

FLUX-CORED WIRE ELECTRODE FOR USE IN GAS-SHIELDED
ARC-WELDING

This invention relates to a flux-cored wire electrode suitable for use in gas-shielded arc-welding.

5 The consumption of flux-cored wire electrodes tends to increase more and more for gas-shielded arc-welding work, because flux-cored wire electrodes have advantages in that they assure easy and efficient welding work and, especially, they feature good arc stability, produce less spatter and hence give
10 excellent bead appearance. However, one of their most serious problems is that they are accompanied by a great deal of emission of welding fumes. The emission of such welding fume may reach as much as 1.5 to 2.0 times the welding fumes generally emitted
15 when a solid wire electrode is used. Emission of a large volume of fumes causes a problem from the viewpoint of labour hygiene for welding workers. Also, it becomes difficult to see the weld line due to fumes when welding in a poorly-ventilated room,
20 thereby raising another problem that the accuracy of the welding is lowered.

Counter measures for solving such problems may comprise (1) a reduction of the fumes concentration
25 by ventilation; (2) suction and discharge of the fumes through a duct or the like provided near the site of the welding work; (3) the wearing of dust mask; and (4) reduction of fumes through improvements to welding materials and method. Regarding the

countermeasures (1) to (3) of the above-referred countermeasures, a variety of methods and apparatus has already been proposed. These proposals are however reactive measures and cannot be considered as break-throughs or perfect countermeasures. The most important countermeasure against fumes is countermeasure (4), that is reduce the emission of fume. No sufficient investigations have however been made on this point.

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With the foregoing in view, the present inventors have carried out research with a view toward lowering the fume emission of flux-cored wire electrodes, which are suitable for use in gas-shielded arc-welding, by considering the materials from which are made up. As a result, it has been already found that the emission of fumes can be reduced to a considerable extent when the carbon content in the outer layer of soft steel making up the sheath and the carbon content in an adhering residual lubricant layer from the manufacture of the flux-cored wire electrode are lowered as much as possible. In the course of further research, it has also been found that fume emission can be lowered further when the composition of the flux is suitably adjusted in addition to the above-mentioned reduction in the carbon content.

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An object of this invention is to provide a flux-cored wire electrode suitable for use in gas-shielded arc-welding, which wire electrode emits welding fume at the same low level as solid wire electrodes.

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According to the present invention, there is provided a flux-cored wire electrode for use in gas-shielded arc-welding comprising a soft steel sheath surrounding a flux containing cavity wherein the sum of the carbon content of the soft steel sheath and the carbon content of a lubricant adhering to the sheath is 0.045 wt.% or less relative to the total weight of the sheath, the flux contains 20 to 50 wt.% of TiO_2 , 1 to 15 wt.% of SiO_2 , 2.5 to 10 wt.% of ZrO_2 , 0.1 to 5 wt.% of an arc-stabilising agent, 10 to 45 wt.% of a deoxidiser and iron powder present up to 50 wt.%, all based on the total weight of the flux, and the flux comprises 10 to 30 wt.% of the total weight of the wire electrode.

In another aspect of this invention, the above flux may further contain 1 to 15 wt.% of Al_2O_3 , 0.1 to 10 wt.% of MgO and 1 to 10 wt.% of iron oxides, all based on the total weight of the flux.

The above and other features and advantages of the present invention will become apparent from the following description and the appended claims, taken in conjunction with the accompanying drawings.

In the accompanying drawings:

FIGURE 1 is a partially cut-away perspective view of an apparatus employed in the measurement of emitted fume;

FIGURE 2 and FIGURE 3 are diagrams showing the relationship between fume emission rate and flux components;

5 FIGURE 4 is a diagram showing the relationship between the vapour pressures of flux components and fume emission rate;

10 FIGURE 5 is a diagram showing the relationship between the total carbon content in soft steel sheath layer and the remaining lubricant and fume emission rate;

15 FIGURE 6(A) and FIGURE 6(B) are respectively cross-sectional views illustrating the manner of fume emission;

20 FIGURE 7 is a diagram showing the relationship between flux content and fume emission rate;

FIGURES 8(A) to 8(D) are schematic illustrations showing the cross-sections of flux-cored wire electrodes;

25 FIGURE 9 is a diagram showing the relationship between the Ar content in CO_2 gas and fume emission rate; and,

30 Figures 10 to 12 are photographs taken by a high-speed camera of the explosion of suspended droplets.

As mentioned above, the present inventors have

already found that the fume emission rate can be significantly reduced when the carbon content in the soft steel sheath layer and the carbon content in the remaining (adhering) lubricant are both lowered (more specifically, to 0.045 wt.% or lower relative to the total weight of the sheath layer). The present inventors have proceeded with further research in other directions, without being fully satisfied with the result of the above finding. The composition of the flux was chosen and subjected to an investigation.

