A NEW PROPOSAL FOR STEEL FILLER WIRE FOR WELDING (COMPLETE THESIS)*

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Contents

1. Introduction

Hitherto, steel wires, containing carbon below 0.15% and small amount of impurities, have been used as filler wires for welding ordinary steels. The elements, acting as deoxidizers, such as manganese and silicon are also conventionally identified with impurities. And it is believed that the less the quantities of these elements, the better the welding results obtained.

But fusion welding is a phenomenon of solidification after fusion of metal in the atmosphere. And if the weld steel is expected to possess high values of density and toughness, its oxygen content should be kept as small as possible. To lower this content, it is important in the first place to prevent the entry of oxygen into the weld and further remove with deoxidizers the oxygen which may slip in it despite precautions. To clarify the latter action, first of all, the author made a

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thorough study of the theory on the cooperative deoxidation of molten steel with manganese and silicon. This led him to a new idea. The idea is that it will be appropriate to obtain the weld steel holding a very low content of oxygen and suitable contents of Mn and Si by using steel filler wires containing somewhat larger quantities of deoxidizers such as Mn and Si.

Then the author prepared various kinds of steel filler wires containing Mn and Si by using electrolytic iron as raw material and performed with them experiments on arc welding with the results assuring that the new idea is hopeful. Further he had these steel filler wires manufactured semi-industrially under the sponsorship of the Yawata Iron & Steel Works and the Daidō Steel Mfg. Co., and as a result of experiments on arc- and gas-welding it was confirmed that the idea is very useful. Thereupon the author proposed new filler wires based on the idea and experimental results. Both the idea and the proposal gained support by Dr. S. Nishikiori, managing director of the Shin-Daidō Steel Mfg. Co. Ltd. And the company undertook production of the new steel filler wires in spring, 1949, sending the products to welding industrial circles including shipyards, rolling stock manufacturing plants, railways and so on. In view of the excellent results of examinations, the new wires went into practical use immediately and are now spreading over the whole heavy industry of Japan.

In this report, the author intends to outline the new idea and describe the results of experiments. Further, he is to show composition ranges of new wires being produced now, and cite the records of practical examinations and some examples of plants using the new wires.

2. A doubt about the low Mn- and Si-contents of conventional steel filler wires for welding mild steel

Up to this time, as for steel filler wires which have been used commonly for welding mild steel, the contents of Mn and Si, deoxidizing elements, are not higher than those of the ordinary steel. Table 1 shows the contents of elements contained in steel core wire, as specified by the present standards in Japan. Such tendencies are also found in America and Europe. That is to say, the manganese contents of steel wires for welding ordinary steel range from 0.30 to 0.65 percent and the silicon contents are below 0.08 percent.[1] [2] [3] [4] [5] [6] Though examples of steel wire being used whose contents are out of the limits of the above range are seen in America and Europe,[7] such cases are very rare and there is no theoretical explanation available. But the author conducted experiments some years ago and found that weld steels deposited with steel filler wires containing somewhat much deoxidizers are given good effects by the same deoxidizers under certain conditions.[8] [9]

Table 1. Contents of elements contained in core wires and wire rods for coated arc welding eleotrodes. [The Japanese Industrial Standards (JIS), G 3523 (1950)]

Wire classification number	Symbol	Contents of elements, %					
		C	Si	Mn	P	S	Cu
No. 1	SWY 1	0.10 max.	0.03 max.	0.35–0.65	0.020 max.	0.025 max.	0.20 max.
No. 2	SWY 2	0.10 max.	0.03 max.	0.30–0.60	0.030 max.	0.030 max.	0.30 max.
No. 3	SWY 3	0.10–0.15	0.03 max.	0.30–0.60	0.030 max.	0.030 max.	0.30 max.

Consequently, it is supposed that only in the case when the entry of oxygen into weld steel is successfully prevented by a thick coating or a gas producing type of coating, or in the case when a large amount of oxygen in weld steel is removed by deoxidizers mixed in coatings, steel core wires having low Mn- and Si-contents such as those shown in Table 1 may serve for the purpose. To obtain weld steel having large values of density and toughness, it is desirable that the cooperative action of the coating and the core wire be effective. The following is considered to be one of the appropriate measures to this end. Namely, if theoretically suitable quantities of deoxidizers, Mn and Si, are included in the core wires, and the effective deoxidation takes place in the course of welding, it will be practicable to adopt thin coatings and facilitate the manipulation of welding rods; and the manufacture of coated rod will become easier and the production cost can be reduced to considerable advantages because of unnecessariness of mixing deoxidizers in the coating.

3. Forms of deoxidation products separated from molten irons at a temperature just above the freezing point

F. Körber and W. Oelsen equilibrated FeO-MnO-SiO_2 slag and molten iron in a silica crucible, and researched into the silicon-equilibrium and the manganese-equilibrium.[10] Based on the results, they state that the two equilibria under FeO-MnO-SiO_2 slag saturated with SiO_2 can be expressed in the equations (A), (B) and (C),

for $$FeO + Mn \rightleftarrows MnO + Fe\,,\quad K^s_{Mn} = \frac{(\Sigma FeO)[Mn]}{(\Sigma MnO)} \quad \cdots\cdots\cdots (A),$$

for $$2FeO + Si \rightleftarrows SiO_2 + 2Fe\,,\quad K^s_{Si} = (\Sigma FeO)^2[Si] \quad \cdots\cdots\cdots (B),$$

for distribution of FeO in slag and metal,

$$L^s_{FeO} = \frac{[FeO]}{(\Sigma FeO)} \quad \cdots\cdots\cdots (C),$$

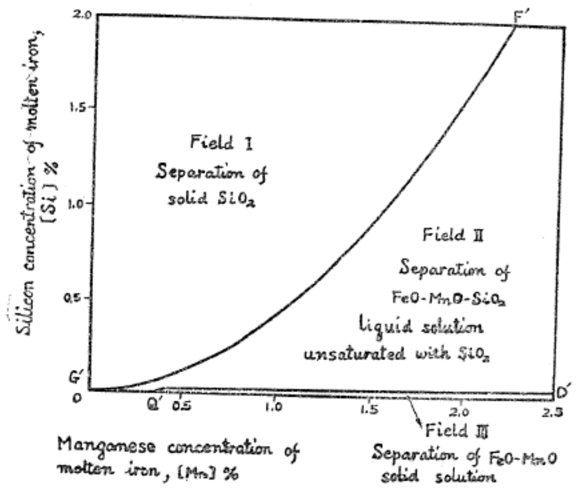


Fig. 1. Relation between composition of molten iron and forms of deoxidation products separated from the iron. (Equilibrium diagram at a temperature just above the freezing point of iron.)

where K^s_{Mn} and K^s_{Si} are respectively concentration constants for the manganese- and the silicon-equilibrium in the case of slag saturated with SiO_2; (ΣFeO) and (ΣMnO), respectively concentrations of total iron oxide and total manganese oxide in slag under the same condition; [Mn], [Si] and [FeO], respectively concentrations for manganese, silicon and iron-oxide dissolved in molten iron under the same condition; and L^s_{FeO}, the distribution constant of FeO between the molten iron and the slag under the same condition.

Moreover, they made clear that the relation between forms of deoxidation products, separated from molten irons at a temperature just above the freezing point, and Mn- and Si-contents of the molten iron is as shown in Fig. 1. Namely, in the case of molten irons expressed by one point in Field I, solid SiO_2 appears as a deoxidation product. And FeO-MnO-SiO_2 liquid solution unsaturated with SiO_2 appears in Field II. The curve $G'F'$ marks the boundary between the Fields I and II, and the curve $Q'D'$, the one between Fields II and III. In Field III, FeO-MnO solid solution appears as a deoxidation product.

4. The conditions for obtaining clean iron or steel

With the falling temperature of molten iron, the dissolved FeO, that is, oxygen becomes unstable for dissolved Si and Mn in it. Consequently, the reaction of deoxidation advances with cooling. The consumption of FeO occures also in the process of solidification: it occurs as follows because the composition of solidified metal differs from that of residual molten metal. In the first place, as the Mn- and Si-contents in the solidified metal are small, the contents of these elements in the residual molten iron rise. But the concentration ratio of the two elements in this case remains nearly the same as in the molten iron before solidification starts. Now in Fig. 2, let abscissa stand for the Mn-concentrations of molten iron just before solidification begins and ordinate for the Si-concentrations, and let compositions of molten irons be expressed with points, e.g. as the points X, Y, Z, U, V and W. Then the composition of each residual molten metal changes along the

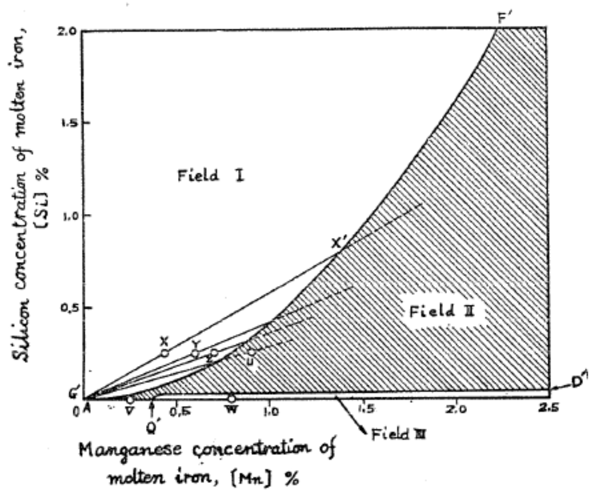


Fig. 2. The progress of deoxidation with Mn and Si in solidification of molten iron. (The curve $G'F'$ is constructed based on the results of calculation for 1510°C.)

extension of the straight line drawn approximately from the origin A to each composition point with progress of solidification. In this case, the Si- and Mn-contents in solidified iron are very small and its composition point exists in the neighbourhood of the origin A. If the Mn- and Si-contents of a certain molten metal just before solidification begins are given by the point X, firstly solid SiO_2 appears as the result of deoxidation reaction, and the Mn- and Si-contents in the residual molten iron increase along the line XX' with progress of crystallization. If the composition changes over the point X', FeO-MnO-SiO_2 liquid solution begins to appear in the residual molten iron. When the composition point of residual molten iron reaches the point X', the quantity of solidified metal is shown by the lever relation. That is, the following relation exists between the quantity of residual molten iron M_l and that of solidified metal M_s,

$$M_l : M_s = XA : XX',$$

where XA and XX' are respectively the length of the corresponding part of those straight lines. In this case, after solidification of 70 percent of the total metal, the liquid silicate solution separates itself from the residual molten metal. Similarly, in the case of molten iron Y which is located near the boundary $G'F'$, 40 percent of metal should solidify before the separation of molten silicate solution. As for the molten iron Z, 16 percent should solidify. With the molten iron U, however, the molten silicate solution appears in the residual molten iron from the very start of metal solidification. Next, as to the molten iron V, though the molten silicate solution emerges at the beginning of metal solidification, after some progress of this phenomenon, the composition of residual molten iron enters into Field III, and FeO-MnO solid solution appears in the residual molten iron. In the case of molten iron W, such solid solution appears from the start of metal solidification.

Though the deoxidation product is suspended in the molten iron in the state of high degree of dispersion at the beginning of separation, those particles of the product gradually rise to the surface of molten iron on account of the difference between their specific gravities and have a tendency to enter into the slag-layer. Accordingly, if the molten iron is held in liquid state for a long time, the deoxidation products escape out of the metal layer. But if the temperature of molten iron falls and at last solidification begins, numerous particles of deoxidation product appear again in the residual molten iron as mentioned previously. Usually enough time is not allowed for these particles to rise to the surface; so one part of deoxidation products is apt to remain in the metal.

Now if the form of particles of deoxidation product is assumed to be sphere, the rising-up velocity can be represented by the following Stoke's formulae,[11]

$$C=\frac{2}{9}gr^2\,\frac{S_M-S_D}{\eta}, \quad \text{or} \quad C=\frac{2}{9}g\left(\frac{3}{4}\,\frac{V}{\pi}\right)^{2/3}\frac{S_M-S_D}{\eta},$$

where

C : rising-up velocity of particles consisting of deoxidation product, cm/sec,
g : acceleration of gravity, 981 cm/sec^2,
η : coefficient of viscosity of molten iron,
S_M: density of molten iron, g/cm^3,
S_D: density of deoxidation product, g/cm^3,
r : radius of a particle consisting of deoxidation product, cm,
V : volume of a particle consisting of deoxidation product, cm^3.

Therefore, it is clear that the rising-up velocity of a spherical particle is directly proportional to square of the radius or 2/3 power of the volume.

