	1	2.5	3
Calcium Fluoride	40	48	52	35	30	25	28	26	60
Silica	—	1	1	1					—
Alumina	1	0.5	$\frac{1}{2}$	—	1	1	1	1	2
Cryolite	—	—	—	15	—	—			—
Iron Powder	38	27.5	22 $\frac{1}{2}$	24	48.5	54	54	59	—
Calcium Carbonate	6	4	6	3	3	4	4	3 $\frac{1}{2}$	12
Magnesium Carbonate	2	7	5	9	4	1.5	—	—	2
Core as percentage by weight of the electrode	28	25	25	25	32	33	36	43	15

Mechanical Test Results from Example No. 1

Yield point t.s.i.	26.2
U.T.S. t.s.i.	33.7
Elongation %	21
R. of A. %	47
Charpy ft. lbs. at 20°C.	45

(average of three specimens)

15 CATEGORY 5
These electrodes include in some instances manganese oxide in the core and sufficient aluminium to reduce the oxide to manganese

which is recovered, as such, in the weld metal. The core constitutes 30—33% by weight of the electrode and the core is of the following composition by weight:—

	General range	Preferred range
Iron powder	0 — 40%	5 — 30%
Aluminium powder	4 — 20%	8 — 15%
Manganese oxide	0 — 15%	3 — 10%
Iron oxide	0 — 25%	2 — 15%
Silica	0 — 15%	3 — 10%
Potassium titanate and/or rutile	0 — 10%	1 — 7%
Carbonates	0 — 10%	2 — 8%
Fluorides	10 — 40%	15 — 30%

the total amount of manganese oxide, iron oxide and silica being at least 20% and the total amount of carbonates and fluorides being at least 15%.

5

The manganese oxide may be MnO_2 , Mn_2O_3 or MnO . The carbonates content may be calcium carbonate, barium carbonate, strontium carbonate or magnesium carbonate. The silica may be present in the core as such, or in

10

mineral form, e.g. as feldspar or wollastonite. The fluoride content consists of calcium fluoride, with or without minor additions of cryolite, potassium silicofluoride, sodium fluoride and/or potassium fluoride.

The following are examples of core compositions of typical electrodes of this category:—

15

	1	2	3	4	5
Iron Powder	30	30	30	22	30
Aluminium Powder	12	12	12	13	12
MnO_2	7	3	11	8	7
Magnetite	10	10	10	11	10
Silica	7	11	3	8	7
K_2TiO_3	4	4	4	4	4
$Ca CO_3$	5	5	5	6	5
$Ca F_2$	25	25	25	18	22
Na F	—	—	—	10	3

20 The weld metal compositions obtained with these electrodes were as follows:—

	1	2	3	4	5
Titanium	0.05%	0.05%	0.05%	0.06%	0.06%
Aluminium	0.40%	0.30%	0.41%	0.41%	0.47%
Manganese	1.35%	0.70%	1.85%	1.31%	1.34%
Silicon	0.51%	0.70%	0.28%	0.45%	0.53%
Carbon	0.06%	0.08%	0.05%	0.06%	0.06%
Iron the balance, apart from incidental impurities.					

The mechanical properties of weld metal obtained from these electrodes were as follows:—

	1	2	3	4	5
Y.S. t.s.i.	23.4	20.2	27.4	24	25
U.T.S. t.s.i.	32.6	31.5	37.4	32	33.9
Elongation % on 2 inch gauge length	23	26	19	19	21
Reduction of Area %	40	45	35	30	30
Charpy ft. lbs. at 20°C. (Average of 3 specimens)	58	41	45	47	62
Charpy ft. lbs. at -30°C. (Average of 3 specimens)	40	28	31	30	44

- 5 When electrodes according to the invention are to be used with A.C. current at a current density of 20,000—120,000 amperes per sq. in., they should have a diameter in the range of 0.03—0.14 inch and be of the following composition in parts by weight of the electrode:— 10

	Overall Range	Preferred Range
Aluminium	1.5 to 4.5%	2 to 2.8%
Manganese	0.3 to 1.6%	0.5 to 1%
Silicon	0 to 0.6%	0.25% max.
Calcium fluoride	5 to 15%	10 to 13%
Arc stabilisers	1 to 8%	2 to 3.5%
Slag modifiers	1 to 4%	1 to 4%
Iron and incidental impurities	balance	balance

15 While the fluoride constituent is specified as calcium fluoride it may contain minor amounts, not exceeding 50% by weight, of other fluorides such as sodium fluoride or cryolite.