Certain basic experiments were conducted in order to clarify the relationship between the composition of the flux and the fume emission rate. Fluxes, containing slag-forming agents, arc-stabilising agents, deoxidisers, iron powder, etc. which form part of the electrode are known. They may be classified into titania-base fluxes, lime/titania base fluxes, lime-base fluxes, etc., in accordance with the kinds and the inclusion or exclusion of slag-forming agents, the basicity of slag and the like. When performing the experiments, a titania-base flux which had the lowest fume emission rate was used as a standard composition. By changing the content of each of the slag-forming agent (TiO_2 , SiO_2 , Al_2O_3 , ZrO_2 , Fe_3O_4 , MgO), arc-stabilising agent (NaF), deoxidiser (Mn) and iron powder, which are the principal components of titania-base fluxes, the relationship between each of the principal components and the fume emission rate was investigated. The below-described sample wire specification and welding

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conditions were used in the investigation. The measurement of each fume emission rate was carried out by collecting the fumes which were emitted upon conducting a welding operation in accordance with the procedure prescribed in JIS (Japan Industrial Standard) 3930, in its entirety by means of a high-volume air sampler in an apparatus as illustrated in FIGURE 1 with a part thereof cut away. In FIGURE 1, there is illustrated a collection box 1, a sampler 2, an observation window 3, an access opening 4, air-feed holes 5, each of 40 mm diameter, a welding table 6, and a sample plate 7. With such an apparatus the fume emission rate per unit time (mg/min), was measured and each experiment repeated three times, and an average of the fume emission rates in the three experiments was calculated.

SAMPLE WIRE AND WELDING CONDITIONS:

20 Electrode Wire

Sheath-forming metal:	Soft steel
Flux:	Titania-base flux
Flux content:	15 wt.%
25 Lubricant:	MoS ₂ -base lubricant
Cross-sectional shape:	As illustrated in FIGURE 8(A) which will be described herein.
Wire diameter:	1.6 mm

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Welding Conditions

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Welding current: 300 A, DC(+)
Welding voltage: 32V
Welding speed: 30 cm/min
Shielding gas: CO₂, 20 litres/min
5 Distance between electrode
tip and mother plate 17 mm
Mother plate 12 mm^t, soft steel
Welding method: Bead-on-plate method

10 Results are diagrammatically shown in FIGURE 2 and
FIGURE 3.

As is apparent from FIGURE 3 and FIGURE 4, the fume
emission rate is inversely proportional to the
15 content of each of ZrO₂, Al₂O₃, SiO₂, TiO₂ and MgO
but is proportional to the content of NaF. However,
the contents of Mn, Fe₃O₄ and iron powder have little
influence on the fume emission rate. In FIGURE 4,
the vapour pressure of each flux component is plotted
20 along the horizontal axis while the extent of an
increase or reduction in fume emission rate per unit
weight proportion of each component is plotted along
the vertical axis, both based on data obtained in the
above experiment. ZrO₂, SiO₂, Al₂O₃, MgO and TiO₂
25 tend to reduce the fume emission rate, NaF tends to
increase the fume emission rate, and iron powder,
Fe₃O₄ and Mn have little effect on the fume emission
rate. As can be understood from the above-described
results, the amounts of high-temperature vapours in
30 an arc decrease and the fume emission rate decreases
as components having lower vapour pressures increase,
because the relative content of the components having

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high vapour pressures decrease.

In the present invention, the content of each component of a flux can be limited as will be described below by taking into consideration its
5 aforementioned influence on the fume emission rate and its required properties as a flux component.

TiO_2 : 20 to 50 wt.%

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As mentioned above, TiO_2 is effective in reducing the fume emission rate and, besides, is a component indispensable for improving the stability of an arc and the slag-covering property. Its content must be
15 at least 20% of the total weight of each flux. Any TiO_2 content exceeding 50 wt.% results in excessively high slag viscosity, whereby the shapes of beads will be poor and, as a result of the inclusion of excess reduced titanium and titanium oxide in the welded
20 metal, the mechanical properties (especially, toughness) of the metal weld will be lowered.