If particles of deoxidation product are liquid, their form becomes sphere by surface tension and a large number of small particles tend to agglomerate into a small number of large particles. It means that each particle grows in radius or volume and rises quickly to the surface of molten iron. But if they are solid, they are generally needle-like crystals rather than spheres and difficult of agglomeration as mentioned above. Hence these particles can merely rise in molten iron at a very low velocity. This reason makes it desirable to have the deoxidation product in molten state.

Though Fig. 2 shows the results on Mn-Si-Fe alloys free from carbon, this is also applicable generally to industrial molten steel. Therefore, in order to secure rapid rising of the deoxidation product, it is essential to select the composition of molten steel in Field II in which liquid deoxidation product is found. And such selection is the decisive condition to obtain clean steel. If this condition is not satisfied, solid SiO_2 (in Field I) or FeO-MnO solid solution (in Field III) is separated from the molten metal. Such solids or crystals are fine and have a small tendency to agglomeration; so their rising velocity is small though these are separated from metal phase. Then they are easily caught among dendrites of metal, liable to stay unremoved. Hence it is difficult to obtain clean steel in this case.

5. Theoretical equations and explanatory diagrams showing the relations among Mn-, Si- and O-concentrations of molten irons in equilibrium

Referring to the thesis[10] published by Körber and Oelsen, the author derived the theoretical equations on deoxidation.[12] In this place, the abstract only is described.

As for the molten part of slag or deoxidation product saturated with SiO_2, the concentration of total silica (ΣSiO_2) is always about 50 percent.[13] Therefore, if we assume this to be constant, the following equations can be derived from the equations (A), (B) and (C) described in Section 3,

$$[\mathrm{FeO}] = \frac{50\, L^s_{\mathrm{FeO}} \cdot K^s_{\mathrm{Mn}}}{K^s_{\mathrm{Mn}} + [\mathrm{Mn}]} \quad \cdots\cdots\cdots (1),$$

$$[\mathrm{Si}] = \frac{K^s_{\mathrm{Si}} \cdot L^{s\,2}_{\mathrm{FeO}}}{[\mathrm{FeO}]^2} \quad \cdots\cdots\cdots (2),$$

$$[\mathrm{Mn}] = K^s_{\mathrm{Mn}} \left\{ 50 \sqrt{\frac{[\mathrm{Si}]}{K^s_{\mathrm{Si}}}} - 1 \right\} \quad \cdots\cdots\cdots (3).$$

The curve $G'F'$ in Fig. 1 and 2 is expressed by equation (3); and concentrations of oxygen, that is, concentrations [FeO] in the molten irons having the compositions in Field I by equation (2). In other words, [FeO] is decided only by [Si]. That is to say: if we show the equation (2) graphically, many straight lines being parallel to the abscissa (for example, ij) will be obtained in Fig. 3.

Moreover, according to Körber and Oelsen, it may be no great error to consider that the slag being in equilibrium with the molten iron, which is located below and near the curve $G'F'$, is rich in SiO_2 and is almost saturated with it. Consequently,

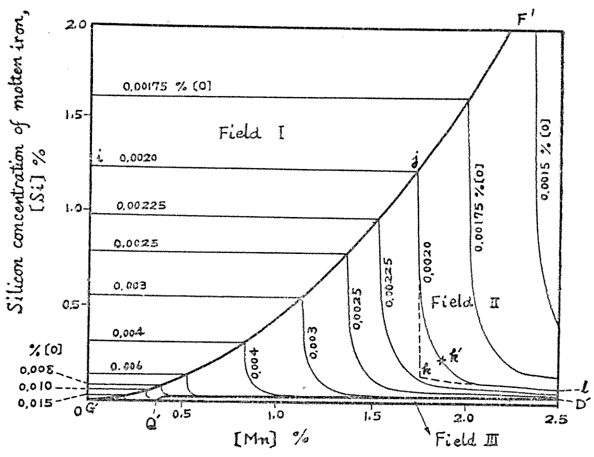


Fig. 3. Relation among oxygen-, manganese- and silicon-concentrations of molten iron in the state of equilibrium at 1510°C. (Straight lines in Field I and curves in Field II show iso-concentration-lines for oxygen.)

in the part near the curve $G'F'$ of Field II, equation (1) is applicable approximately. Namely, upper parts of iso-oxygen-concentration curves in Field II of Fig. 3 (for example, jk) are expressed by equation (1). In other words, concentrations of oxygen depend only upon [Mn]-concentrations.

In the lower part of Field II in Fig. 3, that is, in the part situated near the boundary $Q'D'$, equation (1) can not be applied to express iso-oxygen-concentration lines, because of the slag in equilibrium with the molten iron being far from the condition "to be saturated with SiO_2." So, using the equation[14] derived by H. Schenck and the following equation,

$$(\mathrm{FeO}) = \frac{[\mathrm{FeO}]}{L_{\mathrm{FeO}}},$$

the author derived the equation (4), which is regarded as the one determining the iso-oxygen-concentration lines in this part,

$$[\mathrm{Si}] = K_{\mathrm{Si}} \frac{100 - \left(\frac{[\mathrm{FeO}]}{L_{\mathrm{FeO}}}\right)\left(1 + \frac{[\mathrm{Mn}]}{K_{\mathrm{Mn}}}\right)}{\left(\frac{[\mathrm{FeO}]}{L_{\mathrm{FeO}}}\right)^2 + \left(\frac{[\mathrm{FeO}]}{L_{\mathrm{FeO}}}\right)^4 \left(\frac{1}{D_{(\mathrm{FeO})_2\mathrm{SiO}_2}} + \frac{[\mathrm{Mn}]^2}{K_{\mathrm{Mn}}^2 \cdot D_{(\mathrm{MnO})_2\mathrm{SiO}_2}}\right)} \cdots\cdots (4),$$

where [Mn], [Si] and [FeO] are concentrations of these elements or compound dissolved in molten iron; K_{Mn} or K_{Si}, respectively the equilibrium constant for deoxidation reaction with Mn or Si; L_{FeO}, the distribution constant of FeO for molten irons and slags in the case in which concentrations of SiO_2 in the slags are very small; and $D_{(\mathrm{FeO})_2\mathrm{SiO}_2}$ and $D_{(\mathrm{MnO})_2\mathrm{SiO}_2}$, respectively dissociation constants.

From the equations (1) and (4), iso-oxygen-concentration lines in Field II in Fig. 3 are constructed as jkl for example. But in the neighbourhood of the point k at which the line jk representing the equation (1) and lk representing the equation (4) intersect, application of equation (1) is unsuitable, because the slag in equilibrium with molten iron is in the state far from satisfying the condition "to be saturated with SiO_2." Again, as somewhat much SiO_2 is dissolved in the slag corresponding to the part, the equation (4) is also inapplicable. Accordingly it is considered that the iso-oxygen-concentration line does not pass the point k and takes the form such as $jk'l$.

K^s_{Mn}, K^s_{Si}, L^s_{FeO}, K_{Mn}, K_{Si}, L_{FeO}, $D_{(FeO)_2SiO_2}$ and $D_{(MnO)_2SiO_2}$ are respectively functions of temperature, and were determined and reported by many researchers as follows,

$$\left.\begin{array}{ll} \log K^s_{Mn} = -\dfrac{7940}{T} + 3.172 & \cdots\cdots\cdots(a) \\ \log K^s_{Si} = -\dfrac{19057}{T} + 11.101 & \cdots\cdots\cdots(b) \\ L^s_{FeO} = 3.8\times10^{-5}t - 0.0512 & \cdots\cdots\cdots(c) \end{array}\right\} \text{Results[15) measured on FeO-MnO-SiO}_2 \text{ slag saturated with SiO}_2 \text{ by Körber-Oelsen,}$$

$$\left.\begin{array}{ll} \log K_{Mn} = -\dfrac{6234}{T} + 3.026 & \cdots\cdots\cdots(d) \\ L_{FeO} = 0.588\times10^{-4}t - 0.0793 & \cdots\cdots\cdots(e) \end{array}\right\} \text{Results[16) measured on FeO-MnO slag by Körber-Oelsen,}$$

$$\left.\begin{array}{ll} \text{og } K_{Si} = -\dfrac{11106}{T} + 4.50 & \cdots\cdots\cdots(f) \\ \log D_{(FeO)_2SiO_2} = -\dfrac{11230}{T} + 7.76 & \cdots\cdots(g) \\ \log D_{(MnO)_2SiO_2} = -\dfrac{18880}{T} + 10.77 & \cdots(h) \end{array}\right\} \text{Results[17) measured by Schenck-Brüggemann,}$$

where T is an absolute temperature represented by °C and t is a temperature represented by °C. At a constant temperature, these functions are constants. The author calculated these constants for 1510°C using the above-mentioned equations (a)$\sim$(h), and put them in equations (1)$\sim$(4), thus drawing the boundary curve $G'F'$ and a number of iso-oxygen-concentration lines in Fig. 3.

6. Mn- and Si-concentrations which weld metal deposited on steel should have just before solidification begins

Considering the action of atmospheric oxygen in the course of welding steel, it is necessary to prevent its entry into molten iron in order to avoid the bad effects and obtain excellent welded parts, but it will be effective further to induce forced deoxidation. In effecting forced deoxidation, it is important to consider as follows, based on "the condition for obtaining clean steel" described in Section 4 and "the relations among concentrations [Mn], [Si] and [O] of molten iron in equilibrium state" described in Section 5.

(A) Molten iron produced by welding has a comparatively high temperature, and cools after the pass of electric arc or flame, finally starting to solidify. Oxygen in the atmosphere is apt to steal into the molten iron during the process from deposition to solidification. Consequently, when deoxidizers exist already in the molten iron or are supplied to it from coating or slag, the reaction of deoxidation takes place, and its product separated from metal phase is apt to enter into a slag layer. But if the product is solid SiO_2 or solid solution FeO-MnO, owing to the small tendency to agglomeration, floating of the product goes sluggish. When the rates of cooling and solidification of weld steel are high, the solidification is completed before the escape of the product is completed, and a large number of non-metallic inclusions are left. Accordingly, for obtaining clean weld steel, it is required that the molten steel produced by welding does not separate solid deoxidation product from its own phase, in higher temperature states just after deposition, in the midst of cooling to the freezing point and also in the process of solidification. That is to say, the composition-point showing Mn- and Si-concentrations in weld steel should be located in Field II of Fig. 3 in higher temperature states, in the midst of the cooling and also in the interval of solidification.

(B) Next, from the order of arrangement of iso-oxygen-concentration lines in Field II of Fig. 3, it can be understood that if the composition point of molten iron is located farther to the upper or the right or the upper right, its oxygen concentration is lower in equilibrium state. For this reason, to secure higher density, sufficient elongation and excellent impact value of solidified weld steel by lowering its oxygen content, it is desirable that the Mn- and Si-concentrations of molten steel just before solidification be on a high level.

(C) But on the other hand, if the contents of Mn and Si remaining in solidified weld steel are higher, the weld steel will become stronger, harder and more brittle owing to their alloying-effects.

(D) It can be surmised that though the density and elongation of weld steel increase with the increase in Mn- and Si-contents owing to the effect (B), its elongation decreases on the other hand by the effect (C).

Accordingly, the most excellent properties will be obtained in the case of weld metal having suitable contents of Mn and Si. And in the case of arc welding, the position in Field II of composition point of a suitable weld steel just after deposition will differ, depending upon the conditions of coating (namely, compositions of slag-forming materials, contents of reducing-gas producing materials[18] or deoxidizers), quantity of coating (thin or thick), arc length (long or short), manipulation of rod and so on. In the case of gas welding, the position of such composition point will be different with adjustment of flame, manipulation of the torch and filler wire and so on.

To sum up, under the condition that considerable amount of oxygen enters into the molten weld, high initial contents of Mn and Si in molten steel are desirable; but under the condition of slight entry of oxygen, it is considered that the lower initial contents of these elements suffice for the purpose.

7. A new idea of steel filler wire for welding

To obtain excellent weld steel, it is necessary to satisfy the conditions mentioned in Section (6). And the author considered it as a suitable method of obtaining such weld steel to select the composition of filler wire for welding as follows:

(a) to take the composition point showing Mn- and Si-contents of steel filler wire for welding from within Field II of Fig. 3,

(b) to hold Mn- and Si-contents of steel filler wire properly in higher concentration depending on the composition and quantity of covering.