20 The arc stabilisers in the above table are oxides of magnesium, alkali metals or alkaline earth metals, which may be present as such or as compounds, such as carbonates, titanates or silicates, which will decompose to yield these oxides at the temperature of the arc. The amount of fluoride plus arc stabilisers must amount to at least 5.5% by weight of the electrode. The slag modifiers in the above table are alumina, silica, titania and/or zirconia, as such or as compounds which will decompose

to yield these oxides, with the proviso that the total amount of titania and zirconia must not exceed 0.5% by weight of the electrode.

It will be appreciated that when the oxide acting as an arc stabiliser and the oxide acting as a slag modifier are present in one and the same compound, for example as alkali metal titanate, the content of each oxide present in the electrode as a whole will fall within the above-defined limits.

Calcium and magnesium carbonates are effective arc stabilisers but suitable alternatives are carbonates of strontium, barium, lithium, caesium, rubidium, sodium and potassium. Iron powder in the core of the electrode assists in arc stabilisation and should preferably

be present in an amount of not less than 6% by weight of the electrode. There is no objection to the use of grades of iron powder containing up to 0.3% by weight of carbon.

- 5 The above described slag modifiers may be replaced by an oxide of manganese and/or iron, which also tends to stabilize the arc, but in this case the electrode will contain more aluminium to ensure reduction to metal of said
10 oxide and the preferred range of aluminium content will be 2.5—4.5%. In this case the content of manganese oxide must not exceed 3% but the content of iron oxide may be as high as 5%.

- 15 Electrodes as just described deposit ductile, tough weld metal containing 0.4—1.6% manganese, 0.2—1% aluminium, 0.5% max. silicon, 0.15% max. titanium + zirconium, balance iron apart from incidental impurities. Preferably the weld metal is of the following composition:—carbon 0.11% max., aluminium
20 0.45—0.8%, manganese 0.6—1.1%, silicon 0.2—0.4%, titanium 0—0.1%, sulphur 0.03% max., phosphorous 0.03% max., iron the balance.

- 25 The A.C. power source may be of any conventional type and good results may be obtained by the use of conventional transformers primarily designed for welding with
30 manual electrodes. Thus the power may be derived from the mains through a transformer or may be provided by a suitable A.C. generator. It may be single phase, three phase or derived from two phases or between line and

neutral of a three phase supply. The load characteristic of the transformer may be of the drooping, sloping or level type.

A typical transformer circuit is shown in Fig. 1 of the accompanying drawings, in which L_1 , L_2 represent the A.C. supply terminals, T represents a transformer, I represents an inductance and T_1 , T_2 are terminals for connection to the work and to the electrode respectively.

In a conventional circuit for manual arc welding, using a 250 volt A.C. supply, the transformer T is designed to give an open circuit voltage of 80 volts and the inductance I has a value of 0.5 millihenries. For use in accordance with the present invention the transformer may be designed to give an open circuit voltage of 30—60 volts and the circuit so arranged as to cause the voltage to drop to 25—40 volts when the arc is struck and the characteristic to be substantially level, the voltage drop being within the range of 0—0.1 volts per ampere and preferably 0.008—0.06 volts per ampere.

The following are examples of typical electrodes for use under the above-described A.C. current conditions:—

In each case the diameter of the electrode is 0.094", the sheath is of rimming quality mild steel containing 0.06% C, 0.5% Mn, 0.03% S, 0.03% P, balance iron; the core constitutes 30% by weight of the electrode and the composition is as follows in percentage by weight of the electrode:—