SiO_2 : 1 to 15 wt.%

25 SiO_2 is also effective in reducing the fume emission rate. Besides, it is effective in making good bead shapes. These effects are exhibited to noticeable extents when SiO_2 is added in an amount of 1% or more. When the content of SiO_2 exceeds 15%, the
30 viscosity of the fused slag is lowered, thereby adversely affecting the easiness and efficiency of the welding work, aggravating the appearance and

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shape of each bead, and reducing the toughness of the welded metal.

ZrO₂: 2.5 to 10 wt.%

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ZrO₂ is a component which is not only extremely effective in reducing the fume emission rate but also capable of enhancing the slag coverability. In order to draw out these effects of ZrO₂ to significant
10 extents, it is necessary to add ZrO₂ in an amount of 2.5% or higher. Due to the high solidification point of ZrO₂, there is a possibility of ZrO₂ inducing such defects as slag inclusion when added in excess of 10%.

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Arc-stabilising agent: 0.1 to 5 wt.%

As arc-stabilising agents may be mentioned materials capable of undergoing ready ionisation in arcs, for
20 example, the oxides, fluorides, carbonates, nitrates of Li, Na, K, b, Cs, Ca, Sr, Ba. When incorporated in amounts less than 0.1%, arcs are unstable and problems develop from the viewpoint of the readiness and efficiency of welding work, for example, the
25 occurrence of frequent spattering. On the other hand, the arc-stabilising agent, for example, NaF has a high vapour pressure as shown in FIGURE 4 and tends to increase the fume emission rate. Therefore, it is necessary to limit the content of the arc-stabilising
30 agent below 5% so as to avoid such a problem.

Deoxidiser: 10 to 45 wt.%

5 A deoxidiser is a component effective in reducing the content of non-metals in the welded metal and thus improving the physical properties of the welded metal owing to its deoxidising action. As representative deoxidisers may be mentioned such metals as Mn, Si, Al, Mg, Ti, Zr and the like as well as their iron alloys. When a deoxidiser is used in an amount less
10 than 10%, the deoxidisation is insufficient, leading to poor X-ray examination results. Accordingly, a deoxidiser must be added in an amount of 10% or higher. When the content of deoxidiser exceeds 45%, there is too much deoxidisation and the toughness and
15 anti-cracking property of the welded metal are lowered. A deoxidiser does not significantly influence the fume emission rate as is apparent from the results with Mn illustrated by way of example in FIGURE 4. However, Mg is an exception and tends to
20 increase the fume emission rate. Therefore, it is desirable to lower the content of a deoxidiser as much as possible when Mg is used as the deoxidiser.

Iron powder: up to 50 wt.%

25 As illustrated in FIGURE 4, iron powder has almost no influence on the fume emission rate. However, it acts to increase the deposition rate and to improve the welding efficiency. Therefore, iron powder may
30 be incorporated up to 50 wt.%. When the content of iron powder exceeds 50%, the relative content of the slag-forming agent is decreased, thereby worsening

the shape of the beads and, in addition, inducing the occurrence of welding defects such as pits and blowholes due to insufficient shielding.

5 Al_2O_3 , MgO and iron oxides, which will be described below, are not always essential components but are also effective in reducing the fume emission rate. Therefore it is desirable to add them.

10 Al_2O_3 : 1 to 15 wt.%

Al_2O_3 is a component which is effective in reducing the fume emission rate. In addition, it raises the solidification temperature of slag and hence improves the shape of the beads in vertical welding. In order to increase these effects of the Al_2O_3 without failure, it is desirable to add Al_2O_3 in an amount of at least 1%. When the content of Al_2O_3 exceeds 15%, it tends to cause defects such as slag inclusion and to lower the removability of the slag, and to increase non-metallic inclusion in the welded metal and thus to lower the toughness of the welded metal.

MgO : 0.1 to 10 wt.%

25 MgO is also effective in reducing the fume emission rate. MgO may preferably be added for its effects in improving the slag coverability and bead shapes as well as the toughness and ductility of welded metals rather than its fume-lowering effect. In order to increase these effects to a noticeable extent, it is necessary to add MgO in an amount of 0.1% or higher.