As stated in Section (2), Mn- and Si-contents of the usual steel filler wire are generally low. And if we show the Mn-range (0.30–0.65%) and Si-range (0.03% max.) of Table 1 in Fig. 4, the rectangle *abcd* is constructed in the neighbourhood of the origin. Even with such steel filler wire, if a covering of suitable thickness con-

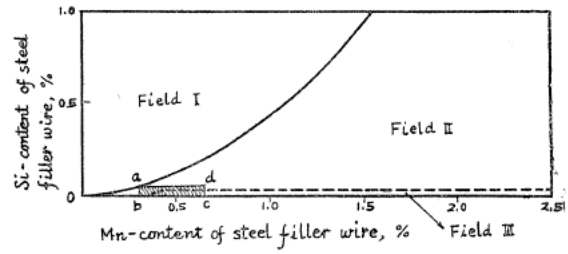


Fig. 4. Range of Mn- and Si-contents of steel filler wires prescribed by JIS. G 3523.
Remarks: Rectangle *abcd* shows the range.

taining reducing-gas producing materials or deoxidizers is provided on the wire, the property of the weld metal obtained will be excellent because it may have a low content of oxygen. But, when the covering has no reducing-gas producing material or no deoxidizer, or when a thin coating is done for the sake of convenience in usability, the above mentioned steel filler wire will be unsuitable and the one having higher contents of Mn and Si will be better. But, if the Mn- and Si-contents of steel filler wire become higher, its electric resistance becomes larger. If such a wire is used without covering, deterioration of arc-phenomena may follow. But in the case of coated electrodes, as important factors influencing the arc-phenomena are mainly connected with the covering, it is inferred that no obstruction may be caused, unless filler wires having extraordinary high contents of Mn and Si are used.

Steel filler wires are rarely found, with composition points located far out of the rectangle *abcd*, in the upper part beyond the curve $G'F'$, that is, in Field I in Fig. 4, and as is clear by the description in Section 4 such steel filler wires are not suitable to produce clean weld steel.

In the manufacture of welding rods for high tensile steel or hard steel, easy production of the excellent ones seems possible by providing some suitable covering with ferro-alloy or other elements on core wires having adequate contents of Mn and Si.

The author considers that the two items (a) and (b), which give his new idea of steel filler wires for welding, are also important and useful in the case of steel filler wires for gas welding and submerged arc welding.

8. Experiments on arc welding with steel core wires made in the laboratory

Using electrolytic iron as raw material, many kinds of steel core wires having various contents of Mn and Si were prepared. Then different covered electrodes were prepared by making coverings of various compositions on these core wires. By means of these electrodes, weaving beads were deposited on mild steel plates and the outward appearances of these beads were observed. And the following results were gained.[19]

(A) When the Si-content of a core wire is as high as in Field I of Fig. 5, small holes appear, having each opening on the surface of bead. This trend is more obvious with increase of the Si-content of core wire.

(B) When CaF_2 is contained in the covering and the Si-content of the core wire is on a certain high level, the said tendency is observed in a core wire, too, whose composition point falls in Field II.

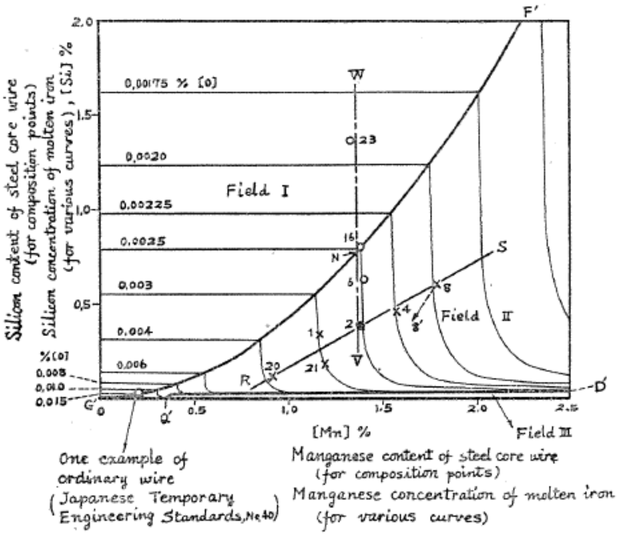


Fig. 5. Positions of composition points showing Mn- and Si-contents of steel core wires made in the Laboratry. (Note: Points × or ○ are composition points. Curve $G'F'$ and $Q'D'$ and iso-oxygen-concentration lines are the same as in Fig. 3.)

Table 2. Composition of a covering mixture (A), %

Limestone	Silica	Manganese dioxide	Ilmenite	Ferric oxide	Alumina	Soluble starch
15	15	15	26	12	7	10

Remarks: 30 cc water-glass (30° Baumé) is added to 100 grammes of this mixture as a binding material.

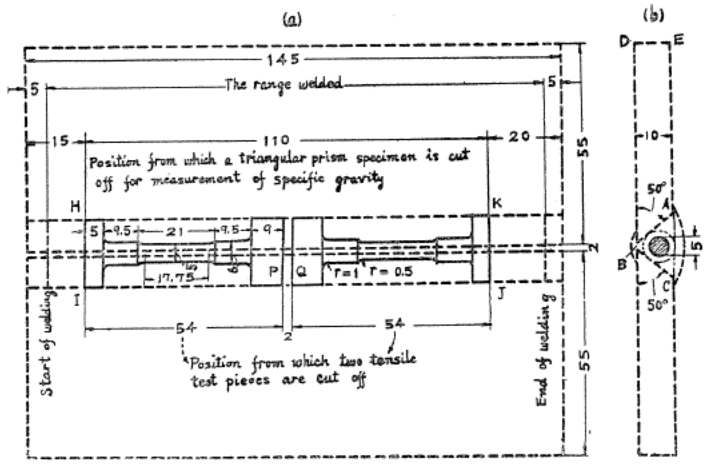
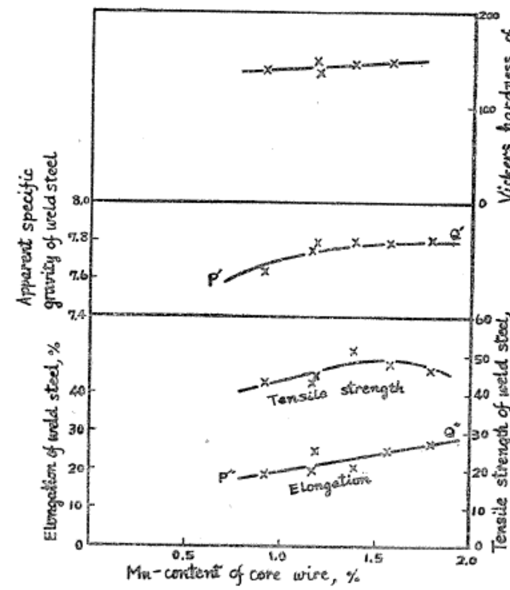


Fig. 6. Bevel angle, groove angle, and root opening before butt-welding of mild steel plates, and forms of specimens cut off after welding.

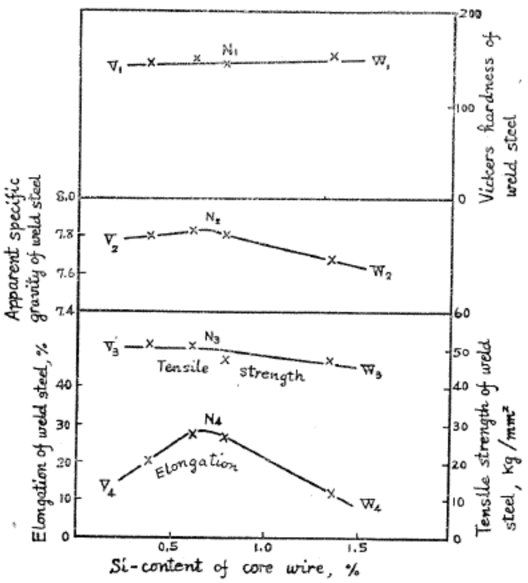
Next, welding rods were prepared by coating various core wires with the covering whose composition is represented in Table 2. By these electrodes two steel plates situated in V-butt state as shown by dotted lines in Fig. 6 were arc-welded. Then small tensile test specimens were taken out of the V-shape weld part as shown in the same figure, and mechanical properties were measured. The outstanding tendencies recognized are as follows.

(C) When the core wire, whose composition point is located in the neighbourhood of the straight line RS in Fig. 5, is used, the elongation and the apparent specific gravity of weld steel deposited by it increase with the increase in Mn-content (accordingly, Si-content) of the core wire as shown in Fig. 7.

(D) When the core wire, whose composition point is located in the neighbourhood of the straight line VW in Fig. 5, is used, the elongation and the apparent specific gravity increase first with the increase in Si-content, and reach maximum values at the Si-content indicated by the point N_4 (or N_2) in Fig. 8. The two properties of weld steel deteriorate



↑ Fig. 7. Relation between Mn-content and properties of weld steel (in the case when composition points showing Mn- and Si-contents are located in the neighbourhood of the straight line RS in Fig. 5).



← Fig. 8. Relation between Si-content and properties of weld steel (in the case when composition points showing Mn- and Si-contents are located in the neighbourhood of the straight line VW in Fig. 5).

on the contrary with the further increase in Si-content beyond the point N_4 (or N_2). And the Si-content represented by N_4 (or N_2) in Fig. 8 corresponds to the Si-content represented by N, the point of intersection of the curve $G'F'$ and the straight line VW in Fig. 5.

The phenomenon (A) and the tendencies represented by N_4W_4 and N_2W_2 in Fig. 8 seem to be due to the separation of solid SiO_2 (deoxidation product) from molten iron phase and its remaining in solidified weld steel owing to the difficulty of floating; and the phenomenon (B) is supposed to be connected with the generation of SiF_4 gas. The tendencies indicated by $P''Q''$ and $P'Q'$ in Fig. 7 and also by V_4N_4 and V_2N_2 in Fig. 8 are supposed to be caused by the decrease in oxygen, accompanying the increase in Mn- and Si-concentration in iron as shown by the arrangement of iso-oxygen-concentration lines in Fig. 5. In short, these facts prove that the author's new idea mentioned in Section 7 is reasonable.

9. Experiments on arc welding with steel core wires manufactured in plants

To ascertain whether the hopeful tendencies recognized in the previous section exist with steel core wires manufactured semi-industrially, the following experi-

Table 3. Composition of a covering mixture (B), %

Limestone	Silica	Manganese dioxide	Ilmenite	White asbestos	Dextrine
15	15	15	30	15	10

Remarks: 35 cc water-glass (30° Baumé) is added to 100 grammes of this mixture as a binding material.

Table 4. Core wires for arc welding rods and properties of all-deposited metals

Steel core wire					Properties of all-deposited metal					
Symbol	Field*	Content, % Mn	Content, % Si	Saturation** value of oxygen, %	Apparent specific gravity	Elongation,*** %	Charpy impact value, mkg/cm²	Rockwell hardness, (B-Scale)	Ultimate*** tensile strength, kg/mm²
A		0.27	0.05	0.0150–0.0080	7.6748	15.6	9.5	64.9	37.5
M	II	1.21	0.30	0.0030–0.0025	7.7896	23.7	13.1	82.5	53.3
R	II	1.32	0.16		7.8260	23.1	12.5	82.0	53.9
N	II	1.36	0.36		7.8066	26.6	12.9	85.3	53.6
O	II	1.40	0.35		7.8001	23.7	11.6	79.8	52.8
P	II	1.44	0.41	0.0025–0.00225	7.8095	27.5	14.6	79.0	52.7
G	II	1.64	0.09		7.8279	30.3	14.3	81.7	53.7
S	II	1.49	0.56		7.8189	32.2	18.1	78.9	50.9
T	II	1.64	0.66	0.00225–0.00200	7.7855	21.0	15.3	91.3	55.9
B		1.26	0.65	0.00300–0.00225	7.8136	21.6	15.9	84.2	54.2
D	I	0.93	0.78		7.7889	12.4	12.9	75.3	47.7

Remarks: * Field in which each composition point showing Mn- and Si-contents of steel core wire is located (See Fig. 9).

** Saturation value of oxygen content in each molten iron whose contents of Mn and Si are equal to those of the core wire used [at a temperature (1510°C) just above the freezing point].