	1	2	3	4	5
Aluminium powder	2.2%	2.4%	4.4%	3.8%	3.3%
Manganese	0.7%	0.8%	—	—	—
Mn ₂ O ₃	—	—	2.2%	1.8%	2%
Ferrosilicon	0.3%	0.2%	0.2%	0.2%	0.2%
Calcium fluoride	11%	13.5%	8%	12%	8%
Alumina	0.6%	0.2%	—	—	—
Silica	—	0.5%	—	—	—
Iron powder	11%	7%	8%	9%	7%
Fe ₃ O ₄	—	—	—	—	5%
Ca CO ₃	2%	4%	4%	3%	—
Mg CO ₃	1%	—	—	—	2%
K ₂ CO ₃	1%	1%	—	—	—
Iron as sheath	balance	balance	balance	balance	balance

As will be apparent from the foregoing, all electrodes to be used in accordance with the invention consist of a mild steel sheath enclosing a core containing nitrogen fixing and deoxidising elements and can successfully be used without shielding because these elements remove, or at least nullify, the harmful effects of atmospheric nitrogen and oxygen which enter the weld pool and which, but for the effect of deoxidizers and nitrogen fixers, would cause a very severe loss of impact strength and ductility. It is essential, in order to secure weld metal as specified above, that some amounts of aluminium, manganese and silicon are recovered into the weld metal but the extent of recovery varies according to the following factors:—

1) The arc length has a major effect on alloy recovery, a long arc tending to lose by atmospheric reaction much of the alloying elements present in the electrode and a short arc assisting their recovery.

2) The welding current also has a major effect on recovery, a high current increasing recovery and a low current diminishing recovery.

Accordingly, if the arc length is excessive too much aluminium will be lost and the weld metal is liable to become porous, while if the arc length is too short and the welding current is too high, so much aluminium, and perhaps also silicon and manganese, will be retained in the weld metal so as to increase its tensile strength and undesirably reduce its ductility.

It is accordingly highly desirable to operate the electrodes under conditions such that $V=1.9A+x$ when A.C. welding current is used and $V=1.1A+y$ when D.C. welding current is used; V being the arc voltage, A being the current density expressed as

$$\frac{1}{1000} \frac{c}{d}$$

where c is the welding current in amperes and d is the diameter of the electrode in inches, x being between 18 and 29 and y being between 19 and 30.

Operation thus takes place in the regions between the lines A and B in Fig. 3 and between the lines C and D in Fig. 2 of the accompanying drawings in which arc voltage is plotted as ordinates and current density expressed as

$$\frac{c}{1000 d}$$

as abscissae. These lines are as follows:—

Line A	$V=1.9A+29$
Line B	$V=1.9A+18$
Line C	$V=1.1A+30$
Line D	$V=1.1A+19$

If operation takes place above the line A or C the weld metal tends to exhibit porosity while if operation takes place below the line B or D the weld metal tends to exhibit a loss of ductility and impact strength.

Satisfactory weld metal can be secured by compliance with these operating conditions using a tubular electrode having within its mild steel sheath a core containing 0.8—4.5% aluminium, 0.06% silicon, 0.03% titanium and 0.3—1.6% manganese based on the weight of the electrode.

The following are the results of tests showing the effect of working under different conditions with a D.C. supply on the electrode identified as No. 1 in category 5 above:—

	Test 1	Test 2	Test 3
Arc Volts	21	26	35
Welding current amps	400	400	400
Current density, as defined above	4.3	4.3	4.3
Al in weld	1.3	0.7	0.3
Si " "	0.5	0.25	0.12
Mn " "	1.4	0.95	0.7
Ultimate tensile strength of weld metal t.s.i.	39	33	24
Elongation %	16	24	10
Reduction of Area %	31	47	15
Charpy Impact Strength at 0°C.	18	46	24
Weld metal soundness	Good	Good	Porous

WHAT WE CLAIM IS:—

1. A process of automatic or semi-automatic welding which consists in depositing from a cored tubular electrode, having a mild steel sheath devoid of external flux, without external shielding of the arc, weld metal having an elongation of at least 18%, a reduction of

area of at least 25%, and a Charpy impact strength of at least 35 ft/lbs. at 20° C and at least 20 ft/lbs. at -30° C when tested in accordance with the mechanical test procedure given in B.S.S. 639, 1964, the weld metal being of the following composition by weight:—

aluminium	0.12 — 1.3%
manganese	0.3 — 2%
silicon	0.1% — 1%
carbon	0.12% max.
titanium	0.12% max. if the silicon content exceeds 0.35% and 0.25% max. if the silicon content is 0.35% or less
balance	iron apart from incidental impurities.