If too much MgO is present, however, the viscosity of the fused slag is considerably lowered, thereby making welding manipulation difficult and making the bead shapes poor. Therefore, the upper content limit of MgO should be set at 10%.

Iron oxides: 1 to 10 wt.%

Iron oxides may include FeO, Fe₂O₃ and Fe₃O₄ as well as individual minerals containing such iron oxides as their main components and mixtures of such minerals. As readily envisaged from the Fe₃O₄ given by way of example in FIGURE 4, iron oxides do not substantially effect the fume emission rate. It is preferred however to add iron oxides in a total amount of 1% or more, because they improve the slag coverability and bead shape. If the content of such iron oxides exceeds 10%, the arcs become unstable and spattering frequently occurs, and the viscosity of the slag is lowered and the coverability of the slag is lowered further.

The composition of a flux useful in the practice of this invention has been described above.

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A further parameter affecting the fume emission rate, is the H₂ content in each wire electrode. The fume emission rate decreases as the H₂ content becomes lower, because the temperature of the arc rises owing to the high ionisation voltage of H₂ and the concentrations of metal vapours, which serve as the sources of the fumes, increase when H₂ penetrates

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into the arc. These disadvantageous effects of H_2 appear very noticeably when the H_2 content in a wire electrode reaches about 50 ppm or higher. Therefore, it is desirable to limit the H_2 content below the above-mentioned level in each wire electrode.

It is possible to lower the fume emission rate to a considerable extent by controlling the contents of components in a flux in the electrode. However, such an adjustment in flux composition can by itself lower the fume emission rate by about 10 to 20% only and by itself cannot be considered as a satisfactory solution for the reduction of the fume emission rate. We wish to reduce the fume emission rate to the levels of fume emission rates of solid wire electrodes. In order to achieve this object, it is necessary to lower the fume emission rate by about 40 to 50% compared with the fume emission rates of conventional flux-cored wire electrodes.

Therefore, with a view toward achieving a further reduction in the fume emission rate, an additional investigation has been carried out, on the basis of the above-obtained finding, with respect to the relationship between the fume emission rate and the carbon content of the soft steel sheath and the residual lubricant adhering as a result of the production process of a flux-cored wire electrode.

As will be described next, electrode wires having different carbon contents relative to the total weights of their respective sheaths were produced

using soft steel and lubricant samples having different carbon contents. Their fume emission rates were then determined by conducting a welding test under the same conditions as employed in the experiment whose results are diagrammatically shown in FIGURE 2 and FIGURE 3.

Electrode Wire

10	Wire diameter:	1.6 mm
	Carbon content in sheath-forming soft steel:	0.005 to 0.08 wt.%
	Flux:	Titania-base flux
	Flux content:	15 wt.%
15	Lubricant:	MoS ₂ -base lubricant (carbon content: 20 to 50 wt.%; amount adhering to surface: 0.01 to 0.10 wt.% of soft steel sheath)
20	Cross-sectional shape:	As illustrated in FIGURE 8(A)
25	Flux composition:	Composition No.2 Table 3 which will be given later.

Results are shown in FIGURE 5. Thus, there is clear relationship between the carbon contents relative to the total weight of the sheath steel and the fume emission rate. A reduction in the above carbon

contents has achieved a great effect in suppressing the fume emission rate.

5 Generally speaking, the carbon content of the soft steel sheath and flux of a flux-cored wire electrode (the term "carbon contents" will hereinafter be called "the total carbon content" for brevity) is about 0.07 wt.% or higher. It is thus clear that the fume emission rate is affected not only by the composition of the flux core but also to a significant extent by the total carbon content. The above described flux of low fume level composition was used as a flux core for a flux-cored wire electrode employed in the experiment, the results of which experiment are shown in FIGURE 5. However, the fume-reducing effect is limited to about 15%, no matter how much the total carbon content is reduced. When the total carbon content is limited at a low level in addition to a suitable adjustment to the flux composition, the fume-reducing effect can be significantly increased. The fume emission rate may be lowered to the levels of fume emission rates of solid wire electrodes when the total carbon content is reduced to 0.045% or less. The fume emission rate may be lowered to one half of that of a convention flux-cored wire electrode provided that the total carbon content is limited below 0.02%, thereby successfully achieving the object of fume reduction.

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30 The reasons for the significant influence of the total carbon content on the fume emission rate were clarified by the following verification experiment.