*** Dia. of tensile test piece = 10 mm, Gauge length = 35 mm.

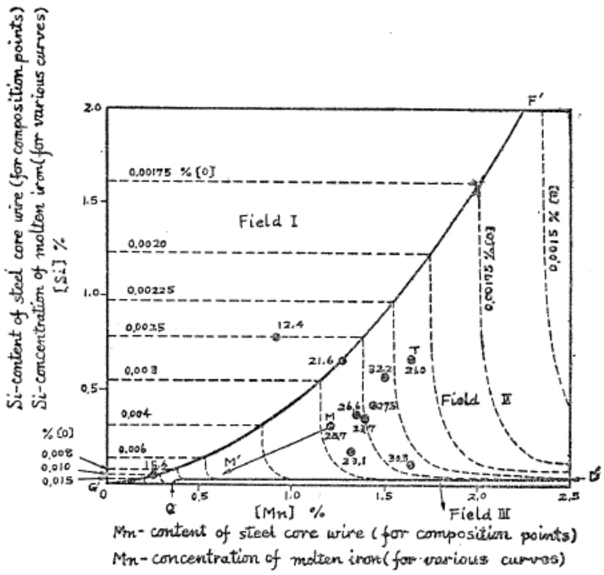


Fig. 9. Relation between properties of weld metals and composition points showing Mn- and Si-contents of core wires used.

Note 1: Black points: Composition points. Dotted lines: Iso-oxygen-concentration lines. Figures near black points: Elongation values of weld metals obtained with the coated wire whose core wire composition is shown by the black point.

Note 2: The composition of core wire (e.g. M) changes to the composition of weld metal (e.g. M') in the case of welding.

ments[20] were performed. Firstly, many steel core wires having various contents of Mn and Si were prepared by rolling and drawing of steel made in electric arc furnaces.* The Mn- and Si-contents of core wires are seen in Table 4 and their composition points shown in Fig. 9. The intended limitations for the contents of other various elements in steel core wires were as follows:

$<0.15\%$ C, $<0.035\%$ P, $<0.035\%$ S, $<0.3\%$ Cu, $<0.3\%$ Ni, $<0.2\%$Cr.

Some core wires, however, got out of the limitations. Though the author desired to substantially lower the limit of these impurities, it could not be realized on account of the scrap situation in post-war Japan.

Then, arc-welding rods were made of these wires (4 mm dia.) which was coated with a mixture having the composition shown by Table 3 at the rate of 10 g for every 38 cm length of the wire. This mixture is the one improved on the covering "A" of Section 8.

Using such covered rods, mechanical properties of weld metals (all-deposited metals) were investigated in accordance with the examination procedure of the Japanese Engineering Standards JES 9001[21] (dia. of tensile test piece: 10 mm, gauge length: 35 mm). Moreover, their apparent specific gravities were measured by the dip method. These results are shown in Table 4. Then the author imagined

* Cooperated by the Hoshizaki plant of the Daidō Steel Mfg. Co., and the Yawata works of the Japan Iron and Steel Co.

the molten irons whose contents of Mn and Si are equal to those of core wires, and estimated the saturation value of the oxygen content for each kind of such molten irons, that is, for each core wire, on the basis of the relations between the composition point of the wire and the iso-concentration curves for oxygen in Fig. 9. Values given in the column "Saturation Value of Oxygen" of Table 4 are estimated in this way. The relations between the saturation value and the properties of weld metal are shown in Fig. 10.

In Fig. 9, to clarify the relations between Mn- and Si-contents of core wire and elongation of all deposited steel, the elongation value is inserted in the neighbourhood of the composition point of the core wire used for the deposition. Of course, Mn- and Si-contents change in the process of welding. For example, a given composition of steel changes from the point M in a core wire to the point M' in the solidified weld deposited with the core wire. A similar consideration must be given to observations in Fig. 10. For example, the movement of the point P toward the direction PP' should be considered. If similar graphical method as shown in Fig. 9 is applied to other properties given in Table 4 and each explanatory figure is made, it will be convenient for understanding the tendencies on properties. In this paper, such treatments are omitted for want of space.

From Fig. 9, Table 4 and Fig. 10, the following tendencies can be noticed.

(A) Under the condition that the composition points showing Mn- and Si-contents of the core wire fall in Field II of Fig. 9, the increase in either Mn or Si or both elements (in other words, the decrease in saturation value of oxygen for the core wire) elevates the apparent specific gravity, elongation and impact value of the weld metal deposited with the covered welding rod.

(B) However, if the Mn- and Si-contents of the core wire become too high (as in the case of the wire T), these properties of the weld metal may deteriorate

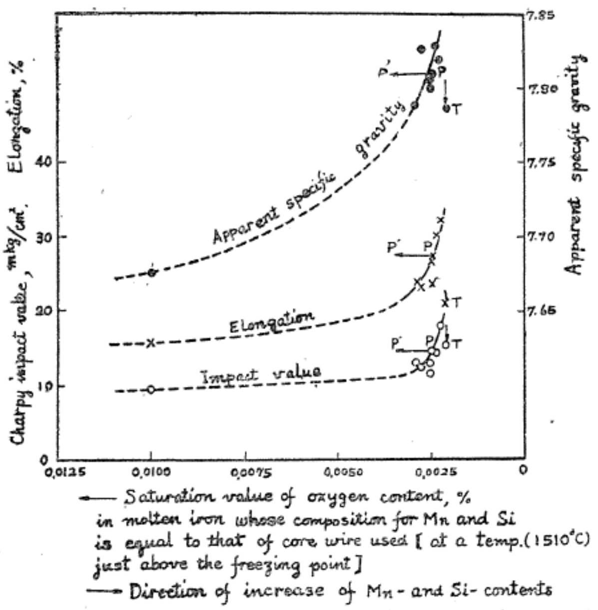


Fig. 10. Relation between properties of all-deposited metal and saturation value of oxygen content of core wire used.

on the contrary as might be interpreted from Fig. 9 or Fig. 10.

But, as such tendency is not recognized in the steel core wires made from electrolytic iron as shown in Fig. 7, in the case of steel core wires manufactured semi-industrially, it may be assumed that maximum values of various properties asserted themselves at the lower Mn- and Si-contents of the core wire owing to somewhat great quantity of impurities.

(C) The elongation and impact values of weld steel obtained from the core wire with its composition point falling in Field I of Fig. 9 are smaller than the value obtained from the one with its composition point falling in the neighbourhood of the same iso-concentration-curve for oxygen in Field II.

(D) The ultimate tensile strength and hardness of weld steel increase with the Mn- and Si-contents of the core wire used.

When the covering of such composition as produces a slag unsaturated with SiO_2 is used, it can be supposed that if the composition point showing the Mn- and Si-contents of steel core wire is within Field II, the composition point of the weld steel deposited with it will probably be also found in Field II. Therefore, the tendencies (A) and (C) can be understood readily by referring to the consideration described in Items (B) and (A) of Section 6. And the tendencies (B) and (D) can be understood easily on the basis of the idea that Mn and Si harden and embrittle the iron which contains them.

Next the author made T-form specimens having a one-layer fillet weld on one side and having a higher cooling rate than that of all deposited metals mentioned above, and made thorough investigation of the bead appearance. Then he examined the fracture of the fillet weld which was broken for test purpose. As a result the following facts were known.

(E) In the case of using steel core wires containing silicon more than 0.3 percent, holes having opening on the surface of bead is apt to yield, and portions with the so-called "striated structures" often emerge in weld metal and moreover minute cracks occasionally develop in some of these portions.

10. Experiments on gas welding with steel filler wires manufactured in plants

Using bare steel filler wires *M, V, Q, R, J, S* and *G* manufactured semi-industrially, the author performed experiments on gas welding.[22] The ordinary wire in conventional use for gas welding, was also tested for the purpose of comparison. Table 5 gives symbols of welding wires, of which A_2 stands for the ordinary wire. Composition points of Mn- and Si-contents of these wires are shown in Fig. 11. Using these filler wires and in accordance with the tentative specification for iron and steel gas welding rods[23] in U.S.A., oxy-acetylene gas welding of 3/4″ (19 mm) thick mild steel plates with 0.18% carbon was carried out. And on test pieces prepared in accordance with the same specification, tensile tests were conducted. The results are shown in Table 5.

On the other hand, bend tests of joint-welded 3/8″ (9 mm) thick mild steel plates were also performed according to the same specification. In any of the wires shown in Table 5, no cracks (or defects with opening) of larger size than the one prescribed by the specification were found on a convex U-shaped surface bent at about 180° by the face bend or by the root bend test.

Table 5. Contents of elements contained in gas welding wire and mechanical properties of weld steel

Symbol	Welding wire: Content, %			Mechanical properties of weld steel*: Treatment after welding, NSR		Treatment after welding, SR	
	C	Mn	Si	Ultimate tensile strength, kg/mm²	Elongation, %	Ultimate tensile strength, kg/mm²	Elongation %
A_2	0.10	0.35	0.02	35.3	23.8	34.3	23.1
M	0.15	1.21	0.30	46.4	15.7	45.6	24.0
V	0.15	1.26	0.12	46.9	18.1	47.5	21.5
Q	0.15	1.32	0.20	44.5	16.4	45.1	22.4
R	0.10	1.32	0.16	44.4	15.0	44.9	24.0
J	0.15	1.41	0.19	45.9	15.9	47.0	27.0
S	0.13	1.49	0.56	49.5	18.1	50.4	23.2
G	0.15	1.64	0.09	48.8	16.6	48.2	22.1

Remarks: NSR shows the case as weld,
SR shows the treatment: low temperature annealing (625°C, 1 hr) after welding, and slow cooling.
* Dia. of tensile test piece = 12.7 mm, gauge length = 50.8 mm.

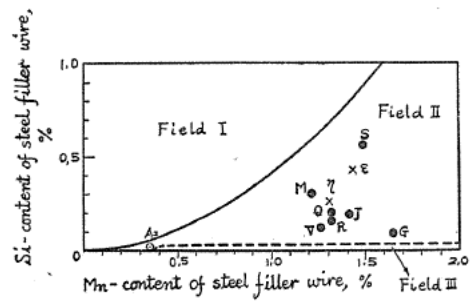


Fig. 11. Mn- and Si-contents of steel filler wire.

Remarks: ◉ point—Ordinary filler wire, used in the experiments of section 10.

● and × points—Filler wires containing more than usual amounts of Mn and Si.

● points—Filler wires used in the experiment of section 10.

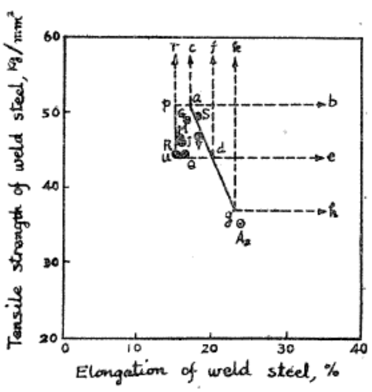
× points—Filler wires used in the examination at the Kawasaki Shipyards.

Table 6. Conditions of gas welding

Kind of test	Thickness of plate, mm	Dia. of welding wire, mm	No. of nozzle	Pressure of oxygen, kg/cm²	Pressure of acetylene, cm (water column)	Welding speed, m/hr: 1st layer	2nd layer	3rd layer	4th layer	5th layer
Tensile	19	4.77	2000	3.0	150	3.7	2.6	1.7	1.2	0.9
Bending	9	4.77	750	2.0	100	5.1	3.8	3.1	2.5	—

Gas welding conditions adopted by the author, in the case of V-shape butt-welding to make tensile test pieces and bend test pieces, are shown in Table 6. And weaving beads were made by the rightward welding technique in this case.

The results of these experiments follow. Both the conventional wire (A_2) and the wires containing Mn and Si (*M, V, Q, R, J, S, G*), when used for gas welding, easily passed the bend tests provided in the specification and there was no considerable difference between them. But as for tensile tests, the results obtained with two kinds of wire mentioned above proved different from each other. If the results of experiments are shown by figures taking ultimate tensile strength as ordinate and elongation as abscissa, a number of points in Fig. 12 and Fig. 13 are



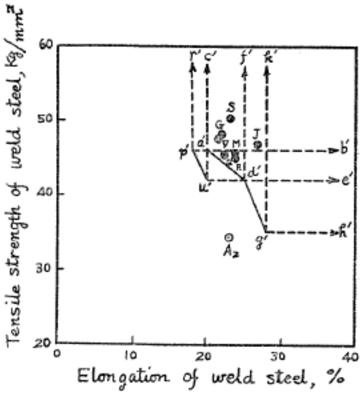


Fig. 12 (*left*). Experimental results of weld steels (non-stress relieved) and ranges of passing for GA and GB rods.

Remarks:	Kind and grade of wire	Range of passing
	GA 65	upper side of *ab* & right side of *ac*
	GA 60	upper side of *de* & right side of *df*
	GA 50	upper side of *gh* & right side of *gk*
	GB 65	upper side of *pb* & right side of *pr*
	GB 60	upper side of *ue* & right side of *ur*

Fig. 13 (*right*). Experimental results of weld steels (stress relieved) and ranges of passing for GA and GB rods.