2. A process as claimed in claim 1, in which the weld metal contains 0.12—0.8% aluminium, 0.7—1.75% manganese, 0.4—0.85% silicon and a maximum carbon content of 0.08%.

3. Weld metal when produced by the process claimed in claim 1.

4. Weld metal when produced by the process claimed in claim 2.

5. A continuous cored tubular arc welding electrode adapted, when used without external shielding of the arc, to deposit weld metal having the physical properties and composition specified in claim 1, said electrode having a mild steel sheath devoid of external flux and enclosing a core consisting of:—

- (a) metal as powder or wire in amounts such that the electrode as a whole contains 0.8—2.5% aluminium, 0.01—1% titanium, 0.05—1.5% silicon and 0.4—1.5% manganese;

- (b) fluorides of alkali and/or alkaline earth metals present in an amount of 0.4—6% by weight of the electrode, part of the

fluorides, in excess of 0.4%, being optionally replaced by carbonates or titanates of alkali or alkaline earth metals; and

- (c) slag forming elements in an amount of 4—8% of the weight of the electrode and constituted by potash feldspar and/or soda feldspar and/or lime feldspar or by fused potassium silicate and/or sodium silicate.

6. An electrode as claimed in claim 5, in which the core also contains as further slag forming elements up to 2% of calcium carbonate, and/or up to 5% of natural or synthetic wollastonite and/or up to 5% of iron oxide, the total amount of slag forming elements not exceeding 10% and all proportions being by weight of the electrode.

7. A continuous cored tubular arc welding electrode adapted, when used without external shielding of the arc, to produce weld metal having the physical properties and composition specified in claim 1, said electrode having a mild steel sheath devoid of external flux and being of the following overall composition in percentages by weight:—



* C L M S *

titanium, as ferrotitanium	0.1% max.
manganese	0.8 — 1.5%
sodium or potassium silicate	0 — 0.3%
fluorides, at least 1.7% being calcium fluoride or cryolite	1.7 — 5.5%
titanium oxide, as titanates or minerals	0.25% max.
aluminium	1.2 — 2.6%
silicon in sheath	0.03% max.
iron as sheath	60 — 85%
iron as powder or ferro alloys	balance

8. A modification of the electrode claimed in claim 7, which also contains in its core a chloride of one or more of the metals caesium, potassium and sodium in an amount of 0.1—1% by weight of the electrode.

9. A modification of the electrode claimed in claim 7 or claim 8, which also contains in its core a carbonate of an alkaline earth metal or an alkali metal in an amount of up to 1% by weight of the electrode.

10. A continuous cored tubular arc welding electrode adapted, when used without external shielding of the arc, to deposit weld metal having the physical properties and composition specified in claim 1, said electrode having a mild steel sheath devoid of external flux and being of the following overall composition in percentages by weight:—

carbon	0.3% max.
aluminium	1.5 — 3.5%
manganese	0.3 — 1.6%
silicon	0 — 0.6%
fluorides	8 — 16%
carbonates	1 — 6%
slag balancers, selected from alumina, silica, titania and zirconia (as such or as compounds)	0 — 4%
iron	balance

the ratio by weight of fluorides to carbonates being between 3.2 and 6, the total amount of titania and zirconia not exceeding 0.5%, and the fluoride content consisting of calcium fluoride or a mixture of calcium fluoride and

cryolite when the calcium fluoride content substantially exceeds 8%.

11. An electrode as claimed in claim 10, which is of the following composition:—



carbon	0.2% max.
aluminium	2 — 2.8%
manganese	0.5 — 1%
silicon	0.2 — 0.3%
fluorides	10 — 15%
carbonates	2.5 — 3.5%
slag balancers	0.2 — 1%
iron	balance

the ratio by weight of fluorides to carbonates being between 4.2 and 4.7.