First of all, FIGURE 6(A) and FIGURE 6(B) are schematic illustrations showing the welding process, namely, are illustrations obtained by observing the arc-producing portions with high-speed cameras in order to investigate the way in which fume occurs when the welding was carried out using flux-cored wire electrodes. In the drawings, there is illustrated a mother plate 8 and a soft steel sheath 9, a flux 10, an arc 11 and droplet 12 and fume 13. As is apparent also from these drawings, the soft steel sheath 9 is fused by the heat of the arc and the droplet 12 is thus formed (see, FIGURE 6(A)), during a welding process. Many droplets are successively built up on the mother plate 8 during the welding. When the droplet 12 suspended from the tip of the wire electrode explodes and the arc 11 is disturbed (see, FIGURE 6(B)), a great deal of fume 13 is produced. The occurrence of the fume 13 may be attributed to an assumption that metal vapours and the like, which are present in the arc atmosphere and cause the fume, are released to the outside of the arc atmosphere due to the disturbance of the arc. Thus, the fume emission rate should be lowered if the explosion of the droplet 12 is avoided and the disturbance to the arc is minimised. Thus, the present inventors looked for the principal cause of the explosion of the droplet 12. As a result, it has been found that the above-described explosion takes place when carbon contained in a wire electrode has undergone a reaction with oxygen in the arc atmosphere and has formed CO gas or CO₂ gas. Thus, the rates of generation of CO and CO₂ decrease as the

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soft steel sheath is converted into droplets, the explosion of droplets is minimised and the fume emission rate is thus lowered when the carbon content in the soft steel sheath is decreased.

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FIGURES 10 to 12 are respectively high-speed pictures (2000 frames/second) illustrating the manner of explosion of suspended droplets, when a flux-cored wire electrode made respectively of a soft steel sheath having carbon contents of 0.01, 0.04 and 0.08% respectively were used to conduct the welding. The droplet explosion becomes extremely violent as the carbon content is increased.

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As is readily understood from the above the carbon content in each flux should be minimised. As shown in FIGURE 6(A) and FIGURE 6(B), the flux core and the droplets separate easily and CO or CO₂, which may be generated from the flux core, does not significantly trigger the explosion of the droplets. Therefore, inclusion of carbon at a low level may be tolerated. It is however desirable to limit the carbon content in the flux below 0.2%, because any carbon content above the above-mentioned level promotes the explosion of droplets and hence increases the fume emission rate.

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As a sheath-forming soft steel useful in the practice of this invention, may be mentioned a cold-rolled or hot-rolled steel having a good deep drawability in view of its formability. As is apparent from the above, a soft steel containing as low a level of

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carbon as possible should be used. Since Mn, Si and the like act as deoxidisers and suppress the generation of CO and CO₂, it is preferable to add them. They reduce, however, the machinability if too much of them is included. Therefore, it is desirable to limit the Mn content and Si content to 2.0% or less and 1.0% or less respectively in the soft steel sheath.

The term "lubricant" as used herein means a drawing lubricant which is used when producing a flux-cored wire electrode. It is possible to use drawing lubricants of the higher fatty acid ester type (ie, the Na, K, Ca, Mg and Ba esters of higher fatty acids and the like), MoS₂-base lubricants, polytetrafluorethylene base lubricants, graphite-base lubricants, and all other conventionally known lubricants. These lubricants contain high levels of carbon. It is therefore necessary to use as little lubricant as possible in the course of each drawing operation so as to lower the amount of the lubricant adhering to the surface of the wire electrodes; or to subject the drawn electrode wires to baking, brushing, solvent-washing and the like so that the total carbon content of each sheath is kept below the prescribed level. However, the wire electrodes will not feed very well when carrying out welding work if the amount of lubricant left on the surface of the wire electrode is too little. Accordingly, it is advantageous to use a lubricant having a low carbon content (preferably 50% or lower). From this viewpoint, it is most preferable to use an MoS₂-base

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lubricant.

Turning now to the flux, it is preferable to provide a flux core comprising 10 to 30% based on the total weight of the wire electrode. If the proportion of the flux is lower than 10%, one cannot incorporate sufficient levels of metal powder and slag-forming agent. On the other hand, a proportion of flux in excess of 30% requires one to make the thickness of the soft steel sheath smaller. This reduces the rigidity of the wire electrode, resulting in poor feeding, reduced conductivity and arc-stability which induce the formation of undercuts and the like and makes it difficult to perform welding with large heat.