Remarks:	Kind and grade of wire	Range of passing
	GA 65	upper side of *a′b′* & right side of *a′c′*
	GA 60	upper side of *d′e′* & right side of *d′f′*
	GA 50	upper side of *g′h′* & right side of *g′k′*
	GB 65	upper side of *p′b′* & right side of *p′r′*
	GB 60	upper side of *u′e′* & right side of *u′c′*

obtained; the symbols GA 65, GA 60, GA 50, GB 65 and GB 60 added in the remarks of the two figures give the combined indication of the kind (GA or GB) and the grade (65, 60 or 50) of the gas welding wire as classified under the specification. In order to qualify a welding wire for a certain kind and grade, the ultimate tensile strength and elongation of weld steel obtained with the wire must exceed the value provided by the specification. In Fig. 12 and Fig. 13, these ranges for qualification are shown in the remarks. When both figures are observed with these remarks in mind, it is seen at once by the relations between the positions of measured points and dotted lines whether welding wire used for the experiment meet the requirements of a certain kind and grade as prescribed in the specification or not.

For example, in Fig. 12, as the point A_2 is not placed to the upper right of *cab*, *fde*, *kgh*, *rpb* and *rue*, the A_2 wire does not satisfy any requirements of GA 65, GA 60, GA 50, GB 65 and GB 60 in the non-stress relieved condition. Therefore it follows that the A_2 wire does not pass any qualifying examination for these kinds and grades. And in Fig. 13, as the point J is to the upper right of $c'a'b'$, $f'd'e'$, $r'p'b'$ and $c'u'e'$, the J-wire satisfies the requirements of GA 65, GA 60, GB 65 and GB 60 in the stress-relieved state. But as the point J is not to the upper right of *k'g'h'*, the *J*-wire is unable to satisfy the requirements of GA 50 in the stress-relieved state.

In order to qualify for a certain kind and grade of welding wire provided by the specification, the filler wire must satisfy the requirements of both cases of "non stress relieved" and "stress relieved." Now in Fig. 12, it is seen that the *J* point stands to the upper right of *rue* only but not of *cab, fde, kgh* and *rpb*. So of course the *J*-wire can not pass for GA 65, GA 60, GA 50 and GB 65; but it will be good for GB 60 alone.

After inspection of Fig. 12 and Fig. 13 in this way, the following things can be found.

(A) The ordinary welding wire A_2 does not satisfy the requirements of any kind and grade in the case of non stress relieved specimen as well as in the case of stress relieved specimen. Accordingly, the A_2 wire is not good for any kind and grade.

(B) The welding wires *R, Q, J, M, V, G* and *S*, to which more than usual amount of Mn and Si is added intentionally, satisfy the requirements of GB 60 in the "non stress relieved" state (these points are located to the upper right of *rue* in Fig. 12), also of GB 60 in the "stress relieved" state (these points are located to the upper right of *c'u'e'* in Fig. 13). This implies that these wires are acceptable for GB 60.

(C) The welding wires *V, G, S* and *J* satisfy the requirements of GA 65 and GB 65 in the "stress relieved" state (see Fig. 13); but not the requirements of GA 65 and GB 65 in the "non stress relieved" condition (see Fig. 12). Hence these wires are not acceptable for these kinds and grades.

Judging from the above description, it is clear that the wires which contain more than usual amount of Mn and Si make excellent gas welding rods in comparison with the ordinary wire. In this tests, a welding operator, who had been accustomed to gas welding of very thin steel plates, was temporarily employed to carry out the welding operation on thick plates of 19 mm and 9 mm. In a word, he was unskilled in this job. It may be for this reason that both the ultimate tensile strength and elongation of weld steel tended to show lower values. At any rate, it became apparent from the experiments in this section that the steel filler wire based on the author's new idea is excellent even for gas welding in comparison with the ordinary wire.

11. Examples of the manufacture of steel filler wires based on the author's proposal

The author's new proposal based on his new idea and experimental results performed by him were supported by Dr. S. Nishikiori, managing director of the Shin-Daidō-Steel Mfg. Co. And since spring, 1949, the company has been manufacturing steel filler wires with unusual contents of Mn and Si. The four types* of steel filler wires shown in Table 7 are now being produced by the company on the author's advice. The ranges of Mn- and Si-contents of these wires are defined in Fig. 14. Being supplied to welding industrial circles in Japan, the products are

* Besides, the company is manufacturing the ordinary steel core wire and Linde type steel wire containing much manganese, as shown in Table 8.

Table 7. Steel wires for welding which are being made based on the author's new proposal by Shin-Daidō Steel Manufacturing Co. Ltd.

Symbol of steel filler wire	Contents of elements, %					
	C	Mn	Si	P	S	Cu
DM1	0.15 max.	1.4–1.6	0.40–0.60	0.03 max.	0.03 max.	0.3 max.
DM2	0.15 max.	1.2–1.4	0.10–0.20	0.03 max.	0.03 max.	0.3 max.
DM3	0.10 max.	0.8–1.0	0.05–0.15	0.03 max.	0.03 max.	0.3 max.
UM1	0.15 max.	1.0–1.4	0.05–0.10	0.03 max.	0.03 max.	0.3 max.

Table 8. Other steel wires for welding which are being made by the Shin-Daidō Steel Manufacturing Co. Ltd.

Symbol of steel filler wire	Contents of elements, %						Remarks
	C	Mn	Si	P	S	Cu	
DO1	0.10 max.	0.4–0.6	0.03 max.	0.03 max.	0.03 max.	0.3 max.	Ordinary steel wire for welding
UM2	0.15 max.	1.2–1.4	0.05 max.	0.03 max.	0.03 max.	0.3 max.	Si-content of this wire is lower than that of DM2.
UM3	0.15 max.	1.8–2.0	0.05 max.	0.03 max.	0.03 max.	0.3 max.	Linde type

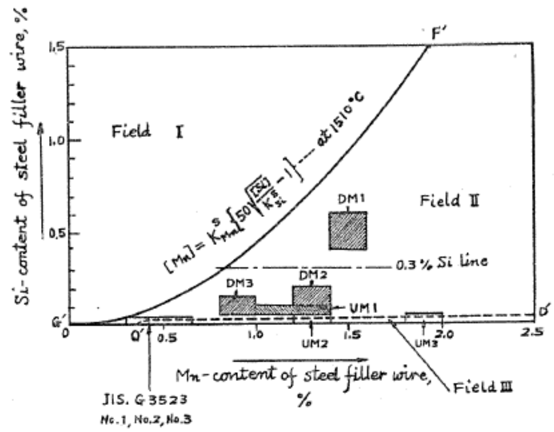


Fig. 14. Relations between Mn- and Si-contents of steel filler wires being manufactured in the Shin-Daidō Steel Mfg. Co. Ltd.

Remarks: Hatched rectangles show the composition ranges of the filler wires based on the author's proposal.

met with a favourable comment and their use is spreading over the whole heavy industry.

"DM1 steel filler wire," one type of the products, is used mainly as a core wire of thin coated gas welding rod for joint welding or surfacing of rails. The DM2 and DM3 types are used for gas welding of mild steel, in the state of bare wire or copper-plated wire. And these wires recently began to be used as the core wire of covered electrodes for arc-welding of mild steel, high tensile steel and rail steel. Further, "DM2" and "UM1" are excellent steel filler-wires for the submerged arc welding. Moreover, any one of these kinds of wire will also suit for the steel filler wire used in the automatic FUS-arc-welding.

12. Examples of the practical examination and uses of steel filler wires based on the author's proposal

Steel filler wires, which contain Mn and Si and are made by the Shin-Daidō Steel Mfg. Co. according to the author's new proposal, are supplied to the whole welding industry in Japan, and are used for the welding of steel. In this section, results of practical examinations, conducted by many plants or research institutes, will be treated and examples of plants which are adopting these steel filler wires will be also cited.

(*A*) *The core wire of a thin coated rod for gas welding of rails*

In order to obtain a gas welding rod which is more convenient for use than the conventional rods and gives the weld whose micro-structure is appropriate and whose hardness well matches rails, Midori Ōtani,[24] member of the Railway Technical Laboratory, Japanese National Railways, invented* in 1947 a production method of welding rods by which various kinds of powder as shown in Table 9 are mixed and rubbed up with water, then with the resulting pasty mixture the steel wire is coated. This kind of thin coated welding rods is called "Tekken G No. 1." In this case, the steel wire DM1 or the one which has higher content of carbon is used as a core wire. Good results are obtained by using such a thin coated wire.

For instance, in the Nagoya Railway Operating Division, Japanese National

Table 9. Composition of covering mixture (Ōtani's proposal) for "Tekken G No. 1" gas welding rod, (%)

Ferromanganese	Ferrosilicon (low Si)	Na_2TiO_3	Dextrine	Titanium dioxide
15–25	35–45	20–30	3–8	3–8

Remarks: Weight ratio [Mn]/[Si] in covering must be nearly in the range 1.8–3.5.

Railways in 1950, each of 38 welding operators performed joint welding of 50 kg rails with an usual thin coated rod by gas-welding. They repeated the same work with the "Tekken G No. 1" gas welding rod made of DM1 as mentioned above. Then each of these 76 welded rails was put on two fulcra which stood at the same height and at a definite distance from each other (1 meter span), so that the welded joint might come in the center of span. And each of these welded rails was bent to break by under a central load. Mean values on 38 welded rails are as shown in Table 10. Further in the same division, using the "Tekken G No. 1" gas welding rod made of the DM1, an experienced welding operator performed the same test.

Table 10. Comparison of results of bending-break-tests on 50 kg rail welded by gas welding, (Span: 1 m)

Welding rod used	Maximum deflection, mm	Maximum load, ton
Thin covered rod "Tekken G No. 1" whose core is DM1	8.5	51.7
Covered rod whose core is carbon steel wire	6.9	44.3

Remarks: Results of examinations performed by 38 welding operators, at the Nagoya Railway Opeating Division, Japanese National Railway, were averaged.

* Patent No. 178368 in Japan.

The result obtained was as follows:

Maximum deflection, 8.1 ~ 16.0 mm.
Maximum load, 61.0 ~ 70.0 ton.

Such being the case, the "Tekken G No. 1" rod is superior to the usual rod. Accordingly, the steel wire DM1 is being practically used extensively on Japanese National Railways.

For example, this kind of light-coated gas welding rods prepared by the Tōkyō Chemical Industries Co. was for the first time used for track maintenance in the vicinity of Tōkyō, Shinagawa and Shinanomachi stations, for the second time it was used between Fuji and Numazu stations on the Tōkaidō line. Nowadays their use is spreading over the whole country.

(*B*) *Gas welding wires for mild steel*

Experimental results, obtained by the author with steel wires whose compositions are shown by Roman letters in Fig. 11, were already described in Section 10. In the shipyards of Kawasaki Heavy Industries Co. in 1949, using the steel wires (made by the Shin-Daidō Steel Mfg. Co.) with compositions as shown by the points η and ε in the same figure, gas welding tests were carried out in accordance with the tentative specification for iron and steel gas welding rods.

The results are shown in Fig. 15, in which the cross marks show the results obtained with steel wires containing more than usual amounts of Mn and Si, while the circles show those obtained with the common welding wire or the so called "pure iron rod." From this, it is understood that if gas welding is performed by a welding operator skilled in welding thick steel plates, low carbon steel wires containing special amount of Mn and Si pass examinations for GA 65, GB 65 and GB 60, but usual steel wires containing small quantities of Mn and Si do not pass most grades of GA and GB, and rarely pass examination for GA 50.

In other shipyards, too, similar tests were done, and it was made clear that good results can be achieved in the case of using steel wires containing smaller Si content than that shown above. So nowadays the steel wire DM2 is mainly used for gas welding mild steel. For example, results of tensile tests, performed in the Kōbe Shipyard and Engine Works in 1949, are as follows:

Contents of elements in the steel filler wire (%):

C	Si	Mn	P	S	Cu	Ni	Cr
0.09	0.19	1.16	0.028	0.014	0.30	0.13	0.10

Results of tensile test of weld metal (non stress relieved):

Tensile strength, 68625 psi (48.3 kg/mm²),
Elongation 34%.

Further, results of bending test are also satisfactory. Therefore this steel wire, which is re-

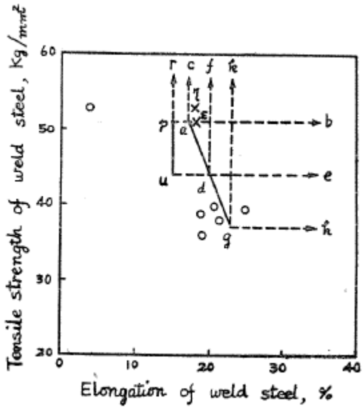


Fig. 15. Examination results of weld steels (non-stress relieved) at the Kawasaki Shipyards.