- 5 12. A continuous cored tubular arc welding electrode adapted, when used without external shielding of the arc, to deposit weld metal having the physical properties and composition

specified in claim 1, said electrode having a mild steel sheath devoid of external flux and enclosing a core which constitutes 30—33% by weight of the electrode and is of the following composition by weight:—

10

iron powder	0 — 40%
aluminium powder	4 — 20%
manganese oxide	0 — 15%
iron oxide	0 — 25%
silica	0 — 15%
potassium titanate and/or rutile	0 — 10%
carbonates	0 — 10%
fluorides	10 — 40%

- 15 the total amount of manganese oxide, iron oxide and silica being at least 20%, the total amount of carbonates and fluorides being at least 15% and the fluoride content consisting of calcium fluoride with or without minor addi-

tions of cryolite, potassium silicofluoride, sodium fluoride and/or potassium fluoride.

20

13. An electrode as claimed in claim 12, in which the core is of the following composition:—



* C L M S *

iron powder	5 — 30%
aluminium powder	8 — 15%
manganese oxide	3 — 10%
iron oxide	2 — 15%
silica	3 — 10%
potassium titanate	1 — 7%
carbonates	2 — 8%
fluorides	15 — 30%

5 14. A continuous cored tubular arc welding electrode adapted, when used without external shielding of the arc with A.C. current at a current density of 20,000—120,000 amperes per sq. in., to deposit weld metal having the physical properties and composition claimed in

claim 1, the electrode having a mild steel sheath devoid of external flux, having a diameter of 0.03—0.14 inch and being of the following overall composition in percentages by weight: — 10

aluminium	1.5 — 4.5%
manganese	0.3 — 1.6%
silicon	0 — 0.6%
calcium fluoride, with or without minor amounts not exceeding 50% by weight of other fluorides	5 — 15%
arc stabilizers (oxides of magnesium, alkali metals or alkaline earth metals) present as such or as compounds	1 — 8%
slag modifiers, selected from alumina, silica, titania and zirconia, present as as such or as compounds	1 — 4%
iron and incidental impurities	balance

15 the amount of fluoride plus arc stabilisers being at least 5.5% by weight of the electrode and the total amount of titania and zirconia, when present not exceeding 0.5% by weight of the electrode.

20 15. An electrode as claimed in claim 14, which contains 2—2.8% aluminium, 0.5—1% manganese, 0.25% max. silicon, 10—13% fluoride, 2—3.5% arc stabilizers and 1—4% slag modifiers.

25 16. A modification of the electrode claimed in claim 14, which contains 2.5—4.5% aluminium, 0.5—1% manganese, 0.25% max. silicon, 10—13% fluoride and 2—3.5% arc

stabilisers and in which the slag modifier content consists of an oxide of manganese and/or iron, the content of manganese oxide not exceeding 3% and the content of iron oxide not exceeding 5%. 30

17. An electrode as claimed in any one of claims 14—16, in which the core contains iron powder in an amount of at least 6% by weight of the electrode. 35

18. A process as claimed in claim 1, in which the electrode is used with A.C. current at a current density of 20,000—120,000 amperes per sq. in. and is as specified in any one of claims 14—16. 40



19. A process as claimed in claim 18, in which the power supply yields an open circuit voltage of 30—60 volts and a voltage drop not exceeding 0.1 volts per ampere.

5 20. A process as claimed in claim 1, in which the welding operation is carried out under conditions such that $V=1.9A+x$ when A.C. welding current is used and $V=1.1A+y$ when D.C. welding current is used; V being
10 the arc voltage, A being the current density expressed as

$$\frac{c}{1000d}$$

where c is the welding current in amperes and d is the diameter of the electrode in inches,

x being between 18 and 29 and y being between 19 and 30. 15

21. A process as claimed in claim 20, in which the core of the electrode contains 0.8—4.5% aluminium, 0—0.6% silicon, 0—0.3% titanium and 0.3—1.6% manganese based on the weight of the electrode. 20

22. A continuous cored tubular arc welding electrode adapted when used without external shielding of the arc to deposit weld metal having the physical properties and composition specified in claim 1 as described in any of the foregoing examples. 25

BREWER & SON,
Chartered Patent Agents,
5—9 Quality Court, Chancery Lane,
London, W.C.2.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1970.
Published by the Patent Office, 25 Southampton Buildings, London, W.C.2, from which
copies may be obtained.