As illustrated in FIGURE 7, the fusing rate becomes greater and the fume emission rate tends to increase slightly as the proportion of flux becomes too high. Thus, it is desirable to limit the flux content below 20%. Therefore, it is desirable to limit the proportion of flux within the range of 10 to 20% of the total weight of each wire electrode. The sample wires, welding conditions and fume weight measurement method used in the experiment whose results are shown in FIGURE 7 were the same as those used in the experiments whose results are respectively shown in FIGURE 2 and FIGURE 3.

There is no limitation on the cross-sectional shape of each wire electrode. For example, it is feasible to form wire electrodes in the various cross-

sectional shapes illustrated in FIGURES 8(A), 8(B), 8(C) and 8(D). In the case of the shape (D) which does not contain any seam in the surface of the sheath, the surface of the wire electrode may be plated with Cu, Al (inclusive of an Al-Si alloy), Ni or Cr. Among these metals, use of Cu is desirable because Cu is relatively cheap and has excellent conductivity and corrosion resistance. This plating treatment is effective also in reducing the fume emission rate, because the plating lowers the fusing rate of the wire electrode. The weight of the plating is desirously from 0.05 to 0.30% by weight based on the total weight of each wire electrode. When applied to a thickness of 0.05% or thinner, the plating does not show any advantageous effect on rust resistance, ease of feeding, fume reduction and the like. If the weight percentage of the plating is higher than 0.30%, the productivity is reduced and the toughness of the welded metal is lowered. Therefore, the thickness of each plating should be controlled so that its weight proportion remains below the above-described upper limit. In addition, the diameter of each wire electrode may be chosen at will such as 1.2 mm, 1.6 mm, 2.0 mm, 2.4 mm, 3.2 mm and so on, depending what end use will be made on the wire electrode.

Preferred embodiments of the present invention are outlined above and these have made it possible to lower the fume emission rate per se to a considerable extent by adjusting the composition of the flux core and, at the same time, the carbon contents in the

soft steel sheath and any lubricant still remaining on the sheath. Therefore, the flux-cored wire electrode according to this invention has extremely practical advantages, including an improvement to the atmosphere of the welding site in effecting arc-welding work with a shielding gas and a reduction in the expense of fume-removing facilities.

Furthermore, Ar reduces the fume emission rate as illustrated in FIGURE 9. Accordingly, it is desirous to mix Ar gas in a shielding gas. Ar gas exhibits this effect when added in an amount of 80 wt% or more in the case of a CO₂-base shielding gas as illustrated in FIGURE 9.

An example of this invention will next be described.

Using sheaths of soft steels of the compositions given in Table 1 and flux cores having the compositions given in Table 3, flux-cored wire electrodes were produced. Lubricants given in Table 2 were also used. The carbon contents (relative to the total weights of sheath and lubricant) in the soft steel sheath and the residual lubricants after production of the wire electrodes are also given in Table 3. The diameters of the wire electrodes were each 1.6 mm and their flux contents were respectively 15 wt%. The wire electrode sample nos. 1 to 13 had the cross-sectional shape shown in FIGURE 8(A). The wire electrode sample no 14 has the cross-sectional shape depicted in FIGURE 8(B). On the other hand, the wire electrode sample no 15 had the cross-sectional

shape illustrated in FIGURE 8(D). In the case of the wire electrode sample no 15, a Cu plating was applied to a thickness of about 1 μ m on the surface of its soft steel sheath.

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Using the flux-cored wire electrodes set out above, bead-on-plate welding was conducted under the conditions given below. Fume emission rates were respectively measured in accordance with the same

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method as described above.