Remarks: See remarks of Fig. 12.

garded as approximately similar to DM2, passes the examinations for GA 60, GA 50 and GB 60. In this way, at present the steel wire DM2 is adopted in the following shipyards:

The Nagasaki Shipyards and Engine Works,
The Kōbe Shipyards and Engine Works,
The Yokohama Shipyards and Engine Works,
The Kawasaki Heavy Industries Co.,
The Mitsui Shipbuilding and Engineering Co.,
The Harima Shipbuilding Works,
The Ishikawajima Heavy Industries Co.,
etc.

Further, in 1951 the author carried out oxy-acetylene gas welding, tensile tests and bend tests using DO1, DM3 and DM2 filler wires with the welding conditions shown in Table 11 under the cooperation of the Nippon Rolling Stock Mfg. Co., in accordance with the tentative specification for iron and steel gas welding rods[23] in U.S.A. The results of tensile tests are shown in Table 12, Fig. 16 and Fig. 17. From the table and figures, it can be seen that the weld steels deposited with DM3 and DM2 wires are excellent in mechanical properties in comparison with the one obtained with the ordinary filler wire (e.g. DO1). But, if we observe the positions of points DM3 and DM2 in Fig. 16 and Fig. 17 compared with the positions of the points V, R and Q in Fig. 12 and Fig. 13, we can understand that welding results very considerably with welding conditions (compare Table 11 with Table 6). Accordingly, a good welding wire and a suitable welding condition must be selected for obtaining excellent welding joints.

Table 11. Conditions of gas welding performed recently by the author

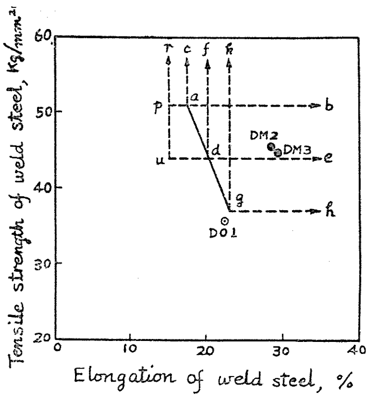
Kind of test	Thickness of plate, mm	Dia. of welding wire, mm	No. of nozzle	Pressure of oxygen, kg/cm²	Pressure of acetylene, cm (water column)	Welding speed, m/hr				
						1st layer	2nd layer	3rd layer	4th layer	5th layer
Tensile	19	4.00*	2000	3.5*	150	3.7	1.7*	1.1*	0.9*	0.8*
Bending	9	4.00*	750	2.0	100	3.4*	2.5*	1.9*	1.7*	—

Remarks: Values with the mark * are different from the corresponding values in Table 6.

Table 12. Comparison of mechanical properties of weld steels deposited with different gas welding wires

Welding wire	Mechanical properties of weld steel			
	Treatment after welding NSR		Treatment after welding SR	
	Ultimate tensile strength, kg/mm²	Elongation, %	Ultimate tensile strength, kg/mm²	Elongation, %
DO 1	35.7	22.4	34.5	21.2
DM 3	44.5	29.4	42.6	37.4
DM 2	45.4	28.4	45.1	35.8

Remarks: See the remarks of Table 5.



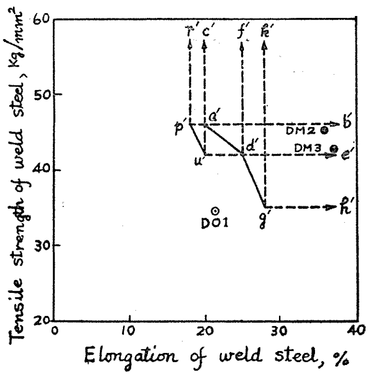


Fig. 16 (*left*). Comparison of mechanical properties of weld steels (non-stress relieved) deposited with different welding wires.

Remarks: See remarks of Fig. 12.

Fig. 17 (*right*). Comparison of mechanical properties of weld steels (stress relieved) deposited with different welding wires.

Remarks: See remarks of Fig. 13.

(*C*) *The core wires of coated electrodes for arc welding of rails or high tensile steels*

Using coated welding rods which were made by providing covering mixture, as shown in Table 3 mentioned already in Section 9, on the DM2 steel wire (binding material: water glass; diameter of core wire: 4 mm; quantity of coating: 10 g/38 cm), in 1949, the Nagoya Railway Co. performed joint welding of 30 kg rails and then bent to break the welded rail resting on two fulcra (span: 1 meter) by applying a central load, the results being given in Table 13. In the case of coated rod made of DM2, maximum deflection and maximum load of the welded rail are larger than with arc welding rods made by coating of the previous ordinary core steel wire (see Table 1). Evidently the coated rod made of DM2 is much better.

Table 13. Comparison of results of bending break tests on 30 kg rail welded by arc welding (Span: 1 m)

Steel core wire	Maximum deflection, mm	Maximum central load, ton
DM2	15.5–43.0*	26.3–36.2*
JIS No. 2 or No. 3	5.8–12.0**	19.0–24.5**

Remarks: * Range for 4 examinations, ** Range for 6 examinations, (at the Nagoya Railway Co. Ltd.)

In the Research Department of the Shin-Daidō Mfg. Co. in 1950, on the basis of the covering material used by the author in his laboratory (see Table 3), further

Table 14. One example of compositions of covering mixture for coated welding rods whose cores are DM2 (Covering *J*)

Limestone	Ilmenite	Silica	Feldspar	Blue asbestos	Manganese dioxide	Ferro-manganese	Cellulose
10	35	10	15	12	10	5	3

Remarks: 34 cc of water-glass (30° Baumé) is added to 100 grammes of this mixture as a binding material.

Table 15. Mechanical properties of all-deposited steel made in accordance with the Japanese Engineering Standards (JES 9001)

Yielding point, kg/mm²	Tensile strength, kg/mm²	Elongation, %
42.1	52.5	30.9
41.6	51.5	31.4

Remarks: Dia. of tensile test piece=10 mm, Gauge length=35 mm.

development was attempted and a covering mixture having the composition shown in Table 14 was obtained.[25] And welding rods coated by dip method with such a mixture proved excellent: The results of mechanical tests performed in accordance with the examination method of the Japanese Engineering Standards (JES) 9001,[21] are as shown in Table 15. In this case, the diameter of steel core DM2 was 5 mm and the quantity of coating was 17 g/40 cm.

Moreover in 1950 at the welding shop of the Kōbe Shipyards and Engine Works, using the DM2 type steel core with compositions shown in Table 16, coated rods

Table 16. Mechanical properties of weld steel made in accordance with the Japanese Industrial Standards (JIS G 3524)

Symbol of core wire	Contents of elements, %						Mechanical properties of weld steel		
	C	Si	Mn	P	S	Cu	Tensile strength, Psi	Tensile strength, kg/mm²	Elongation, %
a	0.15	0.20	1.32	0.020	0.027	0.12	77400	54.4	27.5
b	0.15	0.12	1.26	0.018	0.008	0.20	77737	54.7	26.0

Remarks: Dia. of tensile test piece=12.5 mm, Gauge length=50 mm.

with "covering mixture given in Table 14" were prepared by high pressure method with a coating machine. Then welding and mechanical test were carried out in accordance with the Japanese Industrial Standards (JIS) G 3524.[26] The results are as shown in Table 16.[27][25] The examination method of JIS G 3524 is similar to those of the following specifications of U.S.A.:

a. Tentative Specifications for Mild Steel Arc-Welding Electrodes,[28]
b. Tentative Specifications for Low-Alloy Steel Arc-Welding Electrodes.[29]

The elongation values shown in Table 16 are higher than those prescribed in the above mentioned two specifications. The values of tensile strength shown in Table 16 exceed 62000 psi or 68000 psi which is prescribed in the specification for mild steel, and 70000 psi which is prescribed in the specification for low alloy steel. It can be concluded that the above mentioned rod made of DM2 and a special covering mixture containing ferromanganese is rather suited to the welding of rails or high tensile steels than of mild steel.

With this kind of welding rod, in 1949 the Japan Welding Co. undertook for the first time the work of welding rails on the Mikawa-line of the Nagoya Railroad Company. Afterwards, this type of welding rod came to be used extensively for the arc welding of rails, of which the principal customers are as follows:

The Nagoya Railroad Co.,
The Nagoya Railway Operating Division, Japanese National Railways,
Municipal Bureaux of Traffic of Nagoya, Ōsaka, Kumamoto and Ōita,
etc.

Further, the Shin-Daidō Steel Mfg. Co. which has been engaged since 1950 in production of steel props for coal mines by welding high tensile steel, is using the above mentioned covered rod made of the core wire DM2 for the welding.

(*D*) *The core wires of coated electrodes for the arc welding of mild steel*

A core wire having elements shown in Table 17 belongs approximately to the core wire "DM3." The Tōkyō Kakō Co. manufactured coated arc-welding rods for mild steel by coating the core wire with the mixture containing no ferromanganese as shown in Table 18. The rate of covering quantity to length of the 4 mm core wire was 10.5 g per 38 cm. In effecting the covering on the core wire, the extrusion machine method was applied. The arc depositions on mild steel plate with the coated rod and mechanical tests of all deposited metal were performed by the examination method of the Japanese Engineering Standards (JES) 9001,[21] the results obtained being arranged under the examination No. 1 in Table 19.

Next, using "DM3 core wire" and certain covering mixture without ferromanganese, the Hakusan Tetsugyō Co. also manufactured arc welding rods for mild steel and obtained the results given under the examination No. 2 in Table 19.

Further the Ōsaka Tōkōsha Co. and the Railway Technical Laboratory, Japanese National Railways, tentatively manufactured coated arc welding rods by coating "the core wire DM2" with a cheap covering mixture without ferromanganese, and carried out the welding of mild steel plates, followed by mechanical tests as specified by the Japanese Industrial Standards (JIS) G 3524.[26] The examinations No. 3 and No. 4 in Table 19 respectively show the results obtained by the company and the laboratory.

In comparison with the minimum values specified by the Standards (see Remarks of Table 19), it can be seen that the results shown in Table 19 are excellent in spite of coverings without ferromanganese. So the DM3 and DM2 coated rods are very suitable to the arc welding of mild steel. When the covering mixtures containing no ferromanganese like "*N* covering" shown in Table 18 or other covering devised by these companies and the laboratory are machine-extruded on core wires, abrasion of the nozzle in the machine is relatively little. On the other hand, as the price of ferromanganese is dear in comparison with other covering materials, such a covering mixture as free from ferromanganese is very cheap. So adoption of such covering mixtures brings great benefit to coated-welding-rod makers; there

Table 17. Contents (%) of elements contained in a steel core wire being regarded approximately as "DM3"

C	Si	Mn	P	S	Cu	Ni	Cr
0.11	0.12	1.06	0.018	0.025	0.23	0.09	0.04

Table 18. One example of covering mixture coated on the steel core wire being regarded approximately as "DM3" (Covering *N*)

Limestone	Ilmenite	Silica	Potassium feldspar	Blue asbestos	Manganese dioxide	Cellulose
9	32	9	13	11	16	10

Remarks: This composition is similar to that of the covering mixture *J*, with the exception of ferromanganese.

Table 19. Results of tensile tests on weld steel made by arc welding of mild steel

Coated electrode used		Examination		Mechanical properties of weld steel		Organization in which the examination was performed
Core wire	Ferromanganese in covering	No.	Standard	Tensile strength, kg/mm²	Elongation, %	
DM3	None	1	JES. 9001	50.9	27.1	The Tōkyō Kakō Co. Ltd.
	None	2	JES. 9001	42.5	28.6	The Hakusan Tetsugyō Co. Ltd.
DM2	None	3	JIS. G3524 D4313 D4311 D4320	 50.2 48.2 46.1	 25.6 27.3 30.3	The Ōsaka Tōkōsha Co. Ltd.
	None	4	JIS. G3524	48.9	27.2	The Railway Technical Laboratory, Japanese National Railways

Standard	Diameter, mm	Gauge length, mm
JES. 9001	10	35
JIS. G3524	12.5	50

Remarks 1: Dimensions of tensile test pieces prescribed by the Standards.

Remarks 2: Lower limits of mechanical properties prescribed by the standards.

Standard	Welding rod		Kind of examination	Tensile strength, kg/mm²	Elongation, %
	Symbol	Type			
JES. 9001	—	—	No. 1 No. 2	41 41	20 26
JIS. G3524	D4313 D4311 D4320	high titania high cellulose high iron oxide	—	48 44 44	17 22 25

is a growing tendency for such companies to switch to the core wires DM3 and DM2 which are more suitable to such covering mixtures.

Besides, if these core wires are used, it is easy to make light coated welding rods with an excellent property in the welding operation and be capable of giving comparatively superior weld metal.

Accordingly, these types of core wire are considered to be very useful from such standpoints and their use is on the widening trend.

(E) The filler wires for submerged arc welding of mild steel

S. Sasaki, research pioneer of submerged arc welding method in Japan, used the steel wire "DM1" for the welding in 1949. At that time he stated that if this type of steel wire is used, good results can be obtained also in the case of welding steel plates which are more or less rusty.[30] In the same year Dr. M. Okada and others performed researches on submerged arc-welding of steel by using a steel wire with little impurities and the steel wire "DM1," with the result that the latter wire proved superior. They stated, "It is effective to supply manganese as deoxidizer to weld metal through the steel wire, and the steel wire invented by Dr. H. Sekiguchi is considered to be suitable for submerged arc welding of steel."[31]

In 1949, the Shin-Daidō Steel Mfg. Co. sent samples of DM2, UM1, UM2 and UM3 as steel wires for submerged arc welding to many shipyards and rolling stock manufacturing companies and others, inviting criticisms on their practical uses.

For example, in the Nagasaki Shipyards and Engine Works, by means of a CM37 automatic welding machine made by the Linde Air Products Co., butt joints of mild steel plates of 25 mm thickness were made in 1951 by depositing in two layers.[32] The flux used in this case was the UNIONMELT Grade 20 with the size under 12 mesh and over 20 mesh. And the welding-current, arc-voltage, feeding rate of filler wire and diameter of the wire adopted in this case are as shown under examinations No. 5, 6 and 7 in Fig. 18. And cylindrical specimens (diameter: 12 mm) were cut off from the middle part of the butt weld and tensile tests were performed. Steel wires used were UM1, UM2 and UM3, and their compositions

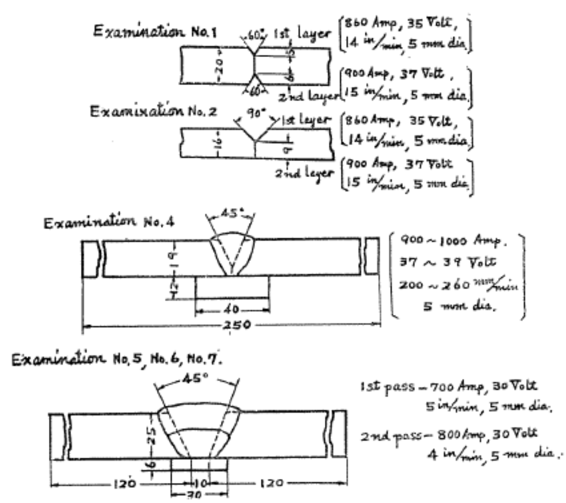


Fig. 18. Types of joint adopted in the case of submerged arc welding.
Note: unit of length; mm.

Table 20. Contents of elements contained in steel filler wires used in examination for submerged arc welding

Steel filler wire		Contents of elements, %							
Type	Symbol of composition	C	Si	Mn	P	S	Cu	Ni	Cr
DM 1	*a*	0.13	0.37	1.43	0.028	0.007	—	—	—
DM 2	*b*	0.15	0.12	1.26	0.018	0.008	—	—	—
	c	—	—	—	—	—	—	—	—
	d	0.15	0.20	1.32	0.020	0.027	0.12	—	—
UM 1	*e*	0.13	0.09	1.31	0.018	0.015	0.24	0.14	0.06
UM 2	*f*	0.11	0.04	1.25	0.022	0.019	0.29	0.14	0.07
UM 3	*g*	0.14	0.03	1.71	0.026	0.013	0.29	0.11	0.09
	h	0.15	0.50	1.36	0.026	0.026	—	—	—

Remarks: The wire h is similar to the wire DM 1.

Table 21. Compositions of fluxes used in examinations for submerged arc welding

Flux		Chemical components, %									
Type	Symbol of composition	SiO_2	CaO	MnO	Al_2O_3	MgO	Na_2O	FeO	Fe_2O_3	TiO_2	F
Test flux	*A*	61.9	35.7	—	0.5	—	—	—	0.4	—	—
Test flux	*B*	42.4	16.7	17.6	—	—	—	—	8.0	—	—
Test flux	*C*	42.3	29.8	2.5	18.4	1.4	—	5.9	—	—	—
T-13	*D*	50	12	25	6	5	some	—	—	—	—
UNIONMELT Grade No. 20	*EFG*	56.1*	22.6*	1.6*	8.6*	8.5*	—	2.0*	—	0.1*	8.5*
Test flux	*H*	46.1	32.2	2.1	13.8	1.4	—	4.8	—	—	—

Remarks: * According to the report by Dr. M. Okada lately returned from U.S.A.

Table 22. Results of mechanical tests on weld steels made by submerged arc welding

Examination No.	Steel filler wire used		Flux used		Dimention of tensile test piece, mm	Mechanical properties of weld steel				Organization in which the examination was performed
	Type	Symbol of composition	Type	Symbol of composition		Tensile strength, kg/mm²	Elongation, %	Contraction of area, %	Impact value	
1	DM 1	*a*	Test flux	*A*	Dia. = 8 G.L. = 28	52.6	26.6	—	Charpy 9.02 mkg/cm²	The Kōbe Shipyards and Engine Works
2	DM 2	*b*	〃	*B*	Dia. = 12.7 G.L. = 50.8	58.7	25.0	—	Izod 34.6 ft-lb	〃
3	DM 2	*c*	〃	*C*	Dia. = 10 G.L. = 35	47.5	31.0	—	—	The Yokohama Shipyards and Engine Works
4	DM 2	*d*	〃	*D*	Dia. = 12.7 G.L. = 50.8	50.0	31.8	53.6	—	The Railway Technical Laboratory
5	UM 1	*e*	UNIONMELT Grade No. 20	*EFG*	Dia. = 12 G.L. = 50	49.8	30.7	55.0	—	The Nagasaki Shipyards and Engine Works
6	UM 2	*f*	UNIONMELT Grade No. 20	*EFG*	Dia. = 12 G.L. = 50	44.7	28.1	42.8	—	The Nagasaki Shipyards and Engine Works
7	UM 3	*g*	UNIONMELT Grade No. 20	*EFG*	Dia. = 12 G.L. = 50	46.5	23.3	30.0	—	The Nagasaki Shipyards and Engine Works

Remarks: G.L. = Gauge Length.

are indicated by values for the symbols *e*, *f* and *g* in Table 20. And the results of tests are shown by values for the examinations No. 5, 6 and 7 in Table 22. Then it was stated that when compared with the steel wire "OXWELD No. 36" imported from U.S.A., the wires UM1 and UM2 show nearly equal results, giving bead appearance no less beautiful than that of "OXWELD No. 36," but the elongation value for UM3 is found more or less inferior to the one for "OXWELD No. 36."

In 1951 Midori Ōtani and others,[33] staffs of the Railway Technical Laboratory, Japanese National Railways, also performed submerged arc welding, using "the steel wire DM2" having elements shown by symbol *d* in Table 20 and the flux "Tekken T-13" having compositions represented by symbol *D* in Table 21; the joint type adopted was the one shown under examination No. 4 in Fig. 18 and the conditions of welding are shown in the additional remark in the same figure. Then, tensile tests on the all deposited metal were carried out and the results represented by values for the examination No. 4 in Table 22 were obtained. The method adopted in this test is similar to that of "Tentative Specification[28] for Mild Steel

Arc Welding Electrodes" of U.S.A., and the results obtained are excellent as stated above. According to the researchers, if "the mixture T-13 flux" containing ferromanganese is used, submerged arc welding will be possible even with the usual steel wire rods with low contents of Mn and Si; only there is a fear of the flux with ferromanganese deterioration through repeated use.

Further, in the Yokohama Shipyards and Engine Works, submerged arc welding was performed by using the steel wire "DM2" and the flux shown by the symbol *C* in Table 21, and mechanical properties of all-deposited metal were investigated. The results are shown by values for the examination No. 3 in Table 22.

In the Kōbe Shipyards and Engine Works, using the wires DM1 and DM2 shown by values for the symbol *a* and *b* in Table 20 and the test fluxes shown by the symbol *A* and *B* in Table 21, and adopting joint-types and welding conditions shown by the examinations No. 1 and No. 2 in Fig. 18, tests on submerged arc welding of mild steel were performed, in 1951. And the results of mechanical tests were as shown by values for the examinations No. 1 and No. 2 in Table 22.

Moreover, in 1951, in the Mihara Works, using a steel wire with a composition shown by values for the symbol *h* in Table 20 nearly corresponding to the "DM1," and a flux with a composition shown by values for the symbol *H* in Table 21, an examination of submerged arc welding was performed under the following conditions,[34]

> Form of groove of "butt-joint": I-type; number of back bead: one layer by hand-welding; thickness of plates: 9 mm; diameter of steel wire for welding: 5.5 mm; welding current: 800 A; arc voltage: 38 V; feeding rate of wire: 680 mm/min; travelling rate of wire: 240 mm/min.

And mechanical tests on the welded part were performed. The results obtained were as shown in Table 23. Then submerged arc welding method with the wire and the flux mentioned above was applied to welding of the center sill of large waggons. But Elongations and Charpy impact values shown in Table 23 are not excellent. In view of the results illustrated in Table 22 and Table 23, it is supposed that the steel wires DM2, UM1 and UM2 are more suitable than the DM1 for submerged arc welding of mild steel.

Table 23. Mechanical properties of welded part made by submerged arc welding in the Mihara Works

Test number	Tensile strength, kg/mm^2	Position of break	Degree of bending	Elongation (gauge length, 35 mm), %	Charpy impact value, mkg/cm^2
1	45.6	Base metal	85°	20.1	6.0
2	43.4	Base metal	80°	19.1	6.5

In this manner, the steel wires manufactured based on the author's proposal are meeting with a favourable comment in Japan as the wires for submerged arc welding; DM2 and UM1 are mostly used at the Nagasaki Shipyards, the Kōbe Shipyards and so on. Further in the Mihara Works, the Kasado Factory of Hitachi Works, the Nippon Rolling Stock Mfg. Co. and so on, these kinds of wires were put to practical tests, and "the Sekiguchi Filler Wires" have been considered to be very promising.

In 1950, some types of steel filler wire for submerged arc welding were imported

Table 24. Contents of elements contained in OXWELD rods for UNIONMELT welding of steel

OXWELD rod No.	Contents of elements, %					UNIONMELT grade to be used
	C	Si	Mn	P	S	
43	0.08	0.03	0.25	0.03	0.03	90 or 50
36	0.13	0.03	1.95	0.03	0.03	20, 70, 80 or 90
29	0.13	0.32	1.05	0.03	0.03	80, 90 or 50

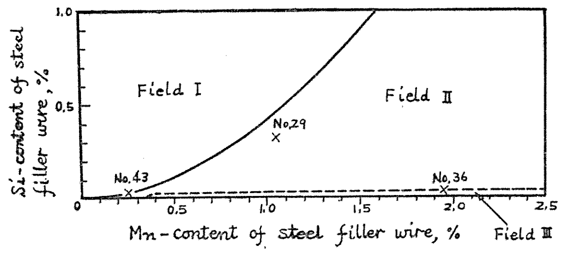


Fig. 19. Relations between Mn- and Si-contents of steel filler wires for submerged arc welding (OXWELD rods), supplied by the Linde Air Products Co.

from U.S.A. into Japan. According to the catalogue[35] of the Linde Air Products Company, the OXWELD rods normally used for strength joints in UNIONMELT (submerged arc) welding of mild steel are approximately of the typical compositions given in Table 24. And in Fig. 19, the crosses show the relations between Mn- and Si-contents of these filler wires. The wire No. 43 is the same one as the usual steel filler wire for arc welding; the wire No. 36 contains a large quantity of Mn; and the wire UM3 mentioned already is similar to this wire. The wire No. 29 is one kind of steel wire containing somewhat great quantities of Mn and Si, and the composition point for Mn and Si is located in Field II mentioned already, namely in the composition range of the new idea introduced by the author.

13. Summary

In this research, firstly, steel filler wires for welding were considered in the light of the principle on deoxidation of molten iron, and further a new idea was introduced. The abstract is as follows.

(1) Mn- and Si-contents of the usual steel filler wire, which has been used for welding of mild steel up to the present, are not higher in comparison with those of ordinary steel. Rather these contents have been generally desired to be lower. But the author considered that such a view is not always correct.