Welding conditions

Welding current: 300 A, DC(+)
 Welding voltage: 32 V
 Welding speed: 30 cm/min
 5 Shielding gas: CO₂, 20 liters/min
 Mother plate: 0.12% C, 0.29% Si,
 1.44% Mn, 0.020% P,
 0.008% S, balance iron.
 Distance between electrode tip and mother plate 17 mm

10 Results are shown in Table 4.

Table 1

Sheath-forming soft steel	C	Mn	Si	P	S
A	0.08	0.35	0.01	0.010	0.010
B	0.02	0.35	0.01	0.010	0.010
C	0.02	0.40	0.80	0.010	0.010

(unit: wt.%)

Table 2

Lubricant	Type
a	Salt of higher fatty acid (calcium stearate)
b	MoS ₂ :graphite:TiO ₂ = 3:4:3 (by weight ratio)
c	MoS ₂ :TiO ₂ = 4:6 (by weight ratio)

Table 3 Sample Wires

No.	Flux composition (% based on total flux weight)										Types of sheath and lubricant*				
	TiO ₂	SiO ₂	Al ₂ O ₃	ZrO ₂	Fe ₃ O ₄	MgO	Arc-stabilizing agent		Deoxidizer			Iron powder	Sheath metal (C-content %)	Lubricant (C-content %)	Total C- content (%)
							NaF	K ₂ SiO ₃	Fe-Si	Mn	Fe-Al				
1	40	5	0	0	1	0	2	0	10	15	0	27	A (0.08)	b (0.02)	0.10
2	40	10	6	4	1	2	1	0	10	15	0	11	A (0.08)	b (0.02)	0.10
3	40	7	4	2.5	1	2	2	0	10	15	0	17	A (0.08)	b (0.02)	0.10
4	45	10	4	4	1	2	0.5	0	10	15	0	8.5	A (0.08)	b (0.02)	0.10
5	40	0	2	0	3	0	5	2	15	10	0	23	A (0.08)	b (0.02)	0.10
6	40	5	0	0	1	0	2	0	10	15	0	27	B (0.02)	b (0.02)	0.04
7	40	0	2	0	3	0	5	2	15	10	0	23	B (0.02)	b (0.02)	0.04
8	40	10	6	4	1	2	1	0	10	15	0	11	B (0.02)	b (0.02)	0.04
9	40	10	6	4	1	2	1	0	10	15	0	11	B (0.02)	c (trace)	0.02
10	30	15	3	10	5	0.2	0	3	10	15	0	6	B (0.02)	b (0.02)	0.04
11	40	5	2	8	1	5	1	0	8	15	3	12	B (0.02)	b (0.02)	0.04
12	25	6	2	10	3	10	1	0	8	15	3	17	B (0.02)	a (0.01)	0.03
13	40	10	6	4	1	2	1	0	10	15	0	11	C (0.02)	c (trace)	0.02
14	40	10	6	4	1	2	1	0	10	15	0	11	B (0.02)	c (trace)	0.02
15	40	10	6	4	1	2	1	0	10	15	0	11	B (0.02)	a (0.01)	0.03

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Table 3 Sample Wires (Cont'd)

No.	Flux composition (% based on total flux weight)										Types of sheath and lubricant*			
	TiO ₂	SiO ₂	Al ₂ O ₃	ZrO ₂	Fe ₃ O ₄	HgO	Arc-stabilizing agent		Deoxidizer		Iron powder	Sheath metal (C-content %)	Lubricant (C-content %)	Total C-content (%)
							NaF	K ₂ SiO ₃	Fe-Si	Mn				
16	15	10	0	0	10	0	2	0	10	15	0	B (0.02)	b (0.02)	0.04
17	35	0	2	0	3	0	3	5	15	10	0	B (0.02)	b (0.02)	0.04
18	30	5	3	8	4	9	1.5	0	7	14	2	B (0.02)	b (0.02)	0.04
19	37.5	3	1	5	4	2.5	1	0	9	17	1	B (0.02)	b (0.02)	0.04
20	40	10	0	4	0	0	1	0	10	15	0	B (0.02)	b (0.02)	0.04
21	40	10	0	4	0	0	1	0	10	15	0	B (0.02)	c (trace)	0.02

* % based on the total weight of sheath

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Table 4

Wire electrode No.		Fume emission rate (mg/min)
1	Comparative Example	1380
2	Comparative Example	1174
3	Comparative Example	1242
4	Comparative Example	1103
5	Comparative Example	1585
6	Comparative Example	829
7	Comparative Example	951
8	Example	705
9	Example	602
10	Example	605
11	Example	640
12	Example	610
13	Example	603
14	Example	627
15	Example	615
16	Comparative Example	902
17	Comparative Example	1012
18	Example	607
19	Example	667
20	Example	756
21	Example	651

From the above experiment results, the following conclusions have been obtained:

- 5 (1) The wire electrode nos. 1 and 5 are comparative examples as their flux compositions and the carbon contents of their sheaths and lubricants were respectively outside their corresponding ranges specified in the present invention. Their fume emission rates were extremely high.
- 10 (2) The wire electrode nos. 2, 3 and 4 are comparative examples as their carbon contents were too much although their flux compositions were still within the flux composition range specified in the present invention. Compared with conventional flux-cored wire electrodes, their fume-reducing effects were limited to 10 to 20% only.
- 15 (3) The wire electrode nos. 6, 7, 16 and 17 are comparative examples because their flux compositions were outside the flux composition range specified in the present invention although their carbon contents satisfied the requirement specified in the present invention. Their fume-reducing effects were insufficient.
- 20 (4) The wire electrode nos. 8 to 15 and 18 to 21 were examples of this invention as each of the wire electrode samples satisfied the requirements specified in the present invention. Their fume emission rates were very low. In the wire electrode no. 13, the composition of the sheath forming soft
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steel had been modified slightly. In the wire electrodes nos. 14 and 15, their cross sectional shapes had been modified. High levels of fume reducing effects were respectively achieved in all of the wire electrode nos. 8 to 15 and 18 to 21.

Having now fully described preferred arrangements of the invention, it will be apparent that many changes and modifications can be made thereto without departing from the scope of the invention as set forth in the claims.

CLAIMS

1. A flux-cored wire electrode for use in gas-shielded arc-welding comprising a soft steel sheath surrounding a flux containing cavity wherein the sum of the carbon content of the soft steel sheath and the carbon content of a lubricant adhering to the sheath is 0.045 wt.% or less relative to the total weight of the sheath, the flux contains 20 to 50 wt.% of TiO_2 , 1 to 15 wt.% of SiO_2 , 2.5 to 10 wt.% of ZrO_2 , 0.1 to 5 wt.% of an arc-stabilising agent, 10 to 45 wt.% of a deoxidiser and iron powder present up to 50 wt.%, all based on the total weight of the flux, and the flux comprises 10 to 30 wt.% of the total weight of the wire electrode.
2. A flux-cored wire electrode for use in gas-shielded arc-welding comprising a soft steel sheath surrounding a flux containing cavity wherein the sum of the carbon content of the soft steel sheath and the carbon content of a lubricant adhering to the sheath is 0.045 wt.% or less relative to the total weight of the sheath, the flux contains 20 to 50 wt.% of TiO_2 , 1 to 15 wt.% of SiO_2 , 2.5 to 10 wt.% of ZrO_2 , 0.1 to 5 wt.% of an arc-stabilising agent, 10 to 45 wt.% of a deoxidiser, iron powder present up to 50 wt.%, 1 to 15 wt.% of Al_2O_3 , 0.1 to 10 wt.% of MgO and 1 to 10 wt.% of iron oxides, all based on the total weight of the flux, and the flux comprises 10 to 30 wt.% of the total weight of the wire electrode.
3. A flux-cored wire electrode as claimed in claim 1



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or 2, wherein the carbon content in the flux is 0.2 wt.% or less relative to the total weight of the flux.

5 4. A flux-cored wire electrode as claimed in claim 1 or 2, wherein the sheath is seamless and is plated to provide 0.05 to 0.30 wt.% relative to the total weight of the wire electrode.

10 5. A flux-cored wire electrode as claimed in claim 4, wherein the plating is copper plating.

15 6. A flux-cored electrode as claimed in any of claims 1 to 5, wherein the flux comprises 10 to 20 wt.% of the total weight of the wire electrode.

20 7. A flux-cored wire electrode as claimed in any of claims 1 to 6, wherein the lubricant is an MoS_2 -base lubricant.

25 8. A flux-cored wire electrode as claimed in any of claims 1 to 7, wherein the sum of the carbon content in the soft steel sheath and the carbon content in the lubricant adhering to the sheath is 0.02 wt.% or less relative to the total weight of the sheath.

30 9. A flux-cored wire electrode as claimed in claim 1 substantially as hereinbefore described in Examples 8 to 15 and 18 to 21 of Table 4.

10. A method of arc welding with a flux-cored wire electrode as claimed in any of claims 1 to 9, using a

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shielding gas comprising a CO₂ gas containing 80 wt% or more of Ar gas.

11. A method of arc welding with a flux-cored wire electrode as claimed in any of claims 1 to 9, using a shielding gas comprising CO₂ gas.
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