(2) Based on the thesis of Körber and Oelsen concerning the forms of deoxidation products separated from the molten iron phase just before solidification of molten iron, conditions necessary for obtaining clean iron were studied. And it is emphasized that the molten steel having Mn- and Si-contents represented by composition points in Field II, in which FeO-MnO-SiO_2 liquid solution unsaturated with SiO_2 is separated from the molten iron as a deoxidation product, becomes clean steel after its solidification.

(3) Theoretical equations, by which relations among Mn-, Si- and O-concentrations of molten iron in equilibrium state can be known, were derived. Then a diagram showing iso-oxygen-concentration lines was made.

(4) Based on the considerations mentioned in the preceding Items (2) and (3), it was deduced that the composition point showing Mn- and Si-contents just before solidification of the molten iron produced by welding is desired to belong to Field II and the contents of the two elements are desired to be suitable high.

(5) The following new idea was presented: for the sake of obtaining the desirable molten weld steel just before solidification, described in the preceding Item (4), it will be a good method to use steel wires having Mn- and Si-contents higher than those of the molten weld steel just before solidification, and it will be desirable that the composition point of the wire be also located at a proper position in Field II.

In order to check validity of this new idea, experimental researches were carried out with the following results.

(i) Using electrolytic iron as raw material, many types of steel core wires were tentatively prepared in the laboratory, and experiments on arc welding were conducted. By this the validity of the new idea was confirmed experimentally, too.

(ii) Then using steel wires of various compositions, which were made on trial in steel making plants:

a. Coated welding rods for arc welding were prepared and properties of all-deposited metals were investigated in accordance with JES 9001.
b. Using bare wires, oxy-acetylene welding was carried out and the properties of weld metal were investigated in accordance with "Tentative specification for iron and steel gas welding rods in U.S.A."

And the author was convinced that the new idea described in Item (5) is appropriate experimentally in the main. But the following fact was ascertained: when the weld metal is cooled rapidly it is suitable to use steel filler wires containing silicon less than 0.3 percent, in order to prevent formation of holes having opening on the surface of bead, portions consisted of striated structure in weld metal and minute cracks in some of the portions.

Next, examples of the manufacture, practical examinations and applications of new steel wires based on the author's proposal were stated briefly as follows.

(I) In response to the author's proposal based on the new idea and the experimental results, the Shin-Daidō Steel Mfg. Co. has begun to make new steel wires for welding. The products are being supplied throughout Japan and they have now good prospects of exportation. Therefore, brief description was made of the compositions of four types of core wires produced by the same company. Composition ranges illustrated in Fig. 14, DM1, DM2, DM3, and UM1, are based on the new proposal.

(II) The steel wires, manufactured by the company based on the new proposal, were examined practically throughout welding circles and now find use as the following items:

A. Core wires of thin coated gas welding rods for rails,
B. Gas welding rods for mild steel,
C. Core wires of coated electrodes for arc welding of rails or high tensile steels.
D. Core wires of coated electrodes for arc welding of mild steel.
E. Steel wires for submerged arc welding of mild steel.

And examples of results of practical tests were shown and examples of production plants which utilize these wires were enumerated.

Some what considerable quantity of copper is contained in the iron ores commonly available in Japan. The present situation on other raw materials for pig iron and steel scraps for steel-making being unfavourable, manufactures of steel wires for welding are experiencing great difficulties in reducing contents of impurities such as S, P, Cu, Ni, Cr and so on. If contents of these impurities can be held down by any means to nearly the same level as the wires of U. S. A., weld steels deposited by various steel wires based on the new proposal mentioned in this report will further improve in elongation and impact value.

14. Conclusions

Hitherto, Mn- and Si-contents of steel wires for welding are rather lower than those of the ordinary steel, and iron wire, which is nearly pure, has been regarded as the best material. In Japan the composition range defined by the rectangle *abcd* in the neighbourhood of the origin of Fig. 4 has been adopted as standards; the similar type of steel wire has been in use the world over.

In the author's thinking generally steel filler wires for welding can fulfill their mission only through remelting in the atmosphere and this constitutes their fundamental difference from the other steels. Starting from considerations concerning the forms of deoxidation products and the iso-oxygen-concentration lines about molten iron containing Mn and Si in equilibrium state, the author conceived a new idea, —"Adoption of the steel filler wires, having composition points showing Mn- and Si-contents within Field II of Fig. 3 and further to the upper right of the rectangle *abcd*, will be one good way of welding ordinary steel."

The appropriateness of this idea was verified experimentally. When the welded part is cooled rapidly, however, it is advisable to hold the Si-content of the filler wire below 0.3 percent.

Conforming to the author's new proposal based on the new idea and experimental results, the Shin-Daidō steel Mfg. Co. has manufactured the new steel wires since spring, 1949, and the products have been supplied to shipyards, railways, rolling stock manufacturing and other plants. Now the new steel filler wires are winning great popularity under the name "Sekiguchi's Filler Wires"[36] or "DM Type Wires"* and are being adopted as core wires for arc welding rods, filler wires for submerged arc welding or rods for gas welding. And these demands are increasing more and more in the industrial circles of Japan.

The degree of oxidation of molten weld steel in the course of welding and the practical demand on strength and ductility of solidified weld steel should be taken into account in selection of the composition point showing Mn- and Si-contents in steel filler wire and the right point should be within the limits of Field II of Fig. 3.**

The author hopes that his views will be fully discussed by experts over the world for further development of the theory and its wider application.

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* Daidō Mansil Types.

** Patents have been gotten in Japan, in regard to the composition of these filler wires.

Ltd; President of the Harima Refractories Co. Ltd.) and Dr. Y. Tanaka (Former Head of the Welding Research Institute; Emeritus Professor of Tōkyō University; Member of the Japan Academy).

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16. References

1) "Core Wires of Coated Arc Welding Rods and Wire Rods for Them," The Japanese Industrial Standards (JIS), G 3523 (1950).
2) N. Motomori and I. Moriguchi, "Suitable Chemical Components in Core Wires of Coated Electrodes for Welding of Mild Steel," J. of Japan Welding Society, **10**, PP. 14–22 (1940).
3) "Core Wires of Coated Welding Rod (The Second Kind of Wire Rods)." The Japanese Temporary Engineering Standards, No. 40, J. of Japan Welding Society, **12**, P. 32 (1942).
4) S. I. Lavroff, Lichtbogenschweisselektroden, P. 8 (1933).
5) H. Harris, Metallic Arc Welding, PP. 24–39 (1935).
6) Schimpke-Horn, Praktisches Handbuch der Gesamten Schweisstechnik, Bd. I, P. 123 (1938).
7) Karl Meller, Elektrische Lichtbogenschweissung, PP. 138–145 (1932).
8) H. Sekiguchi, "An Investigation of Electrode Core Rod for the Arc Welding of Steel (Report 1)—The Effects of Elements in the Electrode-Core-Rod on the Soundness of Deposited Metal," Nippon Kinzoku Gakkai-Si (published by the Japan Institute of Metals), **2**, PP. 444–462 (1938).
9) H. Sekiguchi, "An Investigation of Electrode Core-Rod for the Arc Welding of Steel (Report 2)—The Effect of Deoxidizers in the Electrode Core-Rod on the Apparent Specific Gravity and Mechanical Properties of Deposited Metals," Nippon Kinzoku Gakkai-Si, **2**, PP. 483–494 (1938).
10) F. Körber and W. Oelson, "Die Grundlagen der Desoxydation mit Mangan und Silizium," Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, Bd. XV, PP. 271–309 (Lieferung 21) (1933).
11) H. Schenck, Physikalische Chemie der Eisenhüttenprozesse, Bd. II, P. 202 (1934).
12) H. Sekiguchi, "Research on Steel-Welding-Rods Containing Manganese and Silicon in the

Core (Report 1)—Conception on Steel Core Rods Containing Manganese and Silicon," J. of Japan Welding Society, **19**, PP. 40–48 (1950).
13) The same as (10), P. 279, Fig. 1.
14) H. Schenck, Physikalische Chemie der Eisenhüttenprozesse, Bd. I, P. 249 (1932).
15) The same as (11), P. 139, 134 and 184.
16) *ibid.*, P. 47 and 105.
17) *ibid.*, P. 24, 29 and 134.
18) H. Sekiguchi, "An Investigation of Electrode-Coating for the Arc Welding of Steel (Report 5),—Relations between Quantities of Electrode-Coating for Mild Steel in Market and Mechanical Properties of the Deposited Metals," J. of Japan Welding Society, 8, PP. 411–440 (1938).
19) H. Sekiguchi, S. Andō and K. Nakamura, "Research on Steel-Welding Rods Containing Manganese and Silicon in the Core" (Report 2)—"Preliminary Examination on Relations between Contents of Manganese and Silicon and Properties of Weld Deposited by Arc-Welding," J. of Japan Welding Society, **19**, PP. 101–108 (1950).
20) H. Sekiguchi, I. Morimoto and I. Masumoto, "Research on Steel-Welding Rods Containing Manganese and Silicon in the Core" (Report 3)—"On Useful Effects of Manganese and Silicon Contained in the Core Rod of Arc-Welding Electrode for Steel," J. of Japan Welding Society, **19**, PP. 122–151 (1950).
21) "Covered Arc Welding Rod for General Steel Structure"—The Japanese Engineering Standards, Basic 9001, J. of Japan Welding Society, **17**, PP. 27–29 (1948).
22) H. Sekiguchi and T. Matsunaga, "On Steel Rods Containg Mn and Si purposely for Gas Welding of Steel," Research Report of the Nagoya Industrial Science Research Institute, No. 2, PP. 34–38 (1950).
23) A.S.T.M. Designation: A251–46T (Issued, 1942; Revised, 1946),—Welding Handbook (Third Edition, 1950), PP. 1518–1522.
24) M. Ōtani, "Research on Welding Rods for Building-up Rails," J. of Japan Welding Society, **16**, PP. 195–200 (1947).
25) T. Kubota, T. Okada and S. Koide, "Researches on Welding Rods (Report 8)—On Coating Materials of the Ilmenite Type for the Steel Core Wires DM1 and DM2," The Research Reports of Technical Section in Research Department (The Shin-Daidō Steel Mfg. Co. Ltd.), No. 136, PP. 1–16 (1951).
26) "Coated Electrodes for the Arc Welding of Mild Steel"—The Japanese Industrial Standards (JIS), G3524 (1950).
27) O. Takagi, S. Nishi and K. Suzuki, "On the Results of Tests in which the Shin-Daidō Welding Rods were used as Manual Welding Electrode and Submerged Arc Welding Rod," Report of Welding Researches (The Kōbe Shipyards and Engine Works, Central Japan Heavy Industries Co. Ltd.) No. 21, PP. 1–4 (1951).
28) A.S.T.M. Designation: A233–48T (Issued 1940: Revised, 1942, 1943, 1945 and 1948),—Welding Handbook (Third Edition, 1950), PP. 1508–1517.
29) A.S.T.M. Designation: A316–48T (Issued, 1948),—Welding Handbook (Third Edition, 1950), PP. 1536–1547.
30) T. Kubota, "Researches on Welding Rods (Report 7)—Investigation on Filler Wires and Fluxes for Submerged Arc Welding," The Research Reports of Technical Section (Hoshizaki Factory in the Shin-Daidō Steel Mfg. Co. Ltd.), No. 124, PP. 1–22 (1950).
31) M. Okada, H. Kihara, Y. Arata and H. Kawai, "Researches on Submerged Arc Welding," J. of Japan Welding Society, **19**, PP. 109–115 (1950).
32) T. Kakita and H. Kawai, "Submerged Arc Welding Tests on Steel Wires made by the Shin-

Daidō Steel Mfg. Co. Ltd.," The Miscellaneous Reports of Laboratory (in the Technical Department of West Japan Heavy Industries Co. Ltd.), No. 1363, PP. 1–3 (1951).

33) M. Ōtani, T. Shiraishi and S. Taume, "Researches on Submerged Arc Welding Process," Bulletin of Society of Naval Architects, No. 286, PP. 8–12 (1951).

34) R. Kawarago, K. Satō and S. Ishida, "Application of Automatic Welding for Construction of Freight Cars," J. of Japan Welding Society, **19**, PP. 221–223 (1950).

35) "UNIONMELT" welding materials, Form 5756-A. PP. 1-6 (The Linde Air Products Company, Unit of Union Carbide and Carbon Corporation).

36) Recent Development of Engineering Institutes in Japan and their Activity (From the Annual Report of Science Council of Japan for the Year 1950), P. 46.